RTEMS Remote Debugger Server Specifications

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The RTEMS Project is hosted at `http://www.rtems.com`. Any inquiries concerning RTEMS, its related support components, its documentation, or any custom services for RTEMS should be directed to the contacts listed on that site. A current list of RTEMS Support Providers is at `http://www.rtems.com/support.html`.

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1 Introduction

The TOOLS project aims to provide a complete development environment for RTEMS OS. This environment must be as close as possible to the Chorus one (gnu compiler, gnu linker, gnu debugger, ...), because it is currently the OS which is the most used at CRF and we want to simplify the migration path from the ChorusOs environment to the RTEMS environment. One important item of this development environment is the remote debugger which allows the developer to debug his software on a target machine from a host machine via a communication link (Ethernet, serial link, ...).

The choice of GDB as debugger has been made with because in CRF, every developer, which uses the ChorusOs development environment, debugs his software using the remote debugging functionality of GDB. Providing a remote GDB debug server running on RTEMS, will enable the developers to use transparently the same debugger for a different RTOS. Another reason for the choice of GDB is its constant evolution, and that it can be interfaced with graphic user interfaces like DDD providing a very powerfull debugging environment.

The subject of this document is to explain how GDB works and the way to implement a daemon on RTEMS that will be used as a debugger server for a GDB client. We will call this daemon Rtems GDB Debug Server Daemon (RGDBSD). We aim to provide this debugger running at least on 2 host systems : Linux 2.x and Solaris 2.5.1 as they are the two platforms used for developing Chorus applications today.

2 Document Revision History

Current release :

- Current applicable release is 2.0.

Existing releases :

- 0.1 : Released the 29/09/98. First draft of this document.
- 0.2 : Released the 05/10/98. Second draft version.
- 1.0 : Released the 08/10/98. Version Approved internally.
- 1.1 : Released the 13/13/98. Version Distributed for comments.
- 2.0 : Released the 01/11/98. Version including modifications related to comments we have got from the RTEMS mailing list. It also contains a more precise description of RGDBSD as we now have a first prototype,

Planned releases :

- 2.1 Final specification release intended to include a second round of comments,

3 Objectives

This section is intended to clearly define the current objectives of our work. First, we will try here to list some ambitious requirements for the debugger in section **List of Requirements**. These requirements will deliberately be much more ambitious than what we will provide directly ourselves in the hope that the Internet development model will enable others to implement some features we rejected for man-power reasons in the first step. We are committed to do the core work and redistribute it but would appreciate any comment and enhancement. Then, in section **Requirements Analysis** we will analyze each requirement to see what technical problem must be solved if we want to fullfill it. After this analysis, we will determine in section **Requirements Selection** the requirements we chose to implement and the ones we will not. We will then clearly identify the limits of our solution in section **Implied Restrictions**.

3.1 List of Requirements

We will identify here possible requirements for the type of debug that may be provided :

[(R1)]: We want to use GDB as the front-end debugger,

[(R2)]: We want to support at least Intel and PowerPC as target processor architecture,

[(R3)]: We want to use the GDB thread debugging interface,

[(R4)]: We want to be able to debug a remote target over a serial line,

[(R5)]: We want to be able to debug a remote target over Ethernet,

[(R6)]: The set of target code path we will be able to debug using RGDBSD must be clearly identified. It will be called Debug Path Set (*DPS*) in the remaining of this document,

[(R7)]: *DPS* must include the RTEMS core executive itself,

[(R8)]: *DPS* must include the FreeBSD stack,

[(R9)]: *DPS* must include anything but the FreeBSD stack and the RTEMS core executive,

[(R10)]: We want to enable several persons to debug different parts of the code running on the target,

[(R11)]: As much as possible the system must be frozen during a debug session so that debugging a particular portion of code does not prevent another part from functioning,

3.2 Requirements Analysis

[(R1)]: Worth recalling it. It mainly imposes few restrictions on the binary files type, target processor type as :

- the binary format must be understood by GDB (to find debugging information). Elf, Coff and A.out are the main formats currently supported. Elf/Dwarf 2.0 binary support will be our main target as they are the preferred format for Intel and PowerPC processors. No change in GDB will be required for other binaries except may be a new configuration file changing the binary/debug file format,
- the processor must be supported for disassemble/step instruction command,
- the target system must be supported. As far as I know RTEMS is not currently *officially* supported anyway,

[(R2)]: Our primary targets are Intel and PowerPC. We however do not think implementing RGDBSD for other processors will be a heavy task. It will mainly require :

1. Implementing exception handling for the target processor,
2. Interfacing the generic part of RGDBSD with the low level exception handling and make RGDBSD aware of exception used for debugging (usually illegal instruction or dedicated trap, single step),
3. Making GDB aware of the frame layout pushed on exceptions,
4. Implement the code for data transfer for the exception frame,
5. Implement code to copy data cache back to main memory and invalidate instruction cache. This is needed in order to be sure opcode modification used to set breakpoint that use the data cache will be proagated to the instruction cache,

As soon as we will have completed the first core work a document describing how to port it to a new processor should be written. So far we will organize the source tree with processor dependent directories so that port will be as easy as possible. May be a bare processor support should be created,

[(R3)]: GDB already has an interface for manipulating multi-threaded programs. This interface is rather weak at the moment but it will certainly be improved in the future with the generalization of POSIX thread API on Linux and other operating systems. This implies that either GDB or RGDBSD is able to obtain the list of threads currently executing. The choice of implementing this in GDB or RGDBSD is a tradeof between target code size and simplicity,

[(R4)]: Regular GDB code contains clients code for debugging over a serial line. However only few functions are implemented. We would like to provide a better support and to uniformize serial line debugging with debugging over Ethernet via the use of SLIP,

[(R5)]: Regular GDB code contains client code for debugging over Ethernet for VxWorks via the SUN RPC library. So there will be at least one starting point to implement remote debugging over Ethernet via SUN RPC. The Chorus remote debugging code has been disclosed under GPL and also contains code for debugging suing SUN RPC,

[(R6)]: Due to a classical chicken and egg problems, the remote debugging daemon cannot be used to debug code it uses to function. Thus depending on the API used by RGDBSD, some parts of the target system will not be debuggable via GDB. The most important point is documentation because my feeling is that implementing RGDBSD on a totally different *dedicated* nano kernel should be possible,

[(R7)]: RTEMS core executive is a real-time OS which implements priority level scheduling, synchronization objects, and interrupt handling. As mentioned in previous item, we may not debug theses features if RGDBSD uses them. This requirement is thus very strong because it impose that :

1. RGDBSD is totally interrupt driven (no thread API available),
2. But it does not use RTEMS interrupt management,
3. Nor does not use RTEMS exception management,
4. RGDBSD must provide its own UDP/IP stack as the current FreeBSD code rely on tasks switching and RTEMS provided synchronization object for input path handling,

So our feeling is that the **(R7)** more or less requires to write a *dedicated* nano kernel with a very small dedicated UDP/IP stack.

