

Project #3

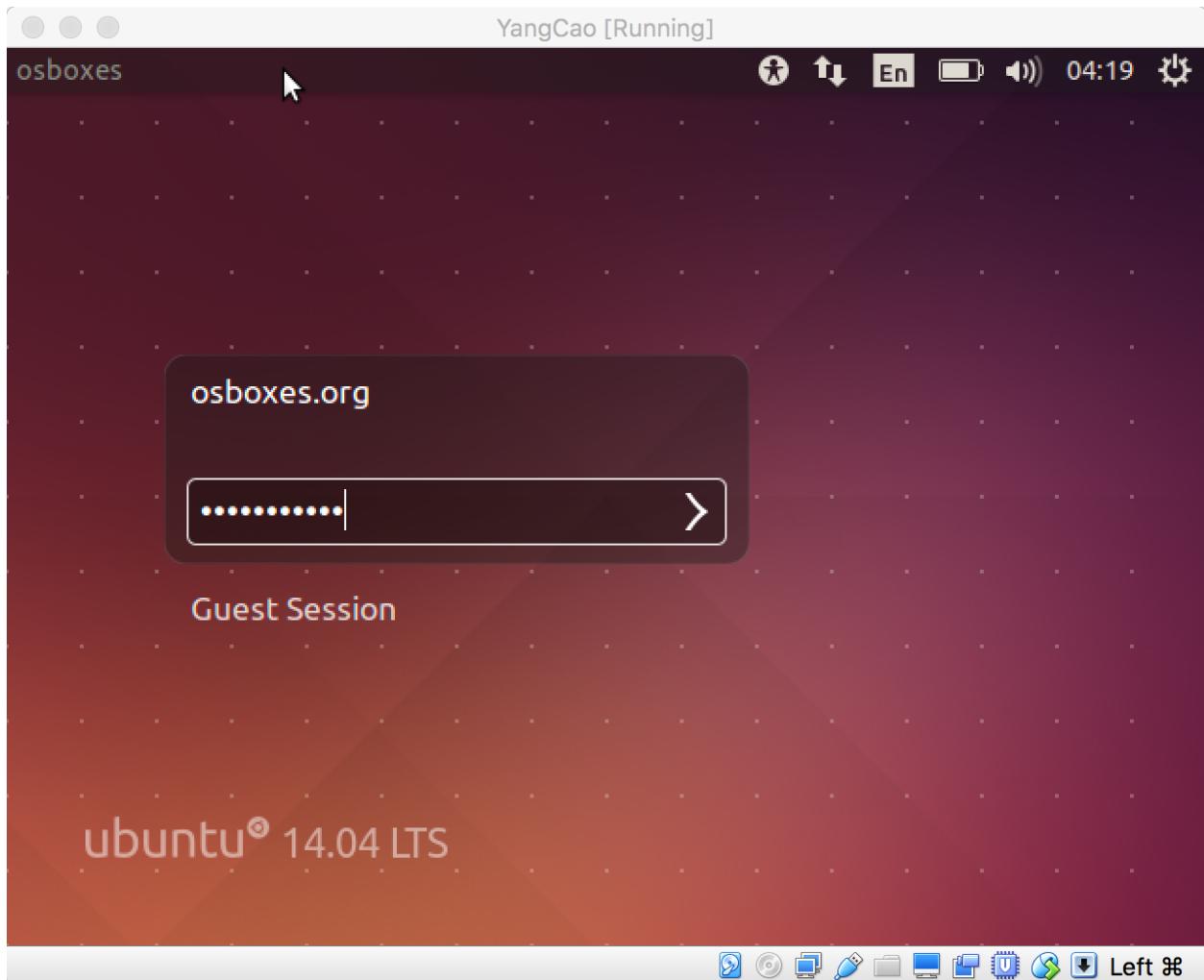
Install ClickOS testbed

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The primary objective of this project is to set up a virtual machine which runs ClickOS and test ClickOS using simple exercises.

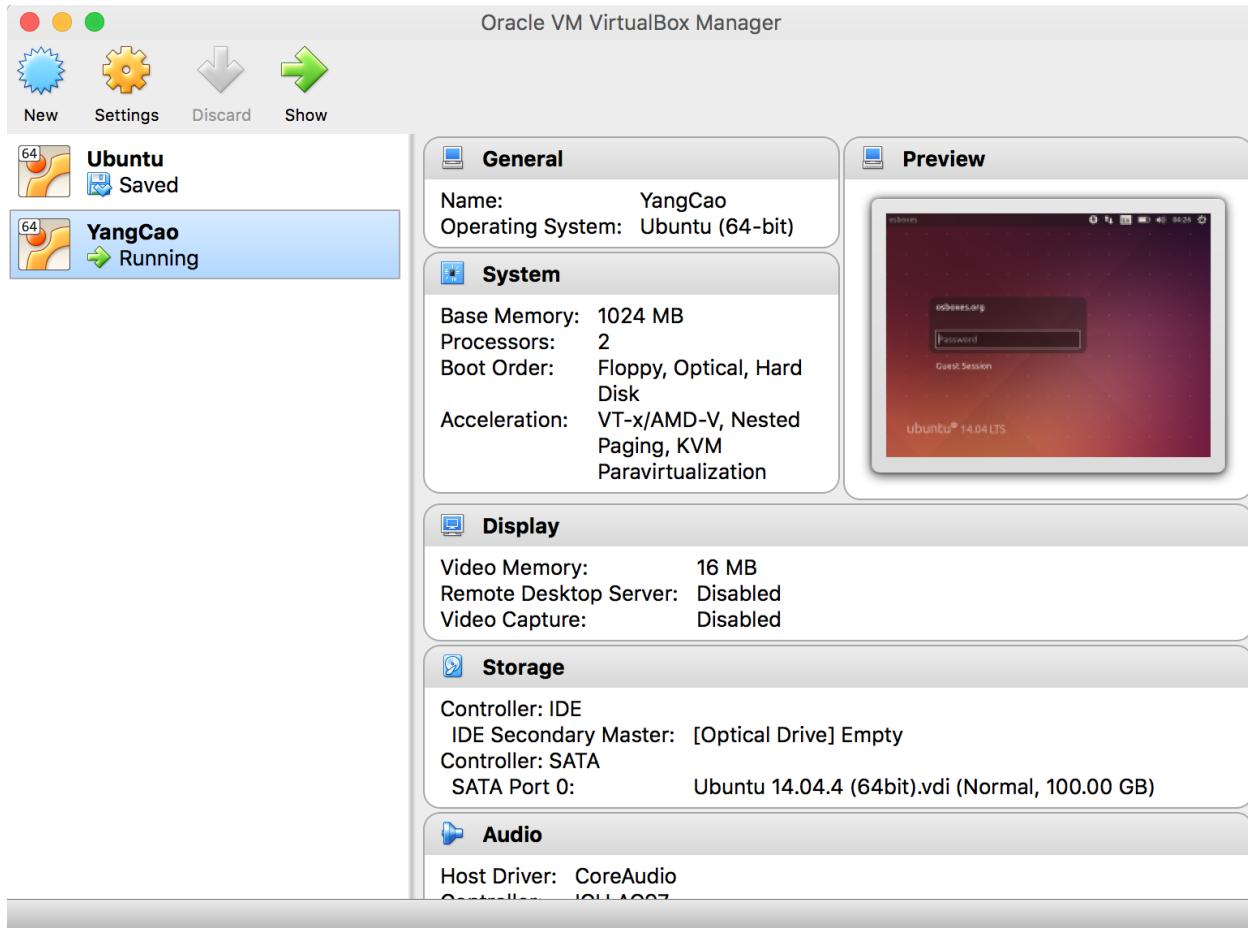
1. Download VM image and install VirtualBox

I downloaded a virtual machine image with Ubuntu 14.04.4 (LTS) 64-bit and added it into my VirtualBox. Also, I renamed it as “YangCao”.



2. Configure the VM

According to what is required in this part, I set the memory of this VM image to 1024MB and the number of processors to 2. The following screenshot shows the result.



