Datacenter Simulation Methodologies: MARSSx86 and DRAMSim2

Tamara Silbergleit Lehman, Qiuyun Wang, Seyed Majid Zahedi and Benjamin C. Lee

This work is supported by NSF grants CCF-1149252, CCF-1337215, and STARnet, a Semiconductor Research Corporation Program, sponsored by MARCO and DARPA.

Tutorial Schedule

Time	Topic
09:00 - 09:15	Introduction
09:15 - 10:30	**Setting up MARSSx86 and DRAMSim2**
10:30 - 11:00	Break
11:00 - 12:00	Spark simulation
12:00 - 13:00	Lunch
13:00 - 13:30	Spark continued
13:30 - 14:30	GraphLab simulation
14:30 - 15:00	Break
15:00 - 16:15	Web search simulation
16:15 - 17:00	Case studies

Agenda

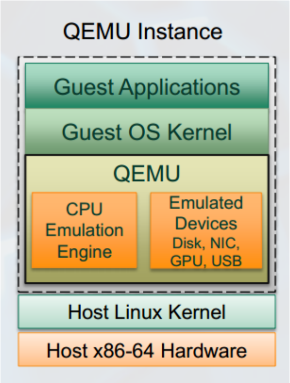
- Objectives
  - Understand simulator components
  - Be able to perform full system simulation
  - Be able to control simulation environment
- Outline
  - Create a disk image, qcow2 format
  - Configure and compile DRAMSim2, MARSSx86
  - Simulate programs
  - Create checkpoints
  - Simulate from checkpoints
  - Parse results

Simulator Requirements

- Software
  - Full system simulation: evaluate software stack behavior
  - Fast and easy to use: simulate long running applications
  - Multithread, multiprogram: support complex workloads
- Architecture
  - x86 support: most servers use x86 architecture
  - Multicore support: servers have many cores
- Future
  - Heterogeneous simulation (e.g., processors, memories)

Full System Simulation Overview

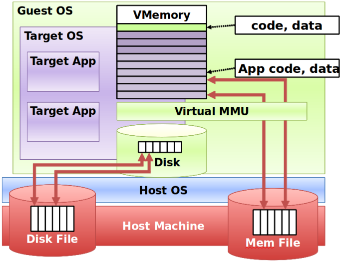
- Simulate complete software stack – applications, libraries, operating system.
- Use emulation engine to manage virtual environment



"MARSS: Micro Architectural System Simulator", ISCA Tutorial 2012 by Ghose *et al.*

A Little About Virtual Machines

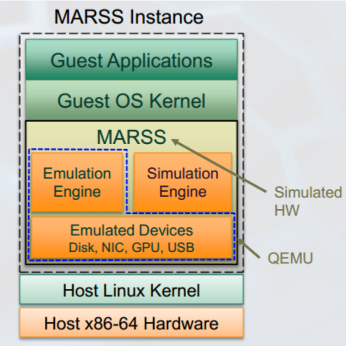
- Physical machine is host
- Emulated machine is guest
- Guest and host communicate in many ways
- Virtual machine disk is a file in the host
- Checkpointing saves disk state at any point in time



"A Survey of Virtual Machine Research" by Landon Cox (Duke CS510)

MARSSx86 Overview

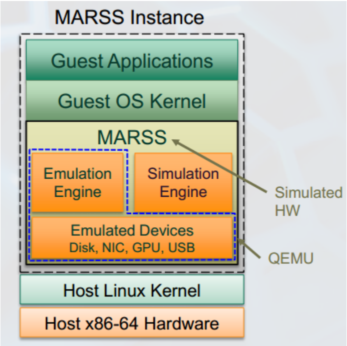
- PTLsim, QEMU Collaboration
- QEMU is emulator engine
- PTLsim is processor simulator
  - Detailed pipeline, cache simulation
  - Simple memory controller interface



"MARSS: Micro Architectural System Simulator", ISCA Tutorial 2012 by Ghose *et al.*