[(R8)]: GDB remote debugging over Ethernet code communicates with the remote target via the SUN RPC protocol. This requires a UDP/IP protocol and a minimal socket like interface. In RTEMS environment, this feature is currently provided by the FreeBSD stack. Again, if we use the FreeBSD stack itself for remote communication, it will be impossible to debug this stack as a breakpoint in the stack code will stop its execution and there would be no more way to communicate with the target. A solution consists in implementing a minimal, dedicated UDP/IP stack (with at least IP and UDP protocols, a minimal BSD sockets) and a simple SUN RPC library, which will be both dedicated to the debug. We can use RTEMS API to implement it if **(R7)** is not required. As the two stack will need to share the same chip, a kind of shared filter must be implemented at the bottom of the two stacks so that Ethernet frames can be dynamically directed either to the dedicated UDP/IP debug stack or to the regular FreeBSD stack. The fact that in the current design, the low level ethernet input routine mainly signal a thread should facilitate the design of this filter. The output path is less complicated as it is run by a task and thus can sleep on a synchronization object,

[(R9)]: This requirement represents what we find reasonable as a first target. However, we can still present to the final user this kind of debugging via different model. RTEMS can be represented as a single threaded system or, because RTEMS is a multitasking system, as an ensemble of separate tasks. In the first representation, the debugger sees only 1 "task" without distinguishing the core executive part from the applicative part. This is the simplest way to implement the debugger but also implies that there is no way to protect the core executive. Some of these tasks are system tasks (tasks form the core executive and from the FreeBSD stack), the other ones are tasks implemented by the developer. The developer wants to debug his tasks, and sometimes only one of his tasks. We can provide a way to debug not the entire system but only the concerned task by testing if the current running task is a debugged task (test on the task identifier). GDB offers an API to "detach" thread so that if a detached thread hits a breakpoint it is automatically restarted without user intervention,

[(R10)]: Several developers can work on a large project, each on a specific module. Sometimes only one target is available for everyone. This requirements is not really meaningfull until RTEMS supports dynamic code loading,

[(R11)]: This requirement heavily depends on the **(R7)** and **(R8)** requirements.

3.3 Requirements Selection

3.3.1 Requirement We Will Take Into Account For the First Implementation

[(R1)]: Obviously.

[(R2)]: As these are our targets. Of course other will be free to contribute. We will however document the works that needs to be done in order to port the debug code to other processors,

[(R3)]: We think it is feasible with only few RTEMS modifications,

[(R5)]: We think serial line debugging is nowadays too restrictive as most equipment are now connected via Ethernet,

[(R6)]: This is a documentation problem and should be fairly easy to describe once we have the RGDBSD code,

[(R9)]: We will try to provide the multi-thread target system presentation,

3.3.2 Requirements We Will Not Implement

[(R4)]: it will not be implemented for the moment. It is just a matter on implementing SLIP in the FreeBSD stack and alternative solutions already exist in the meantime,

[(R7)]: To simplify the first developments, we don't plan to implement a *dedicated* nano-kernel to allow the RTEMS kernel to be debugged. It means that, if any breakpoint is set in the kernel, unpredictable behaviors can occur. So, developers must keep in mind to avoid stopping the kernel. They must also keep in mind, in order to not stop the kernel, that the user's tasks must have a lower priority than the tasks used for debug. The solution is to use a specific very-high priority level for the system tasks used directly or indirectly by RGDBSD. The SYSTEM_TASK attribute that already exists should be fine.

[(R8)]: To avoid increasing the code size and the used memory and because the FreeBSD stack doesn't need to be debug any more, we choose not to implement a minimal TCP/IP stack but rather to use the FreeBSD one as communication protocol,

[(R10)]: We will see later when a file system will be available and we can implement **exec** system call,

[(R11)]: Without a separate TCP/IP stack it will be hard to freeze the system as some interrupts must occur in order to enable the FreeBSD stack to function,

3.4 Implied Restrictions

High priority level must be used for these features :

- FreeBSD interrupt handling thread,
- Debugger threads.

This will allows these tasks not to be stopped when a process is stopped in debug mode

If we don't want to use a "specific" priority level, we must affect priority to each of these tasks as follow :

- FreeBSD stack (high priority)
- Debugger (less high priority)

The user must remember the higher priority level he can use for his software in order not to block one of the previous threads and to not put breakpoints in part of the code executed by RGDBSD.

4 A Rapid Tour of GDB Internals

To help the reader to understand what needs to be implemented, we will present briefly how GDB works regardless if the target is local or remote. A debugger is a tool which enables control of the execution of software on a target system. In most of cases, the debugger connects to a target system, attaches a process, inserts breakpoints and resumes execution. Then the normal execution is completely events driven (process execution stopped due to a breakpoint, process fault, single-step,...) coming from the debuggee. It can also directly access some parts of the target processor context (registers, data memory, code memory,...) and change their content. Native GDB debugger can just be seen as special cases where the host and the target are on the same machine and GDB can directly access the target system debug API.

In our case, the host and the target are not on the same machine and an Ethernet link is used to communicate between the different machines. Because GDB needs to be able to support various targets (including Unix core file, ...), each action that needs to be performed on the debuggee is materialized by a field of the following *targets_op*s structure :

```
struct target_ops
{
  char         *to_shortname;   /* Name this target type */
  char         *to_longname;    /* Name for printing */
  char         *to_doc;    /* Documentation.  Does not include trailing
                              newline, and starts with a one-line
                              description (probably similar to
                              to_longname). */
  void        (*to_open) PARAMS ((char *, int));
  void        (*to_close) PARAMS ((int));
  void        (*to_attach) PARAMS ((char *, int));
  void        (*to_detach) PARAMS ((char *, int));
  void        (*to_resume) PARAMS ((int, int, enum target_signal));
  int         (*to_wait) PARAMS ((int, struct target_waitstatus *));
  void        (*to_fetch_registers) PARAMS ((int));
  void        (*to_store_registers) PARAMS ((int));
  void        (*to_prepare_to_store) PARAMS ((void));

  /* Transfer LEN bytes of memory between GDB address MYADDR and
     target address MEMADDR.  If WRITE, transfer them to the target,
     else transfer them from the target.  TARGET is the target from
     which we get this function.

     Return value, N, is one of the following:

     0 means that we can't handle this.  If errno has been set,
     it is the error which prevented us from doing it (FIXME:
     What about bfd_error?).

     positive (call it N) means that we have transferred N bytes
```

```
     starting at MEMADDR.  We might be able to handle more bytes
     beyond this length, but no promises.

     negative (call its absolute value N) means that we cannot
     transfer right at MEMADDR, but we could transfer at least
     something at MEMADDR + N.  */

  int         (*to_xfer_memory)
                 PARAMS ((CORE_ADDR memaddr, char *myaddr,
                          int len, int write,
                          struct target_ops * target));

  void        (*to_files_info) PARAMS ((struct target_ops *));
  int         (*to_insert_breakpoint) PARAMS ((CORE_ADDR, char *));
  int         (*to_remove_breakpoint) PARAMS ((CORE_ADDR, char *));
  void        (*to_terminal_init) PARAMS ((void));
  void        (*to_terminal_inferior) PARAMS ((void));
  void        (*to_terminal_ours_for_output) PARAMS ((void));
  void        (*to_terminal_ours) PARAMS ((void));
  void        (*to_terminal_info) PARAMS ((char *, int));
  void        (*to_kill) PARAMS ((void));
  void        (*to_load) PARAMS ((char *, int));
  int         (*to_lookup_symbol) PARAMS ((char *, CORE_ADDR *));
  void        (*to_create_inferior) PARAMS ((char *, char *, char **));
  void        (*to_mourn_inferior) PARAMS ((void));
  int         (*to_can_run) PARAMS ((void));
  void        (*to_notice_signals) PARAMS ((int pid));
  int         (*to_thread_alive) PARAMS ((int pid));
  void        (*to_stop) PARAMS ((void));
  enum strata   to_stratum;
  struct target_ops
                *DONT_USE;      /* formerly to_next */
  int           to_has_all_memory;
  int           to_has_memory;
  int           to_has_stack;
  int           to_has_registers;
  int           to_has_execution;
  struct section_table
               *to_sections;
  struct section_table
               *to_sections_end;
  int           to_magic;
  /* Need sub-structure for target machine related rather than comm related? */
};
```

