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Time to debug
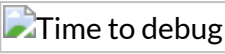
Debugging an application live has always been easy for application
developers, but debugging a live kernel has never been a simple option
for kernel developers — it involves multiple machines with serial
connections. This article shows how to use virtualisation atop a running
OS to help debug a live kernel on a single machine. Readers are expected
to have prior knowledge on how to use GDB, know the fundamentals of
the Linux kernel, understand custom compilation, apart from knowing
how to use VirtualBox or any other virtualisation software.
KGDB (http://kgdb.linsyssoft.com/) is an amazing Linux kernel
debugging tool. It can debug the kernel while it is running, set
breakpoints, and step through the code. Earlier, KGDB used to be a
bunch of patches that had to be carefully merged into the mainline
kernel. However, since version 2.6.26, KGDB has been merged into the
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CASE STUDIES

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A typical KGDB setup requires two machines connected by a serial cable: one as a source machine on which debugging is done, and the other (destination) which is being debugged. With virtualisation, however, we can do away with that second machine.

When we combine VirtualBox with KGDB on a single machine, the host OS is the 'source' machine, while the guest OS (Linux kernel compiled with KGDB enabled) is the "destination". A virtual serial port is enabled between the host and the guest. Figure 1 displays such a setup.
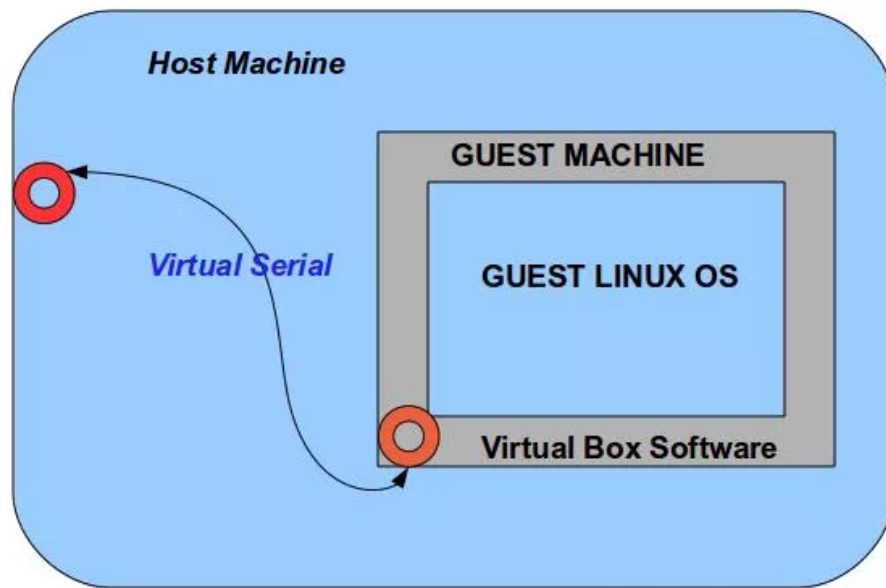

Figure 1: KGDB with the VirtualBox set-up

Prerequisites

For this setup, we'll need:

- The host running a Linux system (you can have a host OS other than Linux, but this article does not cover that). My host system runs Ubuntu Maverick Meerkat 10.10, 64-bit.
- VirtualBox software installed on the host OS. I used the VirtualBox 4.0 distribution-specific binary obtained from the project website (http://www.VirtualBox.org/wiki/Linux_Downloads).
- The `socat` binary installed on the host. This is used to link the pipe file (FIFO) that is created by VirtualBox, with a pseudo-terminal on the host system. Here's the download link (http://www.dest-unreach.org/socat/download/). Normally, GDB takes a physical terminal file (like `ttys0`) as the remote target, but in our case, we will instead provide a pseudo terminal created by `socat` as the remote target for GDB. Refer to the `socat man` pages for more information.
- A VM installed with a Linux guest OS (I used Fedora 14). The VirtualBox documentation shows how to create a VM, if you need it, so I won't repeat it here. Help on how to install an OS in a VirtualBox VM is also in the documentation. I downloaded the Fedora 14 ISO from the Fedora site, attached it to the VM, and booted the VM and installed Fedora.
- The Linux kernel source is accessible to the VM (and the host, too — see below). This can be picked up from kernel.org (http://kernel.org/); I used version 2.6.37. It is used to recompile the guest OS kernel with KGDB-specific options. How to get the source available in the VM is described under "File-sharing between machines" subsection below.

Setting up the guest

Configuring the virtual serial port in VirtualBox

Right-click your virtual machine instance, and go to the *Settings* tab. On the *Port 1* tab, choose "Enable Serial Port". Select "Port Mode" to be "Host pipe". Enter a pipe file-name in the "Port/File Path" text field, as

shown in Figure 2.