QEMU Overview

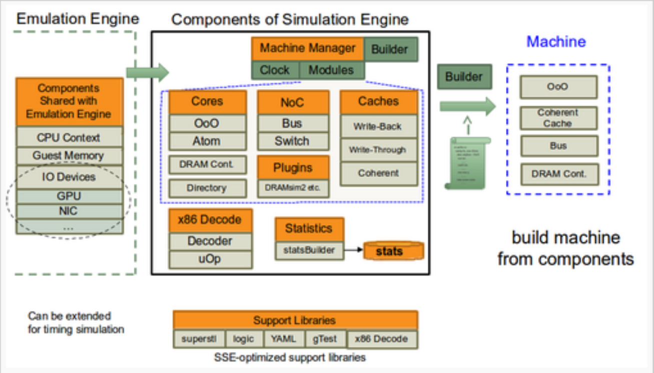
- Fast, easy to use emulator
- Uses dynamic binary translation
    - Translate instructions to C code
    - Compile C code for host
- QEMU emulates devices for functionality only. No performance estimates.



"MARSS: Micro Architectural System Simulator", ISCA Tutorial 2012 by Ghose *et al.*

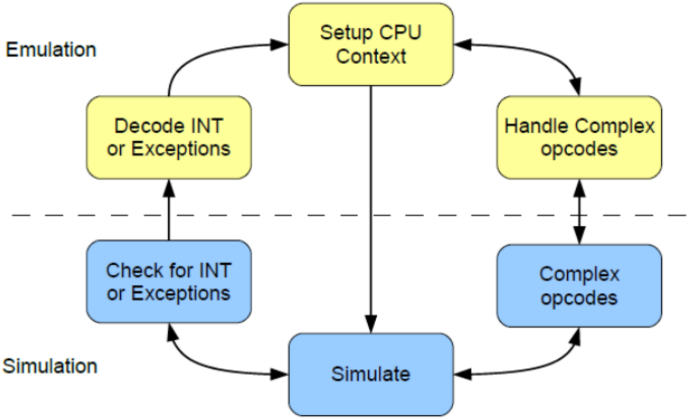
PTLsim Overview

- Cycle-accurate core, cache simulator
- Event-based simulation
- Specify microarchitecture in configuration files



"MARSS: Micro Architectural System Simulator", ISCA Tutorial 2012 by Ghose *et al.*

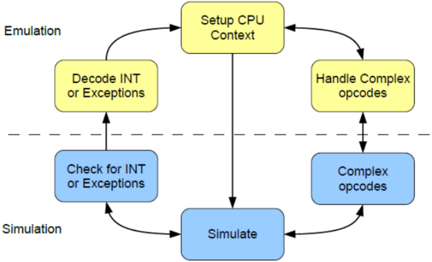
MARSSx86 Execution Flow



MARSSx86 (http://marss86.org)

MARSSx86 Execution Flow

- In simulation mode, PTLsim checks for interrupts, exceptions
- PTLsim saves its state, transfers control to QEMU
- In emulation mode, QEMU handles interrupt, returns control to PTLsim
- PTLsim restores state, continues execution

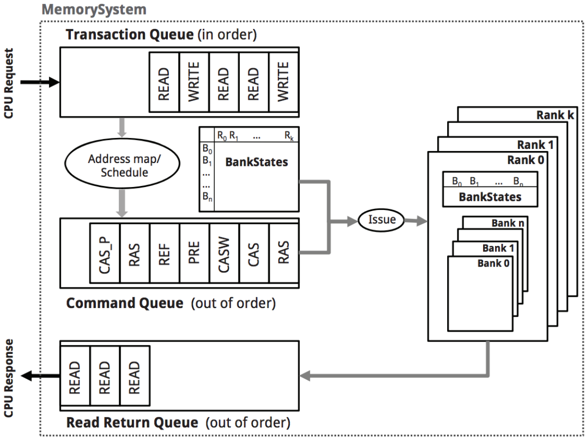


MARSSx86 (http://marss86.org)

DRAMSim2 Overview

- Simulates memory system in detail
- Simulates diverse memory technologies
- Specifies device details in configuration files
  - Scheduling policies
  - Addressing modes
  - Row buffer management policies

DRAMSim2 Overview



P. Rosenfeld *et al.* "DRAMSim2: A Cycle Accurate Memory System Simulator" CAL 2010

Putting All Together

- QEMU handles interrupt, exceptions, complex opcodes
- PTLsim simulates datapath, caches
- PTLsim sends memory requests to DRAMSim2

Questions?