This structure contains pointers to functions (in C++, this would be called a virtual class). Each different target supported by GDB has its own structure with the relevant implementation of the functions (some functions may be not implemented). When a user connects GDB to a target via the “target” command, GDB points to the structure corresponding to this target. Then the user can attache GDB to a specific task via the “attach” command. We have therefore identified two steps to begin a remote debug session :

1. the choice of the target type (in our case RTEMS),
2. the choice of what to debug (entire system, specific task,...),

Note that in the case of natives debugger, the choice of the target is implicitly performed by commands like **run**, **attach**, **detach**. Several figures will now be described showing the main steps of a debug session.

Figure **Debug session initialization** explains how the debugger connects to the target :

1. The debugger opens a connection to the target. The word “connection” doesn't only mean Ethernet or serial link connection but all the ways by which a process can communicate with another one (direct function call, messages mailbox, ...),
2. The targets checks if it can accept or reject this connection,
3. If the connection is accepted, the host “attaches” the process,
4. the target stops the process, notifies a child's stop to the host and waits for command,
5. the host can ask information about the debugged process (name, registers,...) or perform some action like setting breakpoints, ...

Figure **Breakpoint and process execution** explains how the debugger manages the breakpoints and controls the execution of a process :

1. The host asks the debuggee what is the opcode at the concerned address in order for GDB to memorize this instruction,
2. the host sends a CONTINUE command : it asks the target to write the “DEBUG” opcode (for example, the INTEL “DEBUG” opcode is INT3 which generate a breakpoint trap) instead of the debugged opcode.
3. then the host waits for events,
4. after the change of instruction, the target resumes the execution of the debuggee,
5. when the “DEBUG” opcode is executed, the breakpoint exception handler is executed and it notifies the host that the process is stopped. Then it waits for commands (if no command is sent after a certain amount of time, the connection will be closed by the target).
6. the host asks the target to re-write the right opcode instead of the ”DEBUG” opcode and then can ask information

Figure **Breakpoint and process execution** also shows the case of other “CONTINUE” commands (remember that the “DEBUG” opcode has been replaced by the right instruction):

1. Host sends first a “single step” command to execute the debugged instruction,
2. It then waits for “single step“ exception event,
3. the target, once the single step executed, calls the debug exception handler. It notifies the host that execution is suspended and wait for commands.

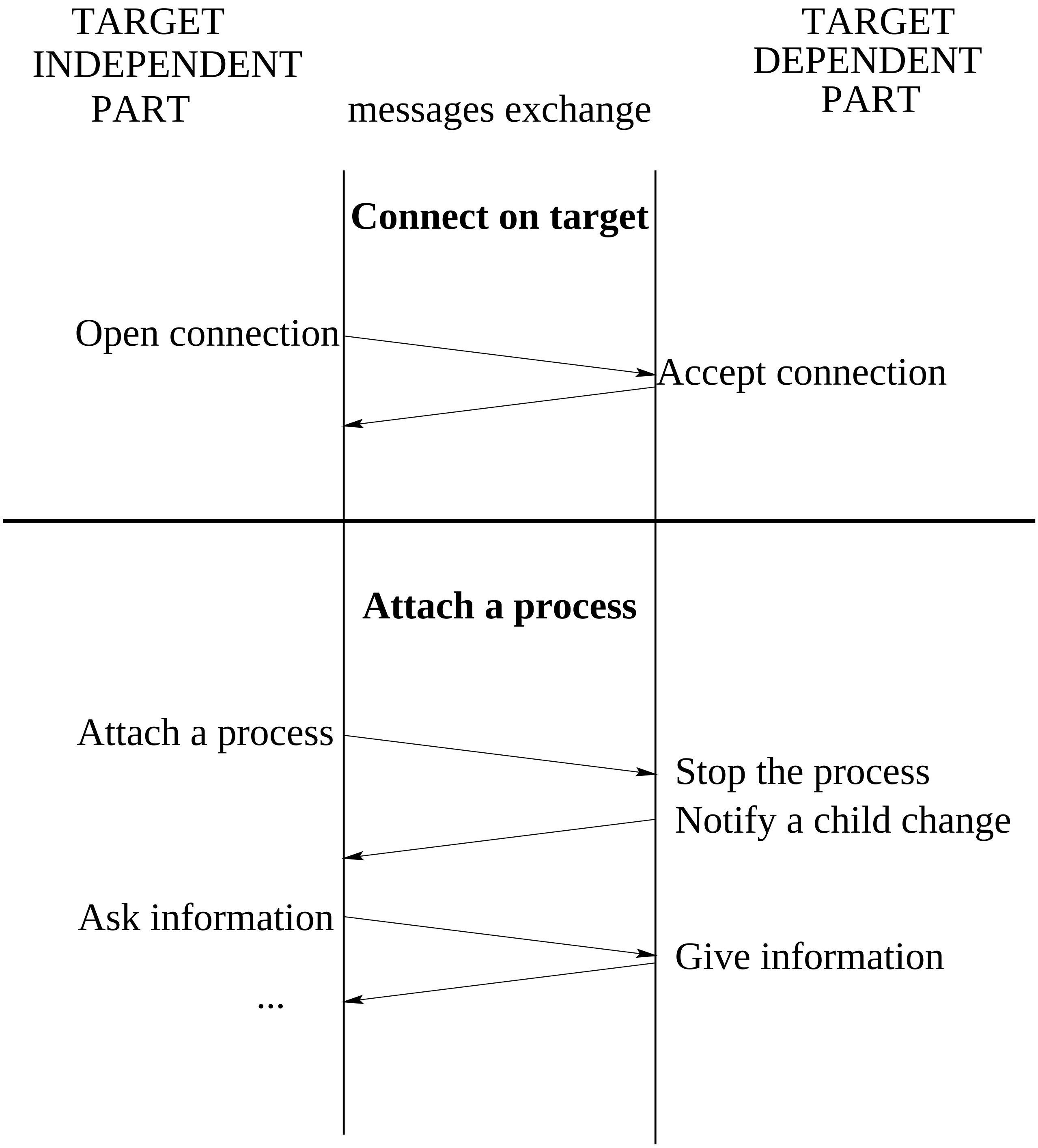
4. the host asks the target to re-write the "DEBUG" opcode (breakpoint trap) instead of the debugged one.
5. then the host sends a "CONTINUE" command in order the target to resume the process execution to the next breakpoint.