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Figure 2: Configuring the serial port in VirtualBox

File-sharing between machines

I have set up networking for the VM and in my Fedora guest, so that I can easily access files on the host. You could set up an optional NFS server on the host machine, and create an NFS share for the kernel source directory. This share is mounted within the guest, and the kernel is compiled and installed from the guest command prompt. View Figure 3 for an idea of my setup.
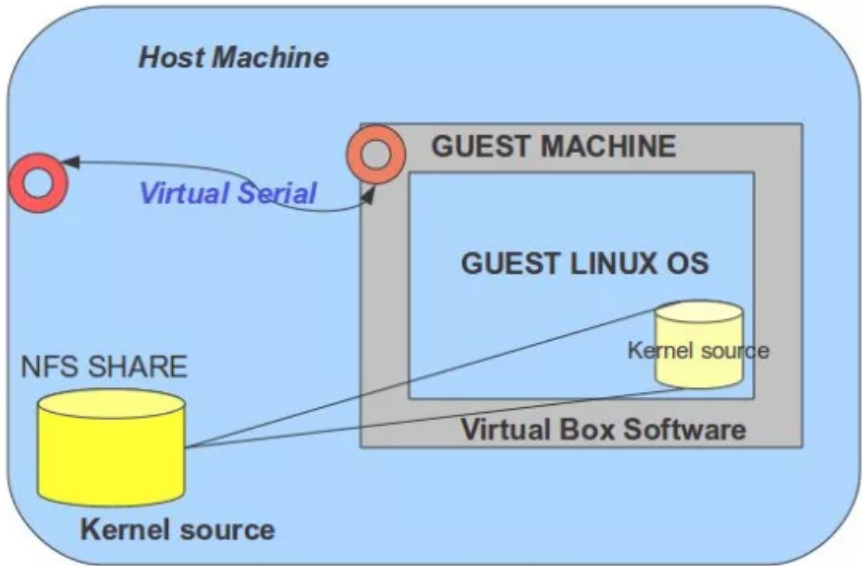
Figure 3: The NFS share set-up with VirtualBox

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There are many benefits in such a setup — the shared kernel source can be used to directly do a `make install` of the kernel within the guest. While debugging, you will need the kernel source files in the host OS, so that they are accessible to GDB — and let's not forget the `vmlinuz` file, which is passed as one of the arguments to the debugger. If you are debugging kernel modules, you can edit the module source (in the NFS-shared folder) from the host, while you debug the guest. There are many other ways of doing this, which you can explore on the Internet.

Preparing and installing the kernel on a guest OS

The kernel source can be compiled either on the guest or the host. Since I have Ubuntu on the host and Fedora in the guest, I preferred to compile the kernel in the guest itself. Wherever you compile it, you will obviously need the build environment set up. Again, preparing a build environment is a task that is documented very well on the Internet. An important point to note is that compiling the kernel in the VM (guest OS) is extremely time-consuming.

INTERVIEWS

During kernel configuration (once you do a `make menuconfig`) ensure you enable the following options:

- Kernel hacking –> (options for kernel hacking)
- Kernel debugging (features for kernel debugging)
- Compile the kernel with debug info (kernel and modules are compiled with the `-g` option)
- Compile the kernel with frame pointers (frame-pointer registers are used to keep track of stack)
- KGDB: Kernel debugger –> (enable KGDB)
- KGDB: Use over serial console (enable serial console support) (see Figure 4)

```
--- KGDB: kernel debugger
<*>    KGDB: use kgdb over the serial console
[ ]    KGDB: internal test suite
[ ]    KGDB: Allow debugging with traps in notifiers
[ ]    KGDB_KDB: include kdb frontend for kgdb
```
Figure 4: KGDB serial console options
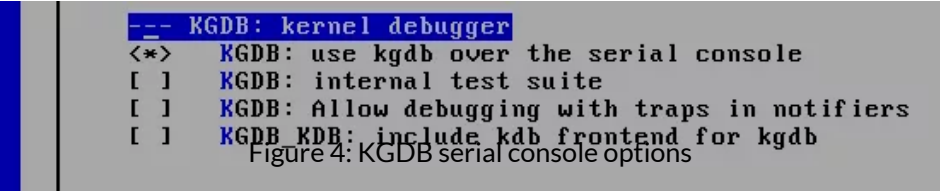
Once the kernel is compiled, if you do a make modules_install and install from within the guest, it will install the newly compiled kernel. Figure 5 shows the Grub option for the new kernel after a guest reboot.