3. Install Xen

In this task, Xen is needed to support the Network Function Virtualization (NFV). So first of all, I needed to switch into the root privilege by executing “`sudo su -`”. Then I installed dependencies for Xen use a series of commands as what the following screenshots show.

YangCao [Running]

Terminal File Edit View Search Terminal Help 04:33

```
root@osboxes: ~$ sudo su -
[sudo] password for osboxes:
root@osboxes:~# apt-get update
Ign http://gb.archive.ubuntu.com trusty InRelease
Get:1 http://security.ubuntu.com trusty-security InRelease [65.
9 kB]
0% [Waiting for headers] [1 InRelease 0 B/65.9 kB 0%] [Waiting
Ign http://extras.ubuntu.com trusty InRelease
Get:2 http://gb.archive.ubuntu.com trusty-updates InRelease [65
.9 kB]
33% [2 InRelease 0 B/65.9 kB 0%] [1 InRelease 43.1 kB/65.9 kB 6
Get:3 http://extras.ubuntu.com trusty Release.gpg [72 B]
43% [2 InRelease 14.2 kB/65.9 kB 22%] [1 InRelease 43.1 kB/65.9
44% [2 InRelease 14.2 kB/65.9 kB 22%] [1 InRelease 43.1 kB/65.9
81% [1 InRelease gpgv 65.9 kB] [2 InRelease 40.2 kB/65.9 kB 61%
Get:4 http://extras.ubuntu.com trusty Release [11.9 kB]
82% [1 InRelease gpgv 65.9 kB] [2 InRelease 40.2 kB/65.9 kB 61%]

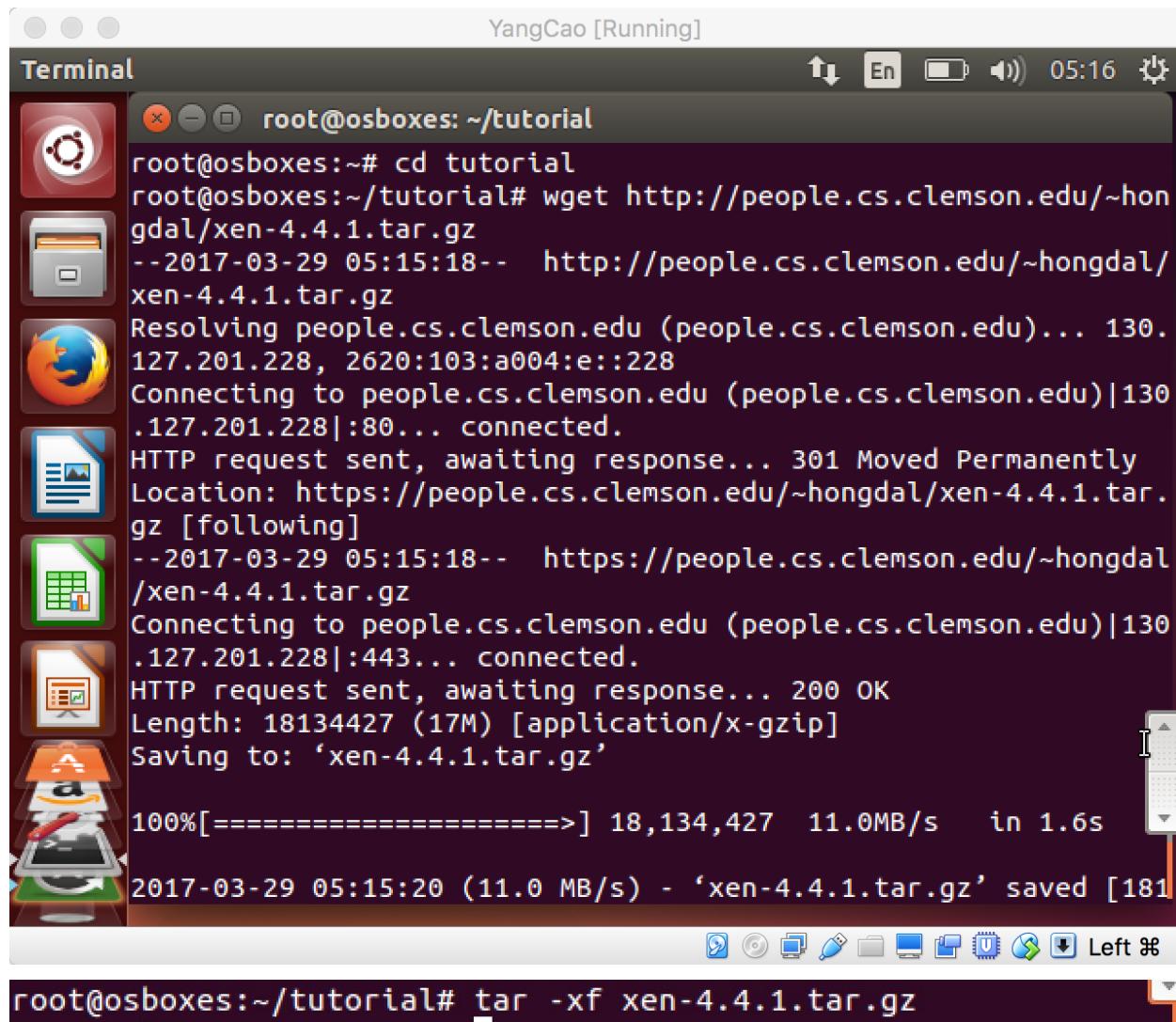
root@osboxes:~# apt-get install build-essential wget
root@osboxes:~# apt-get install bcc bin86 gawk bridge-utils ipr
oute libcurl3 libcurl3 libcurl4-openssl-dev bzip2 module-init-t
ools transfig tgif
root@osboxes:~# apt-get install texinfo texlive-latex-base texl
ive-latex-recommended
root@osboxes:~# apt-get install texlive-fonts-extra texlive-fon
ts-recommended pciutils-dev mercurial
root@osboxes:~# apt-get install make gcc libc6-dev zlib1g-dev p
ython python-dev python-twisted
root@osboxes:~# apt-get install libncurses5-dev patch libsdl-de
v libjpeg62-dev
root@osboxes:~# apt-get install libvncserver-dev
```

```
root@osboxes:~# apt-get install iasl libbz2-dev e2fslibs-dev glib-core uuid-dev ocaml-findlib  
root@osboxes:~# apt-get install libx11-dev bison flex xz-utils libyajl-dev  
root@osboxes:~# apt-get install gettext libpixman-1-dev  
root@osboxes:~# apt-get build-dep xen  
root@osboxes:~# apt-get install libglib2.0-dev  
root@osboxes:~# apt-get install libyajl-dev
```

Then I made a directory called tutorial.

```
root@osboxes:~# mkdir tutorial
```

Download Xen-4.4.1 in the tutorial directory:

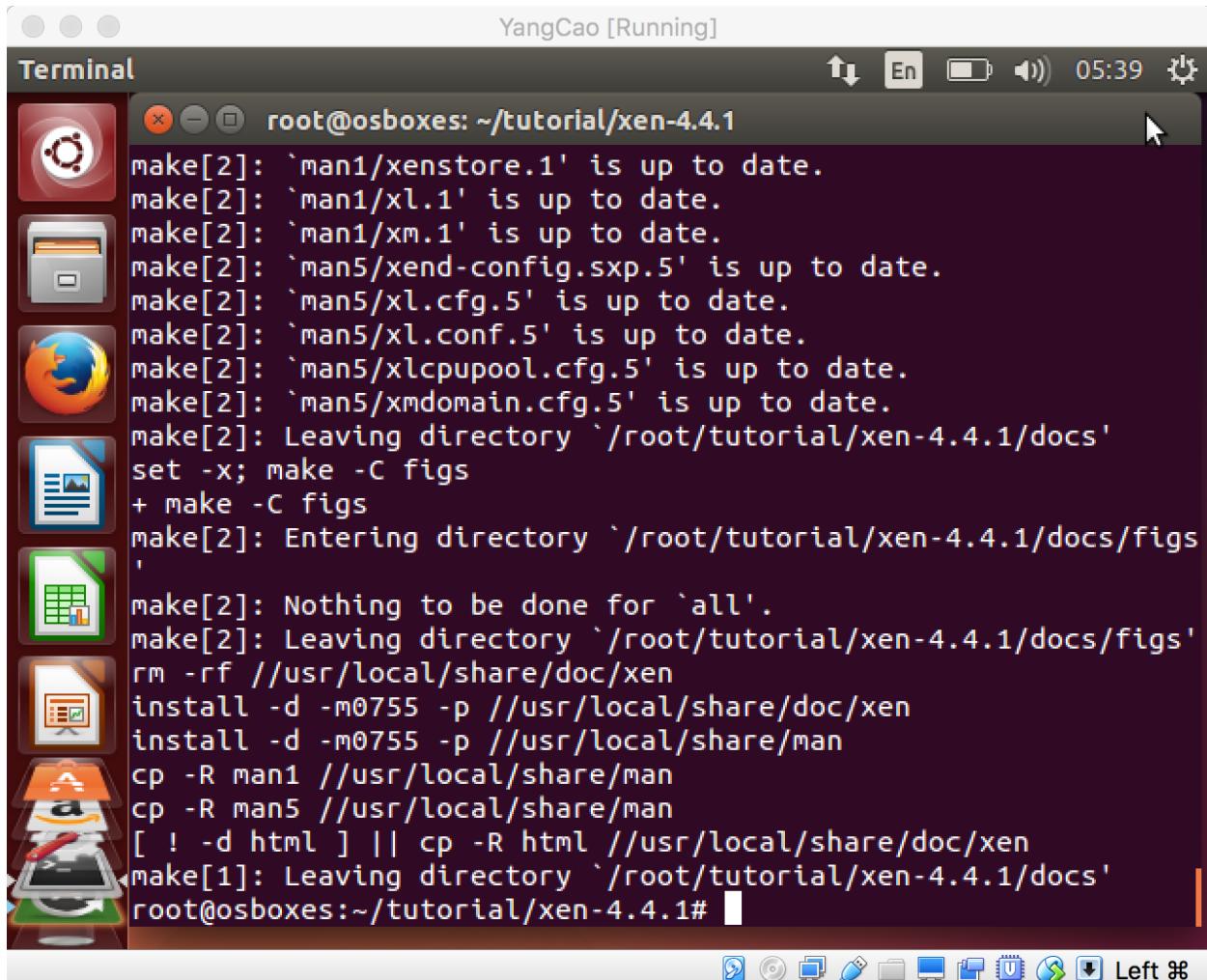


Compile and build Xen:

```
root@osboxes:~/tutorial# export XEN_ROOT=`pwd`/xen-4.4.1
root@osboxes:~/tutorial# cd $XEN_ROOT
root@osboxes:~/tutorial/xen-4.4.1# ./configure
checking build system type... x86_64-unknown-linux-gnu
checking host system type... x86_64-unknown-linux-gnu
Will build the following subsystems:
  xen
  kernels
  tools
  stubdom
  docs
configure: creating ./config.status
config.status: creating ./config/Toplevel.mk
== configuring in tools (/root/tutorial/xen-4.4.1/tools)
configure: running /bin/bash ./configure --disable-option-checking '--prefix=/usr/local' --cache-file=/dev/null --srcdir=.
checking build system type... x86_64-unknown-linux-gnu
checking host system type... x86_64-unknown-linux-gnu
checking for gcc... gcc
checking whether the C compiler works... yes
checking for C compiler default output file name... a.out
root@osboxes:~/tutorial/xen-4.4.1# make world
root@osboxes:~/tutorial/xen-4.4.1# make install
```

Configure the system to boot from Xen:

I took a snapshot of the VM before doing this part.



YangCao [Running]

Terminal

```
root@osboxes: ~/tutorial/xen-4.4.1
make[2]: `man1/xenstore.1' is up to date.
make[2]: `man1/xl.1' is up to date.
make[2]: `man1/xm.1' is up to date.
make[2]: `man5/xend-config.sxp.5' is up to date.
make[2]: `man5/xl.cfg.5' is up to date.
make[2]: `man5/xl.conf.5' is up to date.
make[2]: `man5/xlcpubpool.cfg.5' is up to date.
make[2]: `man5/xmdomain.cfg.5' is up to date.
make[2]: Leaving directory `/root/tutorial/xen-4.4.1/docs'
set -x; make -C figs
+ make -C figs
make[2]: Entering directory `/root/tutorial/xen-4.4.1/docs/figs'
'
make[2]: Nothing to be done for `all'.
make[2]: Leaving directory `/root/tutorial/xen-4.4.1/docs/figs'
rm -rf //usr/local/share/doc/xen
install -d -m0755 -p //usr/local/share/doc/xen
install -d -m0755 -p //usr/local/share/man
cp -R man1 //usr/local/share/man
cp -R man5 //usr/local/share/man
[ ! -d html ] || cp -R html //usr/local/share/doc/xen
make[1]: Leaving directory `/root/tutorial/xen-4.4.1/docs'
root@osboxes:~/tutorial/xen-4.4.1#
```

And then I executed a series of commands as what the following screenshots show.

```
root@osboxes:~/tutorial/xen-4.4.1# /sbin/ldconfig
root@osboxes:~/tutorial/xen-4.4.1# update-rc.d xencommons defau
lts 19 18
update-rc.d: warning: default start runlevel arguments (2 3 4 5 )
do not match xencommons Default-Start values (2 3 5) 
Adding system startup for /etc/init.d/xencommons ...
/etc/rc0.d/K18xencommons -> ../init.d/xencommons
/etc/rc1.d/K18xencommons -> ../init.d/xencommons
/etc/rc6.d/K18xencommons -> ../init.d/xencommons
/etc/rc2.d/S19xencommons -> ../init.d/xencommons
/etc/rc3.d/S19xencommons -> ../init.d/xencommons
/etc/rc4.d/S19xencommons -> ../init.d/xencommons
/etc/rc5.d/S19xencommons -> ../init.d/xencommons
```

```
root@osboxes:~/tutorial/xen-4.4.1# update-rc.d xencommons defaults 21 20
update-rc.d: warning: default start runlevel arguments (2 3 4 5)
) do not match xencommons Default-Start values (2 3 5)
  System start/stop links for /etc/init.d/xencommons already exist.

root@osboxes:~/tutorial/xen-4.4.1# update-rc.d xen-watchdog defaults 22 23
update-rc.d: warning: default start runlevel arguments (2 3 4 5)
) do not match xen-watchdog Default-Start values (2 3 5)
  Adding system startup for /etc/init.d/xen-watchdog ...
    /etc/rc0.d/K23xen-watchdog -> ../init.d/xen-watchdog
    /etc/rc1.d/K23xen-watchdog -> ../init.d/xen-watchdog
    /etc/rc6.d/K23xen-watchdog -> ../init.d/xen-watchdog
    /etc/rc2.d/S22xen-watchdog -> ../init.d/xen-watchdog
    /etc/rc3.d/S22xen-watchdog -> ../init.d/xen-watchdog
    /etc/rc4.d/S22xen-watchdog -> ../init.d/xen-watchdog
    /etc/rc5.d/S22xen-watchdog -> ../init.d/xen-watchdog
root@osboxes:~/tutorial/xen-4.4.1#
```

Update some of the configuration lines at /etc/default/grub to the appropriate values:

Firstly, I installed nano as a text editor.

```
root@osboxes:~/tutorial/xen-4.4.1# apt-get install nano
Reading package lists... Done
Building dependency tree
Reading state information... Done
nano is already the newest version.
The following package was automatically installed and is no longer required:
  libjpeg62
Use 'apt-get autoremove' to remove it.
0 to upgrade, 0 to newly install, 0 to remove and 283 not to upgrade.
```

Then, I needed to change the values of GRUB_DEFAULT and GRUB_HIDDEN_TIMEOUT into the required ones. The results are showed in the following screenshots.

```
root@osboxes:~/tutorial/xen-4.4.1# nano /etc/default/grub
```