Datacenter Simulation Methodologies
Getting Started with MARSSx86, DRAMSim2

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Getting Started With MARSSx86

- Libraries needed:

```
git g++ scons zlib1g-dev libsdl1.2-dev
   libsdl1.2debian qemu
```

- Connect to the remote computer (ssh). You should have received login information.

- Get MARSSx86 source code:

```
$ git clone https://github.com/dramninjasUMD/
   marss.dramsim.git
```

- Get DRAMSim2 source code:

```
$ git clone git://github.com/dramninjasUMD/
   DRAMSim2.git
```

Creating a Disk Image

- The following instructions are just for illustration purposes. For today's tutorial we will use an already prepared image.
- Create a 10 GB qcow2 image:

```
$ qemu-img create -f qcow2 micro2014.qcow2 10
   G
```

- Install the operating system on the image:

```
$ qemu-system-x86_64 -m 4G -drive file=
   micro2014.qcow2,cache=unsafe -cdrom mini.
   iso -boot d -k en-us
```

  - On the installation menu choose the command-line install
    Note: This will take approximately 25 minutes.

Creating a Disk Image

- Once the operating system is installed re-run QEMU to prepare the virtual machine to run with PTLsim.

```
$ qemu-system-x86_64 -m 4G -drive file=
    micro2014.qcow2,cache=unsafe -k en-us -
    nographic
```

- Change the root password and login as root.

```
# sudo passwd root
# su
```

- Create file /etc/init/ttyS0.conf to be able to run simulations with a script:

```
# ttyS0 - getty
#
# This service maintains a getty on ttyS0 from the point the system is
# started until it is shut down again.

start on stopped rc RUNLEVEL=[012345]
stop on runlevel [!012345]

respawn
exec /sbin/getty -L 115200 ttyS0 vt102
```

- Open the tty port

```
# start ttyS0
```

Creating a Disk Image

- Open /etc/default/grub and modify it to look as below:

```
File Edit Options Buffers Tools Conf Help
# 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=0
GRUB_HIDDEN_TIMEOUT=0
GRUB_HIDDEN_TIMEOUT_QUIET=true
GRUB_TIMEOUT=1
GRUB_DISTRIBUTOR=`lsb_release -i -s 2> /dev/null || echo Debian`
GRUB_CMDLINE_LINUX_DEFAULT="quiet splash rootdelay=200"
GRUB_CMDLINE_LINUX=""
```

- After closing the file update grub and power down the virtual machine:

```
# update-grub
# poweroff
```

DRAMSim2 Configuration

- Change into the DRAMSim2 directory
- DRAMSim2 uses system.ini to specify the system configuration parameters
- Open system.ini.example and save it as system.ini

```
; COPY THIS FILE AND MODIFY IT TO SUIT YOUR NEEDS
NUM_CHANS=1
JEDEC_DATA_BUS_BITS=64
TRANS_QUEUE_DEPTH=32
CMD_QUEUE_DEPTH=32
EPOCH_LENGTH=100000
ROW_BUFFER_POLICY=open_page
ADDRESS_MAPPING_SCHEME=scheme2
SCHEDULING_POLICY=rank_then_bank_round_robin
QUEUING_STRUCTURE=per_rank

;for true/false, please use all lowercase
DEBUG_TRANS_Q=false
DEBUG_CMD_Q=false
DEBUG_ADDR_MAP=false
DEBUG_BUS=false
DEBUG_BANKSTATE=false
```

DRAMSim2 Configuration

- The simulated device can be configured with an ini file.
- There are many ini files to choose from provided by the DRAMSim2 team in the ini directory.
- We will use ini/DDR3_micron_8M_8B_x16_sg15.ini

```
NUM_BANKS=8
NUM_ROWS=16384
NUM_COLS=1024
DEVICE_WIDTH=16

;in nanoseconds
;#define REFRESH_PERIOD 7800
REFRESH_PERIOD=7800
tCK=1.5 ;*
```

- Build the shared library to be used by MARSSx86:

```
$ make libdramsim.so
```

side note: for debugging add DEBUG=1 to the command.