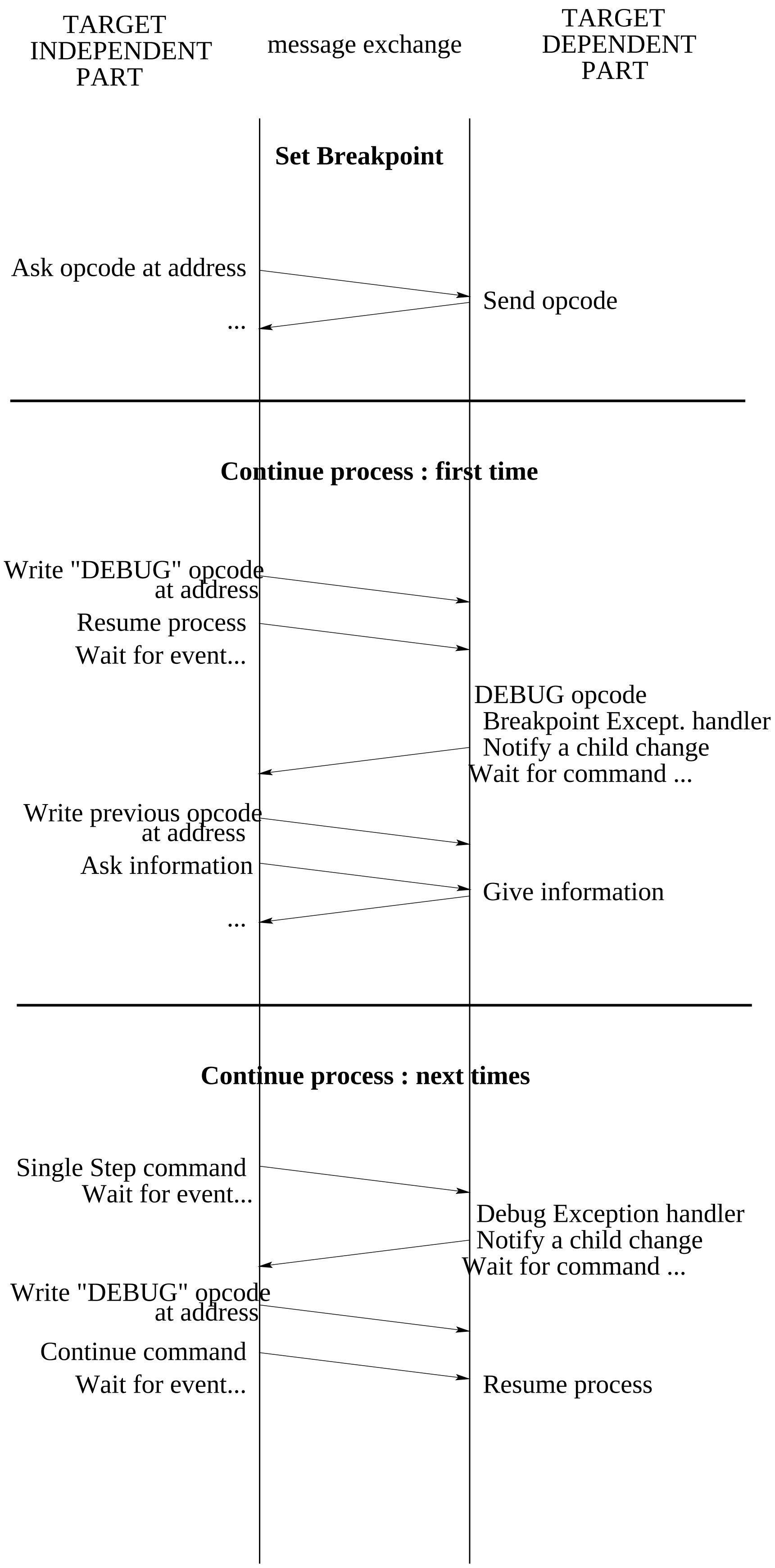
Figure **Detach a process and close a connection** explains how the debugger disconnects from a target :

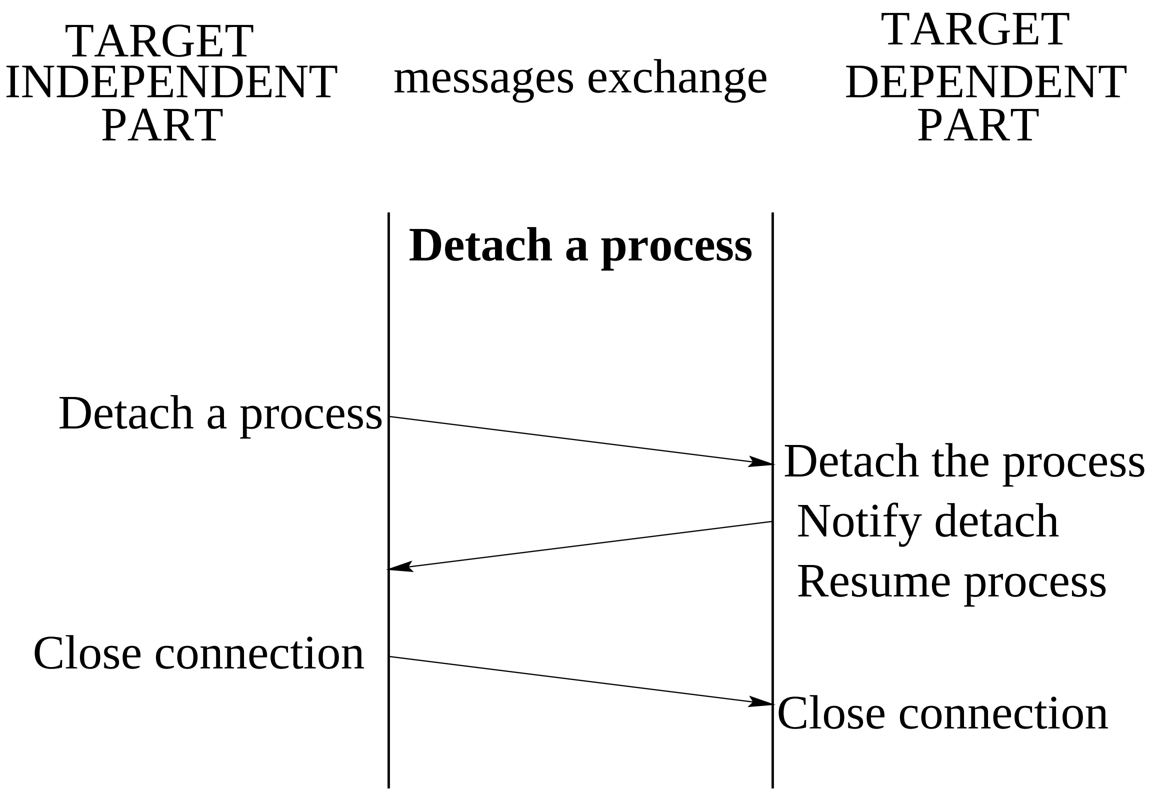
1. the host sends a detach command to the target.
2. the target detaches the concerned process, notifies the detachment and resumes the process execution.
3. once notified, the host sends a close connection command.
4. the target closes the connection.