YangCao [Running]

Terminal

root@osboxes: ~/tutorial/xen-4.4.1

GNU nano 2.2.6 File: /etc/default/grub Modified

```
# If you change this file, run 'update-grub' afterwards to update
# /boot/grub/grub.cfg.
# For full documentation of the options in this file, see:
#   info -f grub -n 'Simple configuration'

GRUB_DEFAULT=3
GRUB_HIDDEN_TIMEOUT=0
GRUB_HIDDEN_TIMEOUT_QUIET=true
GRUB_TIMEOUT=10
GRUB_DISTRIBUTOR=`lsb_release -i -s 2> /dev/null || echo Debian`
GRUB_CMDLINE_LINUX_DEFAULT="quiet splash"
GRUB_CMDLINE_LINUX=""

# Uncomment to enable BadRAM filtering, modify to suit your needs.
# This works with Linux (no patch required) and with any kernel
# the memory map information from GRUB (GNU Mach, kernel of FreeBSD,
# GRUB_BADRAM="0x01234567,0xfefefefe,0x89abcdef,0xefefefef"

^G Get Help ^O WriteOut ^R Read File ^Y Prev Page ^K Cut Text ^C Cur Pos
^X Exit ^J Justify ^W Where I ^V Next Page ^U Uncut T ^T To Spell
```

Update grub and reboot the system:

```
root@osboxes:~/tutorial/xen-4.4.1# update-grub
Generating grub configuration file ...
Warning: Setting GRUB_TIMEOUT to a non-zero value when GRUB_HIDDEN_TIMEOUT is set is no longer supported.
Found linux image: /boot/vmlinuz-4.2.0-27-generic
Found initrd image: /boot/initrd.img-4.2.0-27-generic
dpkg: warning: version '/boot/xen.gz' has bad syntax: version number does not start with a digit
Found linux image: /boot/vmlinuz-4.2.0-27-generic
Found initrd image: /boot/initrd.img-4.2.0-27-generic
Found memtest86+ image: /boot/memtest86+.elf
Found memtest86+ image: /boot/memtest86+.bin
done
```

Verify Xen has been installed successfully:

After rebooting, the system started a graphic user interface (GUI) automatically. However, the virtual machine did not support GUI in Xen. So I needed to switch to a command line interface (CLI). After logging in, I switched to the root privilege. And I used “xl list” command to verify if Xen had been installed successfully. The expected outputs are showed in following screenshot.

The screenshot shows a terminal window titled "YangCao [Running]". The terminal displays the following text:

```
Ubuntu 14.04.4 LTS osboxes tty1
osboxes login: osboxes
Password:
Welcome to Ubuntu 14.04.4 LTS (GNU/Linux 4.2.0-27-generic x86_64)

 * Documentation:  https://help.ubuntu.com/

The programs included with the Ubuntu system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*copyright.

Ubuntu comes with ABSOLUTELY NO WARRANTY, to the extent permitted by
applicable law.

osboxes@osboxes:~$ sudo su
[sudo] password for osboxes:
root@osboxes:/home/osboxes# xl list
Name                           ID   Mem  VCPUs      State      Time(s)
Domain-0                        0    945      2      r-----   16.6
root@osboxes:/home/osboxes# _
```

The terminal window has a standard Linux desktop interface at the bottom, including icons for file operations like copy, paste, and search.

4. Build ClickOS

Get source codes:

I downloaded clickos codes into the tutorial directory. The steps and results are showed in the following screenshots.

```
root@osboxes:/home/osboxes# cd ~/tutorial
root@osboxes:~/tutorial# wget http://people.cs.clemson.edu/~hongdal/clickos.tar
--2017-03-29 06:07:31--  http://people.cs.clemson.edu/~hongdal/clickos.tar
Resolving people.cs.clemson.edu (people.cs.clemson.edu)... 130.127.201.228, 2620
:103:a004:e::228
Connecting to people.cs.clemson.edu (people.cs.clemson.edu)|130.127.201.228|:80.
.. connected.
HTTP request sent, awaiting response... 301 Moved Permanently
Location: https://people.cs.clemson.edu/~hongdal/clickos.tar [following]
--2017-03-29 06:07:31--  https://people.cs.clemson.edu/~hongdal/clickos.tar
Connecting to people.cs.clemson.edu (people.cs.clemson.edu)|130.127.201.228|:443
.. connected.
HTTP request sent, awaiting response... 200 OK
Length: 41185280 (39M) [application/x-tar]
Saving to: 'clickos.tar'

100%[=====] 41,185,280  13.5MB/s   in 2.9s

2017-03-29 06:07:34 (13.5 MB/s) - 'clickos.tar' saved [41185280/41185280]
```

```
root@osboxes:~/tutorial# wget http://people.cs.clemson.edu/~hongdal/mini-os.tar
--2017-03-29 06:09:18--  http://people.cs.clemson.edu/~hongdal/mini-os.tar
Resolving people.cs.clemson.edu (people.cs.clemson.edu)... 130.127.201.228, 2620
:103:a004:e::228
Connecting to people.cs.clemson.edu (people.cs.clemson.edu)|130.127.201.228|:80.
.. connected.
HTTP request sent, awaiting response... 301 Moved Permanently
Location: https://people.cs.clemson.edu/~hongdal/mini-os.tar [following]
--2017-03-29 06:09:23--  https://people.cs.clemson.edu/~hongdal/mini-os.tar
Connecting to people.cs.clemson.edu (people.cs.clemson.edu)|130.127.201.228|:443
.. connected.
HTTP request sent, awaiting response... 200 OK
Length: 1208320 (1.2M) [application/x-tar]
Saving to: 'mini-os.tar'

100%[=====] 1,208,320  --.-K/s   in 0.1s

2017-03-29 06:09:23 (9.86 MB/s) - 'mini-os.tar' saved [1208320/1208320]
```

```
root@osboxes:~/tutorial# wget http://people.cs.clemson.edu/~hongdal/cosmos.tar
--2017-03-29 06:10:52--  http://people.cs.clemson.edu/~hongdal/cosmos.tar
Resolving people.cs.clemson.edu (people.cs.clemson.edu)... 130.127.201.228, 2620
:103:a004:e::228
Connecting to people.cs.clemson.edu (people.cs.clemson.edu)|130.127.201.228|:80.
.. connected.
HTTP request sent, awaiting response... 301 Moved Permanently
Location: https://people.cs.clemson.edu/~hongdal/cosmos.tar [following]
--2017-03-29 06:10:52--  https://people.cs.clemson.edu/~hongdal/cosmos.tar
Connecting to people.cs.clemson.edu (people.cs.clemson.edu)|130.127.201.228|:443
.. connected.
HTTP request sent, awaiting response... 200 OK
Length: 296960 (290K) [application/x-tar]
Saving to: 'cosmos.tar'

100%[=====] 296,960  --.-K/s   in 0.04s

2017-03-29 06:10:52 (7.06 MB/s) - 'cosmos.tar' saved [296960/296960]
```

```
root@osboxes:~/tutorial# wget http://people.cs.clemson.edu/~hongdal/toolchain.tar
--2017-03-29 06:12:01-- http://people.cs.clemson.edu/~hongdal/toolchain.tar
Resolving people.cs.clemson.edu (people.cs.clemson.edu)... 130.127.201.228, 2620
:103:a004:e::228
Connecting to people.cs.clemson.edu (people.cs.clemson.edu) |130.127.201.228|:80...
.. connected.
HTTP request sent, awaiting response... 301 Moved Permanently
Location: https://people.cs.clemson.edu/~hongdal/toolchain.tar [following]
--2017-03-29 06:12:02-- https://people.cs.clemson.edu/~hongdal/toolchain.tar
Connecting to people.cs.clemson.edu (people.cs.clemson.edu) |130.127.201.228|:443
.. connected.
HTTP request sent, awaiting response... 200 OK
Length: 204800 (200K) [application/x-tar]
Saving to: 'toolchain.tar'

100%[=====] 204,800 --.-K/s in 0.02s

2017-03-29 06:12:02 (7.83 MB/s) - 'toolchain.tar' saved [204800/204800]
```

```
root@osboxes:~/tutorial# tar -xf clickos.tar
root@osboxes:~/tutorial# tar -xf mini-os.tar
root@osboxes:~/tutorial# tar -xf cosmos.tar
root@osboxes:~/tutorial# tar -xf toolchain.tar
```