MARSSx86 Configuration

- Change into marss.dramsim directory and open the machine configuration file: config/default.conf
- In this file we can import configuration files

```
# Import files that define various core/caches
import:
  - ooo_core.conf
  - atom_core.conf
  - l1_cache.conf
  - l2_cache.conf
  - moesi.conf
```

- We can specify many machine configurations
- To select which one to simulate, use the machine option in the simulation configuration file.

MARSSx86 Custom Configuration

- Below is the single core configuration example.

```yaml
machine:
  # Use run-time option '-machine [MACHINE_NAME]' to select
  single_core:
    description: Single Core configuration
    min_contexts: 1
    max_contexts: 1
    cores: # The order in which core is defined is used to assign
           # the cores in a machine
      - type: ooo
        name_prefix: ooo_
        option:
            threads: 1
```

- We will create a new configuration file to add microarchitectural details about the core and caches.
- We have provided an example configuration file. Open ~/custom.conf

MARSSx86 Custom Configuration

- Details about configuration file
  - Core section

```
core:
  ooo_custom:
    base: ooo
    params:
      ISSUE_WIDTH: 8
      MAX_PHYS_REG_FILE_SIZE: 196
      PHYS_REG_FILE_SIZE: 196
```

  - Cache section

```
cache:
  l1_32K_moesi_custom:
    base: moesi_cache #or mesi_cache
    params:
      SIZE: 32K
      LINE_SIZE: 64 # bytes
```

  - Memory section

```
memory:
  custom_global_dir_cont:
    base: global_dir
  custom_dram_cont:
    base: simple_dram_cont
```

MARSSx86 Custom Configuration

- More details about the configuration file
  - Machine section specifies number threads per core, which core, cache and memory controller to use

```
machine:
  custom:
    description: Custom Configuration
    min_contexts: 1
    cores:
      - type: ooo_custom
```

  - Within the machine section we can also specify the connections between all the components

```
    interconnects:
      - type: p2p
        connections:
          - core_$: I
            L1_I_$: UPPER
          - core_$: D
```

- More information available on the MARSSx86 web site:
  http://marss86.org/~marss86/index.php/Machine_Configuration

Simulation Configuration

- Simulation configuration parameters are specified through a file (micro2014.simcfg).

```
-logfile micro2014.log
#-run
-machine custom
-corefreq 4G
-stats micro2014.yml
#-kill-after-run -quiet
-dramsim-device-ini-file ini/
   DDR3_micron_8M_8B_x16_sg15.ini
-dramsim-system-ini-file system.ini
-dramsim-results-dir-name micro2014_dramsim
```

Compiling MARSSx86

- Build MARSSx86 with the custom configuration file and 4 cores:

```
$ scons -Q c=4 config=/hometemp/userXX/custom
    .conf dramsim=/hometemp/userXX/DRAMSim2
```

`Note: for debugging add` *`debug=2`*

- Previous command produces a new QEMU binary that integrates PTLsim into it.

Running MARSSx86

- Run MARSSx86 with the simulation configuration file:

```
$ ./qemu/qemu-system-x86_64 -m 4G -drive file
    =/hometemp/userXX/micro2014.qcow2,cache=
    unsafe -nographic -simconfig /hometemp/
    userXX/micro2014.simcfg
```

PtlCalls

- PtlCalls is the interface between PTLsim and QEMU.
- Many different functions:
  - ptlcall_switch_to_sim(): Goes into simulation mode.
  - ptlcall_checkpoint_and_shutdown(chkpt name): Takes a snapshot of the vm and shuts down.
  - ptlcall_switch_to_native(): Goes into emulation mode.
  - ptlcall_kill(): Terminate the simulation.
- Copy the file ptlcalls.h from the ptlsim/tools directory

```
# scp username@hostname://hometemp/userXX/
   marss.dramsim/ptlsim/tools/ptlcalls.h .
```