These 3 examples show that the mains actions that are performed by the host debugger on the target are only simple actions which look like :

- read/write code,
- read/write data,
- read/write registers,
- manage exceptions,
- send/receive messages to/from the host.


TARGET INDEPENDENT PART
messages exchange
TARGET DEPENDENT PART
Connect on target
Open connection
Accept connection
Attach a process
Attach a process
Stop the process
Notify a child change
Ask information
Give information
...


TARGET INDEPENDENT PART
message exchange
TARGET DEPENDENT PART
Set Breakpoint
Ask opcode at address
Send opcode
...
Continue process : first time
Write "DEBUG" opcode at address
Resume process
Wait for event...
DEBUG opcode
Breakpoint Except. handler
Notify a child change
Wait for command ...
Write previous opcode at address
Ask information
Give information
...
Continue process : next times
Single Step command
Wait for event...
Debug Exception handler
Notify a child change
Wait for command ...
Write "DEBUG" opcode at address
Continue command
Wait for event...
Resume process


TARGET
INDEPENDENT
PART
messages exchange
TARGET
DEPENDENT
PART
Detach a process
Detach a process
Detach the process
Notify detach
Resume process
Close connection
Close connection

5 Interfacing GDB with RTEMS as a Target

So, basically, porting GDB to RTEMS environment requires implementing the functions contained in the target_ops structure. The native debugger implementation (where the host machine is also the target one) uses direct function calls. For our needs (remote debugging), these functions must be implemented to support the encapsulation in UDP/IP layers and communications between different types of host machines : the best solution is use the SUN Remote Procedure Calls API (SUN RPC). This SUN RPC module will be explained below (see paragraph **Communication with GDB**).

We can note that the functions described in the target_ops structure are high-level functions. The main reason is that GDB was designed in order to be able to use monitor firmware as a debug server. In the case of a Unix OS target, these high-level functions are implemented themselves using a lower level POSIX API. Because we want to simplify the code running on the target and decrease its size of this code, we propose to use the POSIX layer API used for the debug like **waitpid**, **ptrace**, ... Due to the GDB working mode and due to our requirements, we can establish here a non-exhaustive list of some commands required to implement the previously described functions :

- set up a connection with a target,
- close a connection,
- send a signal to the specified process,
- get a list of process/thread/connection running,
- control process under debug,
- ...

Control means that, with this function, we can read, write the memory of the debuggee, insert breakpoint to stop the process and resume the process execution. This command can be implemented by emulating in the RTEMS environment a Unix function called “ptrace”. This function allows the control of a child process. The “ptrace” function has some sub-functions which are described below (some of these actions and standardized, the others are added due to our needs) :

- PTRACE_PEEKTEXT, PTRACE_PEEKDATA : read word at address,
- PTRACE_POKETEXT, PTRACE_POKEDATA :write word at address,
- PTRACE_CONT : restart after signal,
- PTRACE_KILL : send the child a SIGKILL to make it exit,
- PTRACE_SINGLESTEP : set the trap flag for single stepping,
- PTRACE_ATTACH : attach to the process specified,
- PTRACE_DETACH : detach a process that was previously attached.

This list only contains the command that are described in the ptrace Unix manpage. For some specific needs (debug of one task among several ones, register read/write,...), it is possible to create some special ptrace commands as described after :

- get current task registers,
- set current task registers,

- list of the threads,
- identifier of the target thread,
- restart to address,
- set breakpoint at address,
- clear breakpoint,
- get breakpoints,
- load dynamically a task,
- ...

This list is not exhaustive and can be increased due to the needs. All the described functions will not be implemented in a first version, only the strictly needed. If some commands are added, the modifications must be implemented both in RTEMS and in GDB.

6 Communication with GDB

The RTEMS remote debugger will be accessed by GDB on a host machine through a communication link. We will use the TCP/IP stack included in RTEMS : the FreeBSD stack. The communication link will be based based on the UDP protocol and the BSD sockets which are parts of the FreeBSD stack. On top of these layers, we will plug a module which allows a simple communication between different machines (especially between different endianess machines) : the SUN Remote Procedure Call (SUN RPC). This code is freely available on the net and comes with a BSD like license. With this module, a process can invoke a procedure on a remote system. The RTEMS remote debugger will be seen by GDB as a SUN RPC server. Commands will be packed by the GDB SUN RPC client and sent to the server. This server will unpack these commands, execute them and, if needed, return results to the SUN RPC client.

Only a minimal subset of the SUN RPC library must be implemented. For example, the portmapper related API which allows a dynamic allocation of port numbers will not be implemented and some specific UDP port numbers will be used to establish the communication between the host and the target. The SUN RPC library implements the XDR module (eXternal Data Representation) which is a standard way of encoding data in a portable fashion between different endian systems. Below are figures describing the additional code and data size for the minimal library implementation we currently have already implemented for RTEMS :