Set environment variables:

```
root@osboxes:~/tutorial# export XEN_ROOT=$(pwd)"/xen-4.4.1/"
root@osboxes:~/tutorial# export MINIOS_ROOT=$XEN_ROOT"extras/mini-os/"
root@osboxes:~/tutorial# export CLICKOS_ROOT=$(pwd)"/clickos/"
root@osboxes:~/tutorial# export TOOLCHAIN_ROOT=$(pwd)"/toolchain/"
root@osboxes:~/tutorial# export COSMOS_ROOT=$(pwd)"/cosmos/"
```

Replace mini-os:

MiniOS is an operating system which comes with Xen. ClickOS is built based on MiniOS. Thus, I needed to replace Xen's mini-os with ClickOS's minios.

```
root@osboxes:~/tutorial# rm -rf $MINIOS_ROOT
root@osboxes:~/tutorial# cp -rf $(pwd)"/mini-os/" $MINIOS_ROOT
```

Build toolchain:

I needed to enter the toolchain directory first by executing “cd \$TOOLCHAIN_ROOT” command. Then I executed the following commands orderly.

```
root@osboxes:~/tutorial/toolchain# make_
root@osboxes:~/tutorial/toolchain# export NEWLIB_ROOT=$TOOLCHAIN_ROOT"/x86_64-root/x86_64-xen-elf"
root@osboxes:~/tutorial/toolchain# export LWIP_ROOT=$TOOLCHAIN_ROOT"/x86_64-root/x86_64-xen-elf"
```

Build ClickOS kernel:

```
root@osboxes:~/tutorial/toolchain# cd $CLICKOS_ROOT
root@osboxes:~/tutorial/clickos# ./configure --enable-minios --with-xen=$XEN_ROOT --with-minios=$MINIOS_ROOT_
root@osboxes:~/tutorial/clickos# make minios_
```

Build cosmos:

```
=====
Your clickos build is complete...
Get the image from /root/tutorial/clickos/minios/build/clickos_x86_64.gz
=====
make[1]: Leaving directory `/root/tutorial/clickos/minios'
root@osboxes:~/tutorial/clickos# cd $XEN_ROOT
root@osboxes:~/tutorial/xen-4.4.1# cd tools
root@osboxes:~/tutorial/xen-4.4.1/tools# make -C include
make: Entering directory `/root/tutorial/xen-4.4.1/tools/include'
make -C xen-foreign
make[1]: Entering directory `/root/tutorial/xen-4.4.1/tools/include/xen-foreign'
./checker > tmp.size
diff -u reference.size tmp.size
rm tmp.size
make[1]: Leaving directory `/root/tutorial/xen-4.4.1/tools/include/xen-foreign'
make: Leaving directory `/root/tutorial/xen-4.4.1/tools/include'
root@osboxes:~/tutorial/xen-4.4.1/tools# cd $COSMOS_ROOT
root@osboxes:~/tutorial/cosmos# make DOMLIB=xl
```

```
[● ● ●] YangCao [Running]
root@osboxes:~/tutorial/clickos# cd $XEN_ROOT
root@osboxes:~/tutorial/xen-4.4.1# cd tools
root@osboxes:~/tutorial/xen-4.4.1/tools# make -C include
make: Entering directory `/root/tutorial/xen-4.4.1/tools/include'
make -C xen-foreign
make[1]: Entering directory `/root/tutorial/xen-4.4.1/tools/include/xen-foreign'
./checker > tmp.size
diff -u reference.size tmp.size
rm tmp.size
make[1]: Leaving directory `/root/tutorial/xen-4.4.1/tools/include/xen-foreign'
make: Leaving directory `/root/tutorial/xen-4.4.1/tools/include'
root@osboxes:~/tutorial/xen-4.4.1/tools# cd $COSMOS_ROOT
root@osboxes:~/tutorial/cosmos# make DOMLIB=xl
  MKD /root/tutorial/cosmos/build
  MKD /root/tutorial/cosmos/dist
  MKD /root/tutorial/cosmos/dist/bin
  MKD /root/tutorial/cosmos/dist/lib
  MKD /root/tutorial/cosmos/build/libxcl
  MKD /root/tutorial/cosmos/build/libcosmos
  MKD /root/tutorial/cosmos/build/cosmos
  CC /root/tutorial/cosmos/src/main.c
  CC /root/tutorial/cosmos/src/clickos.c
  CC /root/tutorial/cosmos/src/domain_xl.c
  LD /root/tutorial/cosmos/dist/bin/cosmos
root@osboxes:~/tutorial/cosmos# _
```

Set the PATH environment variable:

```
root@osboxes:~/tutorial/cosmos# export PATH=$PATH":$COSMOS_ROOT/dist/bin"
```

5. Install Open vSwitch

ClickOS should work with Linux bridge, VALE bridge, Open vSwitch, and many other software switches. I needed to use Open vSwitch (OVS) as the software switch. The following commands show how to install OVS.

```
root@osboxes:~/tutorial/cosmos# cd ~/tutorial
root@osboxes:~/tutorial# wget http://openvswitch.org/releases/openvswitch-2.5.0.tar.gz
```

```
root@osboxes:~/tutorial# tar -xf openvswitch-2.5.0.tar.gz
root@osboxes:~/tutorial# cd openvswitch-2.5.0/
root@osboxes:~/tutorial/openvswitch-2.5.0# ./configure --with-linux=/lib/modules
`uname -r`/build_
```

YangCao [Running]

```
config.status: creating ofproto/libofproto.sym
config.status: creating lib/libflow.sym
config.status: creating lib/libopenvswitch.sym
config.status: creating ovn/lib/libovn.sym
config.status: creating vtep/libvtep.sym
config.status: creating Makefile
config.status: creating datapath/Makefile
config.status: creating datapath/linux/Kbuild
config.status: creating datapath/linux/Makefile
config.status: creating datapath/linux/Makefile.main
config.status: creating tests/atlocal
config.status: creating lib/libopenvswitch.pc
config.status: creating lib/libflow.pc
config.status: creating ofproto/libofproto.pc
config.status: creating ovsdb/libovsdb.pc
config.status: creating include/openvswitch/version.h
config.status: creating config.h
config.status: executing tests/atconfig commands
config.status: executing depfiles commands
config.status: executing libtool commands
config.status: executing include/openflow/openflow.h.stamp commands
config.status: executing utilities/bugtool/dummy commands
config.status: executing ovn/dummy commands
config.status: executing ovn/utilities/dummy commands
root@osboxes:~/tutorial/openvswitch-2.5.0# make_
```