- Create 3 binaries for start_sim, stop_sim and kill_sim

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```c
//start_sim.c
#include <stdlib.h>
#include <stdio.h>
#include "ptlcalls.h"

int main(int argc, char ** argv){
  printf("Starting simulation\n");
  ptlcall_switch_to_sim();
  return EXIT_SUCCESS;
}
```

```c
//stop_sim.c
#include <stdlib.h>
#include <stdio.h>
#include <ptlcalls.h>

int main(int argc, char ** argv){
  printf("Stopping simulation\n");
  ptlcall_switch_to_native();
  return EXIT_SUCCESS;
}
```

```c
//kill_sim.c
#include <stdlib.h>
#include <stdio.h>
#include <ptlcalls.h>

int main(int argc, char ** argv){
  printf("Shutting down simulation and vm\n");
  ptlcall_kill();
  return EXIT_SUCCESS;
}
```

Makefile

```
#Makefile
all: start_sim stop_sim kill_sim helloWorld
start_sim: start_sim.c ptlcalls.h
gcc -std=gnu99 -D_GNU_SOURCE -O3 -o $@ start_sim
    .c
stop_sim: stop_sim.c ptlcalls.h
gcc -std=gnu99 -D_GNU_SOURCE -O3 -o $@ stop_sim.
    c
kill_sim: kill_sim.c ptlcalls.h
gcc -std=gnu99 -D_GNU_SOURCE -O3 -o $@ kill_sim.
    c
helloWorld: helloWorld
gcc -std=gnu99 -D_GNU_SOURCE -O3 -o $@
    helloWorld.c
clean:
-rm -f start_sim stop_sim kill_sim helloWorld *~
```

Running MARSSx86

- Create a simple program (helloWorld.c)

```
//helloWorld.c
#include <stdlib.h>
#include <stdio.h>

int main(int argc, char ** argv){
  printf("Hello World\n");
  return EXIT_SUCCESS;
}
```

- Compile and run the program with start_sim, stop_sim and kill_sim.

```
# ./start_sim; ./helloWorld; ./stop_sim
#
# ./start_sim; ./helloWorld; ./kill_sim
```

About Checkpoints

- Checkpoints are snapshots of the qcow2 image.
- Saves the state of your machine at a particular point in time.
- To load a virtual machine from a checkpoint add "-loadvm checkpoint_name" to the MARSSx86 command
- Checkpoints are hardware configuration dependent (number cores, cache sizes, etc)

How to Checkpoint

- There are 3 ways of creating checkpoints:
  - Create checkpoint from the command line within QEMU (we will see this during the WebSearch presentation)
  - Embed ptlcall function calls within the source code
  - Use a script that uses either the first or second method to create multiple checkpoints (batch mode)
- There are 2 ways of running from checkpoints:
  - Add *-loadvm checkpointname* option to the QEMU command
  - Use a script to run multiple simulations (batch mode)

Creating Checkpoints: PtlCall Function Call

- Add a PtlCall to create a checkpoint inside the source code:

```
//helloWorld.c
#include <stdlib.h>
#include <stdio.h>
#include "ptlcalls.h"

int main(int argc, char ** argv){
  char * chk_name=getenv("CHECKPOINT_NAME");
  if(chk_name != NULL){
    printf("Creating checkpoint with name %s\
        n",chk_name);
    ptlcall_checkpoint_and_shutdown(chk_name)
        ;
  }
  printf("Hello World\n");
  ptlcall_kill();
  return EXIT_SUCCESS;
}
```

Creating Checkpoints: PtlCall Function Call

- Run the program again after setting the environment variable

```
# export CHECKPOINT_NAME=helloWorld
# ./helloWorld
```

- Now the checkpoint was created within the source code.