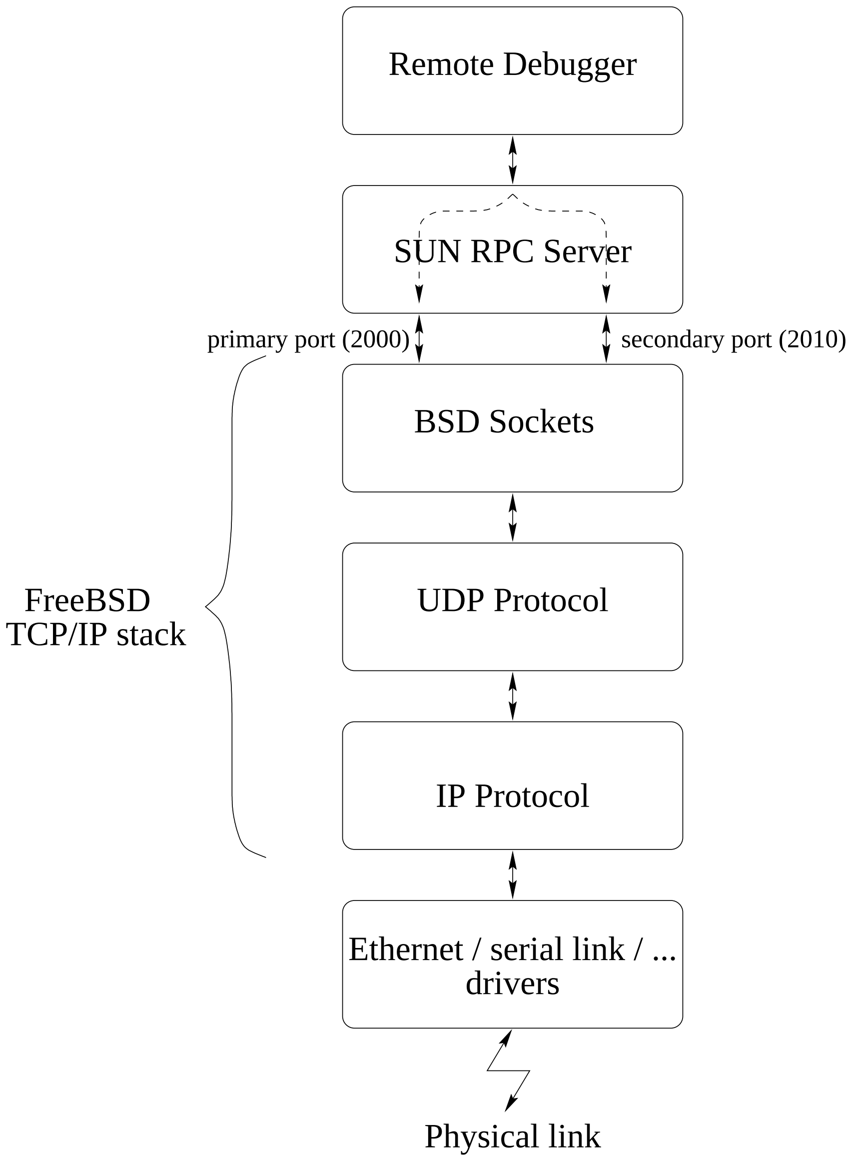
```
$ size -x librpc.a
text  data bss dec hex filename
0x40e 0x0 0x0 1038 40e rpc_callmsg.o (ex librpc.a)
0x2f1 0x18 0x0 777 309 rpc_prot.o (ex librpc.a)
0x458 0x0 0x0 1112 458 svc.o (ex librpc.a)
0x4f 0x4 0x0 83 53 svc_auth.o (ex librpc.a)
0x75c 0x18 0x0 1908 774 svc_udp.o (ex librpc.a)
0x711 0x4 0x10 1829 725 xdr.o (ex librpc.a)
0x149 0x0 0x0 329 149 xdr_array.o (ex librpc.a)
0x165 0x20 0x0 389 185 xdr_mem.o (ex librpc.a)
```

We have a constraint with the use of the UDP protocol. Because this protocol is connectionless, it is impossible, especially for the target, to detect if the connection is always active. On the other hand, using the TCP/IP protocols seems to be heavy especially if we plan to implement a dedicated micro stack for debug in the future. It can be a real problem to let the debugged process stopped during a long time even if there is no more debugger connected to the system. To avoid such a problem, the target must periodically test the connection with the host on another way than the one used to receive the commands. We must therefore open two communication ways so we need two fixed UDP port numbers.

1. One port will be used by the debugger to send its commands to the debugged process and to receive the result of these commands. View from the remote debugger, this port will be called primary port. For this one, we choose arbitrarily the port number 2000.
2. The other socket will be used as secondary port by the target to sometimes test

the connection between the host and the target. These tests will occur in specific situations, when a process will be stopped on a breakpoint, single step instruction or other means. This secondary port will also be used by the target to signal any change in the behavior of a debugged process (stopped, killed, waiting for,...). For the secondary port, we choose the port number 2010.

These two port numbers are used by the remote debugger to open the two communication sockets. GDB will use its own mean to choose its port numbers (probably the Unix portmapper). The figure layer shows the different layers we need to implement.



7 RTEMS Debugger Server Daemon

We will describe in this section how this debugger server will be implemented on RTEMS environment. Our initial target is based on Intel Pentium and we will use an Ethernet link to communicate between the host and the target.

The RTEMS remote debugger will be composed by several tasks and exception handlers :

- an initialization task which opens the sockets and runs the SUN RPC server. This task will also connect the interrupt handlers and launch the communication task
- a communication task which receives the SUN RPC commands, executes them and sends the result to the GDB client,
- A debuggee event management task which waits for events. We need a different task than the command management task in order to be able to still accept commands while no event has yet occurred for the debuggee. An example could be a continue command from GDB and then hitting to DEL key to see what is currently going on on the target side because an expected breakpoint is not caught...
- a debug exception handler which manages the hardware breakpoint and single step exceptions (INT 1 on Intel x86),
- a breakpoint exception handler which manages the software breakpoints exceptions (INT 3 on Intel x86),
- a default exception handler used to catch every possible errors make on the target system,

Figure **remote debugger tasks and handlers** represents these different tasks and handlers. The synchronization between the different task and exception handlers will be described below in the section **Synchronization Among Tasks and Exception Handlers**. Some open issues we have faced for a prototype implementation are described in the section **Open Issues**. The temporary workaround we chose are described in chapter **Workarounds for Open Issues in Prototype**.

7.1 The INITIALIZATION task

This is the task that must be executed at the boot phase of RTEMS. It initializes the debug context. It must :

- open the UDP sockets,
- run the SUN RPC server main loop,
- create the COMMAND MANAGEMENT task,
- connect the DEBUG EXCEPTION handler,
- connect the SOFTWARE BREAKPOINT handler,
- delete itself.

If an error occurs at any step of the execution, the connections established before the error will be closed, before the initialization task deletes itself.

7.2 The COMMAND_MNGT task

This task is in charge of receiving the SUN RPC messages and executing the associated commands. This task must have an important priority because it must be executed each time a command message comes from the debugger. It must be executed even if one or both exception handlers are executed. But the COMMAND MANAGEMENT task must not block the TCP/IP module without which no message can be received.

When not executing a command, this task is waiting for a SUN RPC message on the primary port. This idle state blocks the task, so the other active tasks can run. Once a message comes from Ethernet via the primary port, the COMMAND MANAGEMENT task wakes up and receives the message which is a request from GDB. This request is sent to the SUN RPC server code which extracts the command and its arguments, executes it and, if needed, sends a result to GDB. After having performed these actions, the task sleeps, waiting for another message.

A particular case is the reception of the ATTACH command : in this case the COMMAND_MNGT task creates the EVENT_MNGT task described below before going to wait on UDP socket again.