YangCao [Running]

```
build-aux/check-structs -I./include include/openflow/openflow-1.2.h && \
    touch include/openflow/openflow-1.2.hstamp
PYTHONPATH=./python":$PYTHONPATH PYTHONDONTWRITEBYTECODE=yes /usr/bin/python ./
build-aux/check-structs -I./include include/openflow/openflow-1.3.h && \
    touch include/openflow/openflow-1.3.hstamp
PYTHONPATH=./python":$PYTHONPATH PYTHONDONTWRITEBYTECODE=yes /usr/bin/python ./
build-aux/check-structs -I./include include/openflow/openflow-1.4.h && \
    touch include/openflow/openflow-1.4.hstamp
PYTHONPATH=./python":$PYTHONPATH PYTHONDONTWRITEBYTECODE=yes /usr/bin/python ./
build-aux/check-structs -I./include include/openflow/openflow-1.5.h && \
    touch include/openflow/openflow-1.5.hstamp
PYTHONPATH=./python":$PYTHONPATH PYTHONDONTWRITEBYTECODE=yes /usr/bin/python ./
build-aux/check-structs -I./include include/openflow/openflow-common.h && \
    touch include/openflow/openflow-common.hstamp
PYTHONPATH=./python":$PYTHONPATH PYTHONDONTWRITEBYTECODE=yes /usr/bin/python ./
build-aux/check-structs -I./include include/include/openflow/openflow.h && \
    touch include/openflow/openflow.hstamp
./build-aux/cksum-schema-check vswitchd/vswitch.ovsschema vswitchd/vswitch.ovss
hema.stamp
./build-aux/cksum-schema-check vtep/vtep.ovsschema vtep/vtep.ovsschema.stamp
./build-aux/cksum-schema-check ovn/ovn-nb.ovsschema ovn/ovn-nb.ovsschema.stamp
./build-aux/cksum-schema-check ovn/ovn-sb.ovsschema ovn/ovn-sb.ovsschema.stamp
make[2]: Leaving directory `/root/tutorial/openvswitch-2.5.0'
make[1]: Leaving directory `/root/tutorial/openvswitch-2.5.0'
root@osboxes:~/tutorial/openvswitch-2.5.0# make install_
```



```
YangCao [Running]
/bin/mkdir -p '/usr/local/lib/pkgconfig'
/usr/bin/install -c -m 644 ./lib/libopenvswitch.pc ./lib/libflow.pc ./ofproto/
libofproto.pc ./ovsdb/libovsdb.pc '/usr/local/lib/pkgconfig'
/bin/mkdir -p '/usr/local/share/openvswitch'
/usr/bin/install -c -m 644 vswitchd/vswitch.ovsschema vtep/vtep.ovsschema ovn/o
vn-sb.ovsschema ovn/ovn-nb.ovsschema '/usr/local/share/openvswitch'
/bin/mkdir -p '/usr/local/share/openvswitch/scripts'
/usr/bin/install -c -m 644 utilities/ovs-lib '/usr/local/share/openvswitch/sc
ripts'
/bin/mkdir -p '/usr/local/share/openvswitch/scripts'
/usr/bin/install -c utilities/ovs-check-dead-ifs utilities/ovs-ctl utilities/ov
s-save utilities/bugtool/ovs-bugtool-bfd-show utilities/bugtool/ovs-bugtool-cfm-
show utilities/bugtool/ovs-bugtool-coverage-show utilities/bugtool/ovs-bugtool-f
db-show utilities/bugtool/ovs-bugtool-lacp-show utilities/bugtool/ovs-bugtool-li
st-dbs utilities/bugtool/ovs-bugtool-memory-show utilities/bugtool/ovs-bugtool-t
c-class-show utilities/bugtool/ovs-bugtool-vsctl-show utilities/bugtool/ovs-bugt
ool-ovsdb-dump utilities/bugtool/ovs-bugtool-daemons-ver utilities/bugtool/ovs-b
ugtool-ovs-ofctl-show utilities/bugtool/ovs-bugtool-ovs-ofctl-dump-flows utiliti
es/bugtool/ovs-bugtool-ovs-appctl-dpif utilities/bugtool/ovs-bugtool-bond-show u
tilities/bugtool/ovs-bugtool-conntrack-dump vtep/ovs-vtep ovn/utilities/ovn-ctl
'/usr/local/share/openvswitch/scripts'
make[3]: Leaving directory `/root/tutorial/openvswitch-2.5.0'
make[2]: Leaving directory `/root/tutorial/openvswitch-2.5.0'
make[1]: Leaving directory `/root/tutorial/openvswitch-2.5.0'
root@osboxes:~/tutorial/openvswitch-2.5.0# make modules_install
```

```
YangCao [Running]
root@osboxes:~/tutorial/openvswitch-2.5.0# make modules_install
cd datapath/linux && make modules_install
make[1]: Entering directory `/root/tutorial/openvswitch-2.5.0/datapath/linux'
make -C /lib/modules/4.2.0-27-generic/build M=/root/tutorial/openvswitch-2.5.0/d
atapath/linux modules_install
make[2]: Entering directory `/usr/src/linux-headers-4.2.0-27-generic'
  INSTALL /root/tutorial/openvswitch-2.5.0/datapath/linux/openvswitch.ko
Can't read private key
  INSTALL /root/tutorial/openvswitch-2.5.0/datapath/linux/vport-geneve.ko
Can't read private key
  INSTALL /root/tutorial/openvswitch-2.5.0/datapath/linux/vport-gre.ko
Can't read private key
  INSTALL /root/tutorial/openvswitch-2.5.0/datapath/linux/vport-lisp.ko
Can't read private key
  INSTALL /root/tutorial/openvswitch-2.5.0/datapath/linux/vport-stt.ko
Can't read private key
  INSTALL /root/tutorial/openvswitch-2.5.0/datapath/linux/vport-vxlan.ko
Can't read private key
  DEPMOD 4.2.0-27-generic
make[2]: Leaving directory `/usr/src/linux-headers-4.2.0-27-generic'
depmod `sed -n 's/#define UTS_RELEASE "\\"([^\"]*\")"\\"/\1/p' /lib/modules/4.2.0-27-ge
neric/build/include/generated/utsrelease.h'
make[1]: Leaving directory `/root/tutorial/openvswitch-2.5.0/datapath/linux'
root@osboxes:~/tutorial/openvswitch-2.5.0# /sbin/modprobe openvswitch
root@osboxes:~/tutorial/openvswitch-2.5.0# mkdir -p /usr/local/etc/openvswitch_
```

Configure and run OVS:

YangCao [Running]

```
INSTALL /root/tutorial/openvswitch-2.5.0/datapath/linux/vport-vxlan.ko
Can't read private key
DEPMOD 4.2.0-27-generic
make[2]: Leaving directory `/usr/src/linux-headers-4.2.0-27-generic'
depmod sed -n 's/#define UTS_RELEASE "\\"([^\"]*\")"\\"/\\1/p' /lib/modules/4.2.0-27-generic/build/include/generated/utsrelease.h
make[1]: Leaving directory `/root/tutorial/openvswitch-2.5.0/datapath/linux'
root@osboxes:~/tutorial/openvswitch-2.5.0# /sbin/modprobe openvswitch
root@osboxes:~/tutorial/openvswitch-2.5.0# mkdir -p /usr/local/etc/openvswitch
root@osboxes:~/tutorial/openvswitch-2.5.0# ovsdb-tool create /usr/local/etc/openvswitch/conf.db vswitchd/vswitch.ovsschema
root@osboxes:~/tutorial/openvswitch-2.5.0# ovsdb-server --remote=unix:/usr/local/var/run/openvswitch/db.sock --remote=db:Open_vSwitch,Open_vSwitch,manager_options --private-key=db:Open_vSwitch,SSL,private_key --certificate=db:Open_vSwitch,SSL,certificate --bootstrap-ca-cert=db:Open_vSwitch,SSL,ca_cert --pidfile --detach
root@osboxes:~/tutorial/openvswitch-2.5.0# ovs-vsctl --no-wait init
root@osboxes:~/tutorial/openvswitch-2.5.0# ovs-vswitchd --pidfile --detach
2017-03-29T06:22:15Z|00001|ovs numa|INFO|Discovered 2 CPU cores on NUMA node 0
2017-03-29T06:22:15Z|00002|ovs numa|INFO|Discovered 1 NUMA nodes and 2 CPU cores
2017-03-29T06:22:15Z|00003|reconnect|INFO|unix:/usr/local/var/run/openvswitch/db.sock: connecting...
2017-03-29T06:22:15Z|00004|reconnect|INFO|unix:/usr/local/var/run/openvswitch/db.sock: connected
root@osboxes:~/tutorial/openvswitch-2.5.0# _
```

Create a bridge on OVS:

I used command “ovs-vsctl show” to verify that OVS was running correctly. The outputs showed in the following screenshot are expected.