Figure 5: Newly compiled kernel in the GRUB

Newly compiled kernel in the GRUB menu

Editing the bootloader

To enable KGDB serial console support from the guest, we need to append the options `kgdboc=ttyS0` and `115200 kgdbwait` to the kernel command-line. Here, `kgdboc` (KGDB over console) uses `ttyS0` with the baud rate defined as 115200. The `kgdbwait` option tells the kernel to wait until we connect to it with GDB.

From the Grub boot-loader screen, press *e* and append the options to the kernel line, as shown in Figure 6.

```
Fedora-64 [Running] - Oracle VM VirtualBox
Machine  Devices  Help
[ Minimal BASH-like line editing is supported.  For the first word, TAB
  lists possible command completions.  Anywhere else TAB lists the possible
  completions of a device/filename.  ESC at any time cancels.  ENTER
  at any time accepts your changes.]

<odeset kgdboc=ttyS0,115200 kgdbwait
```
Figure 6: Options in Grub prompt

(http://opensourceforu.com) debugging frequently, is to edit the `/etc/grub.conf`, in my case) and update the kernel command line, as shown in Figure 7. This second method requires a reboot of the VM to activate the new kernel options, if you haven't edited at the GRUB prompt.

```
title
      root (hd0,0)
      kernel /boot/vmlinuz-2.6.37 ro root=UUID=13302919-8474-453e-98b5-8d5025b
b7d3c rd_NO_LUKS rd_NO_LVM rd_NO_MD rd_NO_DM LANG=en_US.UTF-8 SYSFONT=latarcyrhe
b-sun16 KEYBOARDTYPE=pc KEYTABLE=us rhgb quiet kgdboc=ttyS0,115200 kgdbwait
```
Figure 7: Edit the kernel options in the grub.conf

Booting with KGDB options

Once you have these options in the kernel command-line and boot from it, the kernel boots till it gets to the stage where it waits for the remote
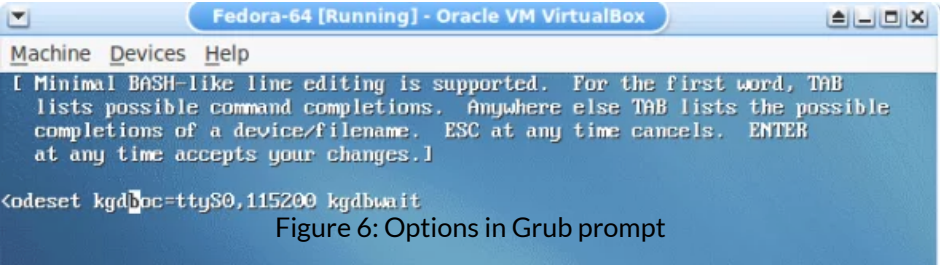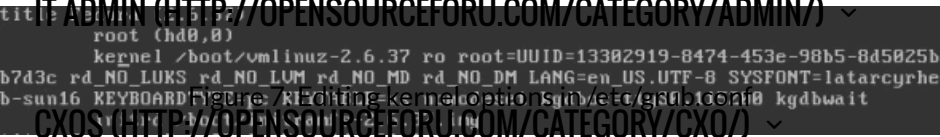
GDB connection over the (virtual) serial port, as shown in Figure 8.

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```
[    0.667829] ACPI: Battery Slot [BAT0] (battery present)
[    0.667954] Non-volatile memory driver v1.3
[    0.667957] Linux agpgart interface v0.103
[    0.668041] Serial: 8250/16550 driver, 4 ports, IRQ sharing enabled
[    0.943165] serial8250: ttyS0 at I/O 0x3f8 (irq = 4) is a 16550A
[    1.225196] serial8250: ttyS1 at I/O 0x2f8 (irq = 3) is a 16550A
[    1.236702] kgdb: Registered I/O driver kgdboc.
[    1.249236] kgdb: Waiting for connection from remote gdb...
```
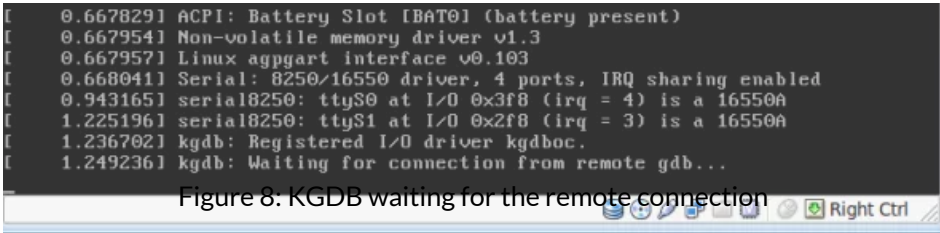Figure 8: KGDB waiting for the remote connection

Linking the serial file on the host to the pseudo-terminal

We need to use `socat` to do this linking, with the following command:

```
# socat -d -d /code/guest/serial PTY:
```

Here, `PTY:` is the pseudo-terminal, and `/code/guest/serial` is the virtual serial port pipe file created by VirtualBox on my host machine as per the VM settings done earlier. When this command is run, it returns the pseudo-terminal number that's allocated (in my case, `/dev/pts/7`), as shown in Figure 9.

Figure 9: Socat with pipe file and pseudo tty

Socat with pipe file and pseudo tty
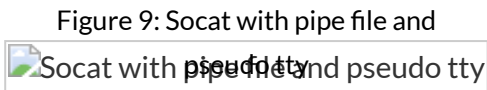
It's important to remember that you should not terminate the `socat` command; it needs to be running in the background for us to be able to use the pseudo terminal, else it breaks the stream.

Firing up GDB

Enter the kernel source directory on the host, and start GDB, telling it to connect to the remote target, which is the pseudo-terminal number returned by `socat`:

```
# cd linux-2.6.37
# gdb ./vmlinux
(gdb) target remote /dev/pts/7
```

This connects us to the waiting Linux kernel session in the VM. If we type `continue` at the GDB prompt, we will see booting resume in the VM's guest OS. To be able to get back the GDB prompt on the host, you need to run the following command in the guest:

```
# echo g > /proc/sysrq-trigger
```

This will break the running session, and give you control in GDB. This can be used to insert break-points and do other debugging operations, like those seen in Figure 10. If you need to debug a kernel module, insert the text address of the module (http://opensourceforu.com/sections/.text) and use it as an argument for the GDB command `add-symbol-file`.

```
root@wn7-cqm462s:/code/guest/linux-2.6.37# gdb -sil vmlinux
Reading symbols from /code/guest/linux-2.6.37/vmlinux...done.
(gdb) target remote /dev/pts/7
Remo
kgdb
960
(gdb) bt
#0  kgdb_breakpoint () at kernel/debug/debug_core.c:960
#1  0xffffffff810ee21c in kgdb_initial_breakpoint () at kernel/debug/debug_core.c:858
#2  0xffffffff810ee72 in kgdb_register_io_module (new_dbg_io_ops=0xffffffff81a42690) at kernel/debug/debug_core.c:900
#3  0xffffffff812d3ff5 in configure_kgdboc () at drivers/serial/kgdboc.c:196
#4
#5
#6  0xffffffff81b52db9 in do_initcalls (unused=<value optimized out>) at init/main.c:777
#7  do_basic_setup (unused=<value optimized out>) at init/main.c:798
#8  kernel_init (unused=<value optimized out>) at init/main.c:889
#9  0xffffffff8100baa4 in ?? () at arch/x86/kernel/entry_64.5:1146
#10 0x0000000000000000 in ?? ()
(gdb)
955
956
957         atomic_inc(&kgdb_setting_breakpoint)
958         wmb(); /* Sync point before breakpoint */
959         arch_kgdb_breakpoint();
960         wmb(); /* Sync point after breakpoint */
961
962
963
964
(gdb)
```
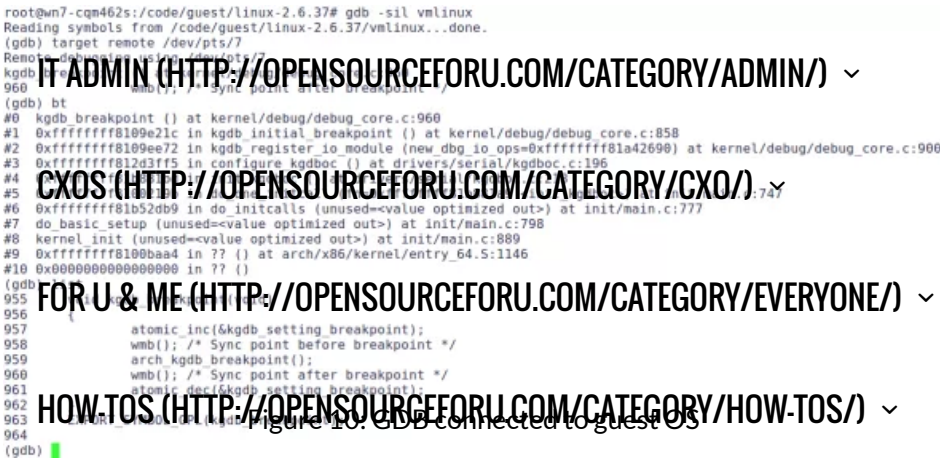Figure 10: GDB connected to guest OS

As you can see, with the above setup, a great deal of control can be achieved in debugging the live kernel.

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