7.3 The EVENT_MNGT task

This task is in charge of managing events happening on the debuggee such as breakpoint, exceptions. This task does a basic simple loop waiting for event on a synchronization variable. It is waken up by exception handlers code. It then signals GDB that an event occurred and then go sleeping again as further requests will be processed by the COMMAND_MNGT task.

7.4 The DEBUG EXCEPTION handler

This handler is connected to the DEBUG exception (INT 1 on Intel ix86). This exception is entered when :

- executing a single-step instruction,
- hardware breakpoint condition is true,

These events will be treated by the debugger because they are the primary event used when debugging a software for instruction stepping. In both cases, the DEBUG EXCEPTION handler code is executed. Please note that the execution context of the exception handler is the supervisor stack of the task that generated the exception. This implies:

- We may sleep in this context,
- We have as many possible execution context for the DEBUG EXCEPTION handler as we need to,

- When we enter the high level exception handler code, a normalized exception context has been pushed on the system stack and a pointer to this context is available as the first argument (cf cpukit/score/cpu/i386/cpu.c for more details),

First the exception handler wakeup the EVENT_MNGT task. Then it will cause the faulting thread to sleep on a synchronization object. As soon as GDB receives the event notifying that the debuggee status has changed, it will start sending requests to get the debuggee status (registers set, faulty task id, ...). These requests are handled by the COMMAND MANAGEMENT task. When this task receive a PTRACE_CONT command it will resume the execution of the task that caused the exception by doing a V on the synchronization object.

7.5 The BREAKPOINT EXCEPTION handler

This handler is connected to the BREAKPOINT exception (INT3 on Intel Ix86). Each time the debugger wants to place a software breakpoint in the debuggee, a debuggee opcode is temporarily replaced by an instruction causing BREAKPOINT exception (the "INT 3" instruction on Intel ix86). When "INT 3" is executed, the BREAKPOINT handler is executed. Otherwise, the exception processing is the same than the one described in previous section.

7.6 Synchronization Among Tasks and Exception Handlers

The previous chapters have presented a simplified and static view of the various tasks and exceptions handlers. This chapter is more focussed on synchronization requirements about the various pieces of code executed when RGDBSD is operating.

7.6.1 Implicit Synchronization Using Task Priorities

This chapter is relevant on Uniprocessor System (UP) only. However, it will also list the requirements for explicit synchronization on Multi-processor Systems (MP). Below are the task priorities sorted by high priority. They are not supposed to be equal :

1. Network Input Task. This is the highest priority task. This can be regarded as a software interrupt task for FreeBSD code,
2. RGDBSD command task. As this task waits on UDP sockets, it shall not prevent the previous task from running. As the main debug entry point, it should preempt any other task in the system,
3. RGDBSD event task. This task should preempt any task but the two mentionned before to signal a debug event to GDB. The command task shall be able to preempt this task for emergency command such as DEL, or REBOOT,
4. Applications tasks (task we are able to debug),

Using theses priorities eliminates the need for adding more synchronization objects in the next section. My belief is that symmetric MP support will require more important change in the RTEMS than RGDBSD itself like multiple scheduler queues, task to processor binding for non symmetric IO, use a different implementation for *task_disable_preemption*, ...

7.6.2 Explicit Synchronization

This chapter will describe the synchronization variables that need to be implemented in order to sequence debug events in a way that is compatible with what GDB code expects. The root of the problem is that GDB code mainly expects that once a debug event has occurred on the debuggee, the entire debuggee is frozen and no other event will occur before the CONTINUE command is issued. This behavior is hard to achieve in our case as once we hit a breakpoint, only the task that hits the breakpoint will be asleep on a synchronization object. Other tasks may hit other breakpoints while we are waiting commands from GDB generating potential unexpected events. There is a solutions if RGDBSD itself use RTEMS threads to fix this problem by creating a task that loops forever at a priority superior to any debugged task but below RGDBSD task priorities. Unfortunately this will not work for the case we use the nano-kernel implementation and we think it is better to study synchronization problems now. We also expects that multi-thread debug support hardening in GDB will remove some event serializations requirements. Here is the list of synchronization variables we plan to use and their usage. They are all regular semaphores. They are not binary semaphores because the task that does V is not the task that has done the P.

- *WakeUpEventTask* : used by exception handler code to wake up the EVENT_MNGT task by doing a V operation on this object. When target code is running normally the EVENT_MNGT task sleeps due to a P operation on this semaphore,
- *SerializeDebugEvent* : used to serialize events in a way compatible to what GDB expects. Before doing a V operation on *WakeUpEventTask*, the exception handler does a P on this semaphore to be sure processing of another exception is not in progress. Upon reception of a CONTINUE command, the COMMAND_MNGT task will issue a V operation so that the exception code can wake up EVENT_MNGT task using the mechanism described above,
- *RestartFromException* : (in fact one semaphore per task) used by exception handling code to put a faulty task to sleep once it has generated an exception by doing a P operation on this semaphore. In the case the exception was generated due to a breakpoint, GDB command will modify back the BREAKPOINT opcode to the original value before doing the CONTINUE command. This command will perform a V on this semaphore. In the case it is a real non restartable exception (faulty memory reference via invalid pointer for example), GDB will not allow to restart the program avoiding any loop. So not special analysis of cause of exception is foreseen as far as RGDBSD code is concerned,

7.7 Open Issues

Here are some problems we have faced while implementing our prototype :

[Protected ReadMem/WriteMem (I1)]:

A GDB user can request to see the content of a corrupted pointer. The request PEEK_DATA will be performed by the COMMAND_MNGT task. It shall not enter the default exception handler set by RGDBSD or it will cause a dead lock in the RGDBSD code. Replacing the default exception vector before calling **readMem/writeMem** can be temporarily sufficient but :

- It will never work on MP system as it will rely on task priorities to insure that other task will not cause exceptions while we have removed the default exception handler,
- This feature should not be usable in RGDBSD only but also by an embedded debugger that may run without any task. It is also unavoidable in case of protected memory and in this case no priority mechanism can be used,
- In the case of using RGDBSD code on a dedicated nano kernel, this code will be called from interrupt level and we need a way to be sure we can debug other interrupts that may also cause exceptions,

[ATTACH Command Implementation (I2)]:

After the *target rtems symbolic_ip_target_name* command, the normal operation is to issue an *attach lid* command where *lid* represents a valid execution context. For Unix this is a process id, for other multitasking system this is the id of a thread. After the attach command, GDB expects to be waken up in the same manner as it is for normal events. Once waken up it expects to have a complete register context available and also that the target task is in a stopped state and that it can restart it using the regular CONTINUE command. In RTEMS there is a way to get force a thread to become inactive via *rtems_task_suspend* but no way to get the full registers set for the thread. A partial context can be retrieved from the task *Registers* data structure. On the other hand, relying on *rtems_task_suspend* will be a problem for the nano-kernel implementation.

[Stopping Target System (I3)]:

Allthough it might not be obvious, most of the actions made by a GDB user assume the target is not running. If you modify a variable via the *set variable = value* command you expect that the value is the one you have put when restarting. If a still running task modifies the same value in the mean time, this may be false. On the other hand, stopping all the tasks on the target system impose to have a very deep knowledge of the system. Using an interrupt driven RGDBSD, may facilitate the implementation on the nano-kernel.