YangCao [Running]

```
root@osboxes:~/tutorial/openvswitch-2.5.0# /sbin/modprobe openvswitch
root@osboxes:~/tutorial/openvswitch-2.5.0# mkdir -p /usr/local/etc/openvswitch
root@osboxes:~/tutorial/openvswitch-2.5.0# ovsdb-tool create /usr/local/etc/openvswitch/conf.db vswitchd/vswitch.ovsschema
root@osboxes:~/tutorial/openvswitch-2.5.0# ovsdb-server --remote=unix:/usr/local/var/run/openvswitch/db.sock --remote=db:Open_vSwitch,Open_vSwitch,manager_options --private-key=db:Open_vSwitch,SSL,private_key --certificate=db:Open_vSwitch,SSL,certificate --bootstrap-ca-cert=db:Open_vSwitch,SSL,ca_cert --pidfile --detach
root@osboxes:~/tutorial/openvswitch-2.5.0# ovs-vsctl --no-wait init
root@osboxes:~/tutorial/openvswitch-2.5.0# ovs-vswitchd --pidfile --detach
2017-03-29T06:22:15Z|00001|ovs numa|INFO|Discovered 2 CPU cores on NUMA node 0
2017-03-29T06:22:15Z|00002|ovs numa|INFO|Discovered 1 NUMA nodes and 2 CPU cores
2017-03-29T06:22:15Z|00003|reconnect|INFO|unix:/usr/local/var/run/openvswitch/db.sock: connecting...
2017-03-29T06:22:15Z|00004|reconnect|INFO|unix:/usr/local/var/run/openvswitch/db.sock: connected
root@osboxes:~/tutorial/openvswitch-2.5.0# ovs-vsctl add-br ovs-lan
root@osboxes:~/tutorial/openvswitch-2.5.0# ovs-vsctl show
292d826e-9703-4649-9d07-489a2b232b9b
    Bridge ovs-lan
        Port ovs-lan
            Interface ovs-lan
                type: internal
root@osboxes:~/tutorial/openvswitch-2.5.0# _
```

6. Start a ClickOS instance

Create configuration file for Xen:

I changed my working directory to “tutorial/clickos/minios” and updated some of the values in config.xen. The file after modified is showed in the following screenshot.

The screenshot shows a terminal window titled "YangCao [Running]". The title bar also displays "GNU nano 2.2.6" and "File: /root/tutorial/clickos/minios/config.xen Modified". The main content of the terminal is the configuration file "config.xen":

```
kernel      = './build/clickos_x86_64'
vcpus       = '1'
memory     = '12'
vif         = ['script=vif-openvswitch,mac=00:00:00:00:01:00,bridge=ovs-lan$'
name        = 'click0'
on_crash    = 'preserve'
```

At the bottom of the terminal, there is a menu bar with various keyboard shortcuts and icons for file operations like Cut, Copy, Paste, Save, and Undo.

Create configuration file for Click:

I created and saved the example script as a file, mirror.click.

The screenshot shows a terminal window titled "YangCao [Running]". The title bar also displays "GNU nano 2.2.6" and "File: mirror.click". The main content of the terminal is the script "mirror.click":

```
FromDevice -> Print('OK') -> EtherMirror -> ToDevice
```

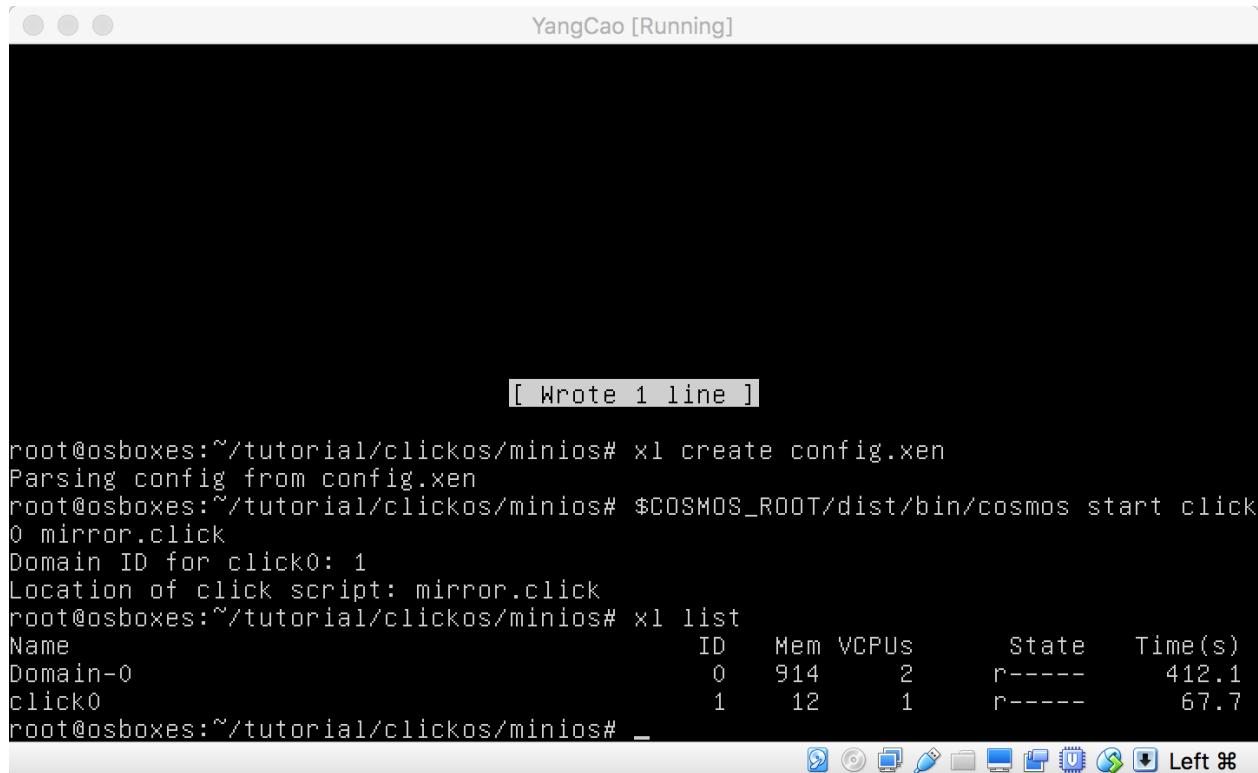
At the bottom of the terminal, there is a message "[Wrote 1 line]" indicating the file was saved. The prompt at the bottom is "root@osboxes:~/tutorial/clickos/minios# _".

Start ClickOS instance:

I used cosmos to start a ClickOS instance and checked whether \$COSMOS_ROOT was intact by typing “echo \$COSMOS_ROOT” and set it appropriately.

```
root@osboxes:~/tutorial/clickos/minios# xl create config.xen
Parsing config from config.xen
root@osboxes:~/tutorial/clickos/minios# $COSMOS_ROOT/dist/bin/cosmos start click
0 mirror.click
Domain ID for click0: 1
Location of click script: mirror.click
root@osboxes:~/tutorial/clickos/minios# _
```

To verify that the ClickOS instance was running, I used a “xl list” command.



The screenshot shows a terminal window titled "YangCao [Running]". The terminal displays the following command-line session:

```
[ Wrote 1 line ]
root@osboxes:~/tutorial/clickos/minios# xl create config.xen
Parsing config from config.xen
root@osboxes:~/tutorial/clickos/minios# $COSMOS_ROOT/dist/bin/cosmos start click
0 mirror.click
Domain ID for click0: 1
Location of click script: mirror.click
root@osboxes:~/tutorial/clickos/minios# xl list
Name                   ID  Mem VCPUs      State   Time(s)
Domain-0                0   914    2      r----  412.1
click0                  1    12    1      r----   67.7
root@osboxes:~/tutorial/clickos/minios# _
```

The terminal window has a dark background with white text. The title bar is light gray. The bottom of the window shows a toolbar with various icons.

To watch the output of click0, I executed “xl console click0” command and got the expected result showed in the following screenshot.

```
root@osboxes:~/tutorial/clickos/minios# xl console click0_
```

```

YangCao [Running]
OK: 107 | 33330000 00fbfeff ffffffff 86dd6000 00000035 11ffffe80
OK: 342 | ffffffff ffffffefff ffffffff 08004510 01480000 00008011
OK: 110 | 33330000 0016feff ffffffff 86dd6000 00000038 00010000
OK: 78 | 3333ffff ffffffefff ffffffff 86dd6000 00000018 3aff0000
OK: 342 | ffffffff ffffffefff ffffffff 08004510 01480000 00008011
OK: 110 | 33330000 0016feff ffffffff 86dd6000 00000038 00010000
OK: 90 | 33330000 0016feff ffffffff 86dd6000 00000024 0001fe80
OK: 70 | 33330000 0002feff ffffffff 86dd6000 00000010 3afffe80
OK: 90 | 33330000 0016feff ffffffff 86dd6000 00000024 0001fe80
OK: 107 | 33330000 00fbfeff ffffffff 86dd6000 00000035 11ffffe80
OK: 90 | 33330000 0016feff ffffffff 86dd6000 00000024 0001fe80
OK: 323 | 33330000 00fbfeff ffffffff 86dd6000 0000010d 11ffffe80
OK: 176 | 33330000 00fbfeff ffffffff 86dd6000 0000007a 11ffffe80
OK: 110 | 33330000 0016feff ffffffff 86dd6000 00000038 0001fe80
OK: 323 | 33330000 00fbfeff ffffffff 86dd6000 0000010d 11ffffe80
OK: 323 | 33330000 00fbfeff ffffffff 86dd6000 0000010d 11ffffe80
OK: 305 | 33330000 00fbfeff ffffffff 86dd6000 000000fb 11ffffe80
OK: 107 | 33330000 00fbfeff ffffffff 86dd6000 00000035 11ffffe80
OK: 245 | 33330000 00fbfeff ffffffff 86dd6000 000000bf 11ffffe80
OK: 342 | ffffffff ffffffefff ffffffff 08004510 01480000 00008011
OK: 305 | 33330000 00fbfeff ffffffff 86dd6000 000000fb 11ffffe80
OK: 107 | 33330000 00fbfeff ffffffff 86dd6000 00000035 11ffffe80
OK: 245 | 33330000 00fbfeff ffffffff 86dd6000 000000bf 11ffffe80
OK: 70 | 33330000 0002feff ffffffff 86dd6000 00000010 3afffe80

```

7. Exercise

ICMP Responder:

I created a Click configuration file as icmp.click and set the IP and MAC addresses appropriately
Also, I made my name printed.

```

GNU nano 2.2.6           File: icmp.click

define($IP 192.168.1.2);
define($MAC 00:00:00:00:01:00);
source :: FromDevice;
sink :: ToDevice;
c :: Classifier(
    12/0806 20/0001,
    12/0806 20/0002,
    12/0800,
    -);

arpq :: ARPQuerier($IP,$MAC);
arpr :: ARPResponder($IP $MAC);

source -> c;
c[0] -> ARPPrint -> arpr -> sink;
c[1] -> [1]arpq;
Idle -> [0]arpq;
arpq -> ARPPrint -> sink;
c[2] -> CheckIPHeader(14) -> ICMPPingResponder() ->Print('YangCao') -> EtherMir$;
c[3] -> Discard;
[ Wrote 20 lines ]

root@osboxes:~/tutorial/clickos/minios# 

```

Kill existing ClickOS instances by executing “`xl destroy click0`” command. Then I needed to start a new instance:

```
root@osboxes:~/tutorial/clickos/minios# xl destroy click0
root@osboxes:~/tutorial/clickos/minios# xl create config.xen
Parsing config from config.xen
root@osboxes:~/tutorial/clickos/minios# $COSMOS_ROOT/dist/bin/cosmos start click0 icmp.click
Domain ID for click0: 3
Location of click script: icmp.click
root@osboxes:~/tutorial/clickos/minios# _
```

Then I added my VM's network interface (assuming it's `eth0`, with IP, 192.168.1.1) to OVS so that I could ping the ClickOS instance from my VM:

```
YangCao [Running]
c[0] -> ARPPrint -> arpr -> sink;
c[1] -> [1]arpq;
Idle -> [0]arpq;
arpq -> ARPPrint -> sink;
c[2] -> CheckIPHeader(14) -> ICMPPingResponder() ->Print('YangCao') -> EtherMir$ 
c[3] -> Discard;
[ Wrote 20 lines ]

root@osboxes:~/tutorial/clickos/minios# xl create config.xen
Parsing config from config.xen
libxl: error: libxl.c:319:libxl__domain_rename: domain with name "click0" already exists.
libxl: error: libxl_create.c:743:initiate_domain_create: cannot make domain: -6
root@osboxes:~/tutorial/clickos/minios# xl destroy click0
root@osboxes:~/tutorial/clickos/minios# xl create config.xen
Parsing config from config.xen
root@osboxes:~/tutorial/clickos/minios# $COSMOS_ROOT/dist/bin/cosmos start click0 icmp.click
Domain ID for click0: 3
Location of click script: icmp.click
root@osboxes:~/tutorial/clickos/minios# ifconfig eth0 0
root@osboxes:~/tutorial/clickos/minios# ovs-vsctl add-port ovs-lan eth0
root@osboxes:~/tutorial/clickos/minios# ifconfig ovs-lan 192.168.1.1 netmask 255.255.255.0 up
root@osboxes:~/tutorial/clickos/minios# ping 192.168.1.2
```

Then ping the ClickOS instance from my VM. I received the responds from the ClickOS.

YangCao [Running]

```
.255.255.0 up
root@osboxes:~/tutorial/clickos/minios# ping 192.168.1.2
PING 192.168.1.2 (192.168.1.2) 56(84) bytes of data.
64 bytes from 192.168.1.2: icmp_seq=1 ttl=255 time=1.21 ms
64 bytes from 192.168.1.2: icmp_seq=2 ttl=255 time=0.208 ms
64 bytes from 192.168.1.2: icmp_seq=3 ttl=255 time=0.229 ms
64 bytes from 192.168.1.2: icmp_seq=4 ttl=255 time=0.178 ms
64 bytes from 192.168.1.2: icmp_seq=5 ttl=255 time=0.123 ms
64 bytes from 192.168.1.2: icmp_seq=6 ttl=255 time=0.119 ms
64 bytes from 192.168.1.2: icmp_seq=7 ttl=255 time=0.123 ms
64 bytes from 192.168.1.2: icmp_seq=8 ttl=255 time=0.120 ms
64 bytes from 192.168.1.2: icmp_seq=9 ttl=255 time=0.127 ms
64 bytes from 192.168.1.2: icmp_seq=10 ttl=255 time=0.122 ms
64 bytes from 192.168.1.2: icmp_seq=11 ttl=255 time=0.114 ms
64 bytes from 192.168.1.2: icmp_seq=12 ttl=255 time=0.122 ms
64 bytes from 192.168.1.2: icmp_seq=13 ttl=255 time=0.135 ms
64 bytes from 192.168.1.2: icmp_seq=14 ttl=255 time=0.165 ms
64 bytes from 192.168.1.2: icmp_seq=15 ttl=255 time=0.137 ms
64 bytes from 192.168.1.2: icmp_seq=16 ttl=255 time=0.118 ms
64 bytes from 192.168.1.2: icmp_seq=17 ttl=255 time=0.136 ms
64 bytes from 192.168.1.2: icmp_seq=18 ttl=255 time=0.214 ms
64 bytes from 192.168.1.2: icmp_seq=19 ttl=255 time=0.140 ms
64 bytes from 192.168.1.2: icmp_seq=20 ttl=255 time=0.426 ms
64 bytes from 192.168.1.2: icmp_seq=21 ttl=255 time=0.619 ms
```

Left ☰

I used the following command to see the outputs of the ClickOS instance. My name was printed.

```
root@osboxes:~/tutorial/clickos/minios# xl console click0
```

YangCao [Running]

```
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 00549fcc 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 00549fce 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 00549fe7 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a02b 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a084 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a0da 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a157 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a1a7 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a278 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a28d 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a324 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a329 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a3fe 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a458 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a468 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a47f 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a491 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a55d 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a58d 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a66a 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a6b7 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a6bf 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a71d 0000ff01
YangCao: 98 | 00000000 01000800 27ebdcb6 08004500 0054a7e4 0000ff01
```

Left ☰