[Getting Tasks Contexts (I4)]:

As previously mentionned there is no way to get tasks execution contexts via the RTEMS API. This is needed when debugging for example via this classical sequence :

1. *(gdb) target rtems symbolic_ip_target_name*
2. *(gdb) info threads* <= get a thread list on screen
3. *(gdb) attach thread_id* <= thread_id is one of the thread in the list
4. *(gdb) b a_function_of_interest*
5. *(gdb) continue*
6. *(gdb) backtrace* <= print the call stack on the screen once we have hit the breakpoint
7. *(gdb) thread target another_thread_li* <= change implicit current thread value for gdb commands
8. *(gdb) backtrace* <= should print the backtrace for the chosen thread

In our execution model, we have a valid context only for the threads that hits the breakpoint as it has been pushed by the exception handler code. The other thread is still running and during the various RPC requesting memory access, it even changes as the COMMAND_MNGT thread is going to sleep. So the backtrace command will fail. We must find a way to make this work as it is very usefull when debugging multi-threaded programs,

[Backtrace Stop convention (I5)]: The backtrace command on RTEMS task does not gracefully terminate as GDB does not find some backtrace termination condition it expects.

7.8 Workarounds for Open Issues in Prototype

[(I1)]: Not implemented.We would rather like to work on the formalization of per thread flags and global flags that are much more general than any kludge we could implement,

[(I2)]: We have tried two solutions in our prototype. The first one was to use the *idle* thread context contained in the *Registers* task control block field. The drawback of this solution was that we had to implement specific code for the continue operation immediately following the attach command. We then decided to create a dedicated task that will only exist during the attach phase. This task will call the "ENTER_RGDB" exception. This call will execute the Exception Handler that saves a valid context and that notifies a change to GDB. After the first CONTINUE command from GDB, this task will continue its execution and delete itself,

[(I3)]: As explained above in the synchronization chapter, we choose to serialize events in a way that makes GDB think the system is frozen,

[(I4)]: As a temporary fix, we have called *rtems_task_suspend* and used the context switch contex for tasks that are unknown to RGDBSD,

[(I5)]: Not Implemented yet. If I remember correctly, setting the frame pointer to 0 at task initialization for CISC processor solves this problem (ebp = 0x0 on Intel or a6 = 0x0 on 680x0). This should be done in rtems_task_create function in the path to really starts the task for the first time. The processor/system specific stop condition can be found as macros in the GDB source tree.

7.9 Output of a Debug Session with the Prototype

This is a sample session with the remote debugging prototype. Note that some lines have been broken so they would print properly when printed.

```
GNU gdb 4.17
Copyright 1998 Free Software Foundation, Inc.
GDB is free software, covered by the GNU General Public License,
and you are welcome to change it and/or distribute copies of it
under certain conditions.  Type "show copying" to see the conditions.
There is absolutely no warranty for GDB.
Type "show warranty" for details.
This GDB was configured as --host=i686-pc-linux-gnu --target=i386-rtems.
Attaching remote machine across net...
Connected to net-test.
Now the "run" command will start a remote process.
Setting up the environment for debugging gdb.
(gdb) attach 1
Attaching program: /build-rtems/pc386/tests/debug.exe pid 1
0x230715 in enterRdbg ()
(gdb) info threads
There are 8 threads:
Id.       Name   Detached   Suspended
134283273 Rini   No         No <= current target thread
0x230715 in enterRdbg ()
134283272 Evnt   No         No
_Thread_Dispatch () at /rtems/cpukit/score/src/thread.c:315
134283271 SPE2   No         No
_Thread_Dispatch () at /rtems/cpukit/score/src/thread.c:315
134283270 SPE1   No         No
_Thread_Handler  () at /rtems/cpukit/score/src/thread.c:1107
134283269 RDBG   No         No
0x230715 in enterRdbg ()
134283268 SCrx   No         No
_Thread_Dispatch () at /rtems/cpukit/score/src/thread.c:315
134283267 SCtx   No         No
_Thread_Dispatch () at /rtems/cpukit/score/src/thread.c:315
134283266 ntwk   No         No
_Thread_Dispatch () at /rtems/cpukit/score/src/thread.c:315
```

```
(gdb) b init.c:89
Breakpoint 1 at 0x200180: file \
    /rtems/c/src/tests/samples/debug/init.c, line 89.
(gdb) c
Continuing.
Thread 134283273 (Rini) has been deleted.
[Switching to Rtems thread 134283271 (Not suspended) \
    ( <= current target thread )]
Breakpoint 1, example2 (argument=4) at \
    /rtems/c/src/tests/samples/debug/init.c:89
89          tuto += tuti;
(gdb) s
90          if (print_enable2)
(gdb) c
Continuing.
Breakpoint 1, example2 (argument=4) at \
    /rtems/c/src/tests/samples/debug/init.c:89
89          tuto += tuti;
(gdb) b init.c:66
Breakpoint 2 at 0x200128: file \
    /rtems/c/src/tests/samples/debug/init.c, line 66.
(gdb) c
Continuing.
Switching to Rtems thread 134283270 (Not suspended) \
    ( <= current target thread )]
Breakpoint 2, example1 (argument=4) at \
    /rtems/c/src/tests/samples/debug/init.c:66
66          toto += titi;
(gdb) c
Continuing.
[Switching to Rtems thread 134283271 (Not suspended) \
    ( <= current target thread )]
Breakpoint 1, example2 (argument=4) at \
    /rtems/c/src/tests/samples/debug/init.c:89
89          tuto += tuti;
(gdb) bt
#0  example2 (argument=4)
    at /rtems/c/src/tests/samples/debug/init.c:89
#1  0xf0009bd0 in ?? ()
(gdb) thread target 134283270
thread 134283270 [SPE1], _Thread_Dispatch () at \
    /rtems/cpukit/score/src/thread.c:315
315         executing = _Thread_Executing;
(gdb) c
Continuing.
Breakpoint 2, example1 (argument=4) at \
    /rtems/c/src/tests/samples/debug/init.c:66
```

```
66          toto += titi;
(gdb) detach
Detaching program: /build-rtems/pc386/tests/debug.exe pid 1
Warning: the next command will be done localy! \
    If you want to restart another remote
program, reuse the target command
(gdb)
```

8 Conclusion

In this document we have presented how we envisage to add remote debugging facilities to RTEMS by implementing a remote debugger daemon for GDB. As any debug implemented in software, it will have limitation but we are confident that most of them can be removed by adding separate software components dedicated to debug activity. We must keep in mind that even with this approach, no software will enable the debug of code with interrupt entirely masked at processor level and that In Circuit Emulator (ICE) or use of BDM extension on the target board are the ultimate way to really debug any portion of an RTOS. BDM support in GDB is still weak but people are working on it and we may get something better in a near future.