```
PTLCALL type PTLCALL_CHECKPOINT
MARSSx86::Creating checkpoint helloWorld
MARSSx86::Checkpoint helloWorld created
MARSSx86::Shutdown requested
```

Checkpoint Management

- Check the checkpoint was created:

```
$ qemu-img info /hometemp/userXX/micro2014.
    qcow2
```

```
image: ../micro2014.qcow2
file format: qcow2
virtual size: 10G (10737418240 bytes)
disk size: 2.2G
cluster_size: 65536
Snapshot list:
ID        TAG                 VM SIZE                DATE       VM CLOCK
1         helloWorld             324M 2014-10-21 13:18:56   01:00:49.718
```

- Delete checkpoint:

```
$ qemu-img snapshot -d helloWorld /hometemp/
    userXX/micro2014.qcow2
```

Creating Checkpoints: Batch

- A Python script to create checkpoints is provided with the MARSSx86 distribution code
- We provided a simplified one: /checkpoint_script.py
- Modify the user variable to match your username
- We added the commands needed for helloWorld checkpoint as shown below.

```
#HelloWorld
bench='helloWorld'
pre_command = "make clean; make ; export
   CHECKPOINT_NAME=\"%s\"\n" % (bench)
cmd = "./helloWorld"
bench_dict = {'name' : bench, 'command' : '%s
   \n%s\n' % (pre_command, cmd) }
check_list.append(bench_dict)
```

Creating Checkpoints: Batch

- Copy the provided ~/checkpoint_script.py into the marss.dramsim/util/ directory

```
$ cp ../checkpoint_script.py util/.
```

- Run script:

```
$ ./util/checkpoint_script.py
```

Simulating from Checkpoints: Direct

- Make sure the simulation configuration file has the run and kill commands: /hometemp/userXX/micro2014.simcfg

```
-logfile micro2014.log
 -run
...
 -kill-after-run -quiet
...
```

- Launch the simulation from the checkpoint

```
$ ./qemu/qemu-system-x86_64 -m 4G -drive file
    =/hometemp/userXX/micro2014.qcow2,cache=
    unsafe -nographic -simconfig /hometemp/
    userXX/micro2014.simcfg -loadvm helloWorld
     -snapshot
```

Simulating from Checkpoints: Batch

- The Python script to run from checkpoints needs a cfg file to specify the simulation parameters
- Open ~/util.cfg
- Update the user name

```
[DEFAULT]
user='userXX '
marss_dir = /hometemp/%(user)/marss.dramsim
```

- Copy ~/util.cfg file into the util/ directory inside the marss.dramsim directory

```
$ cp ../util.cfg util/.
$ emacs -nw util/util.cfg
```

Simulating from Checkpoints: Batch

- util/run_bench.py has been provided with the MARSSx86 distribution
- Command to run the script:

```
$ ./util/run_bench.py micro2014 -d
    micro2014_stats -c util/util.cfg --chk-
    name=helloWorld
```

MARSSx86 Results

- Open micro2014_stats/test.yml

File Edit Options Buffers Tools Help


```
---
base_machine:
  ooo_0_0:
    cycles: 74056
    iq_reads: 61817
    iq_writes: 39517
    iq_fp_reads: 0
    iq_fp_writes: 0
    dispatch:
      width: [62604, 983, 1163, 1016, 8290]
      opclass:
        logic: 8195
        addsub: 10722
        addsubc: 0
        addshift: 496
```


- Script to parse yml files:

```
$ ./util/mstats.py -y --flatten -n
   base_machine::ooo_custom_0_0.*::cycles -t
   total  micro2014_stats/helloWorld.yml
```

DRAMSim2 Results

- Open
  ../DRAMSim2/results/dramsim_helloWorld/DDR3_micron_8M_8B
  _x16_sg15/4GB.1Ch.8R.scheme2.open_page.32TQ.32CQ.RtB.pRank.vis

```
File Edit Options Buffers Tools Help
!!SYSTEM_INI
NUM_CHANS=1
JEDEC_DATA_BUS_BITS=64
TRANS_QUEUE_DEPTH=32
CMD_QUEUE_DEPTH=32
EPOCH_LENGTH=100000
USE_LOW_POWER=true
TOTAL_ROW_ACCESSES=4
ROW_BUFFER_POLICY=open_page
SCHEDULING_POLICY=rank_then_bank_round_robin
ADDRESS_MAPPING_SCHEME=scheme2
QUEUING_STRUCTURE=per_rank
DEBUG_TRANS_Q=false
DEBUG_CMD_Q=false
DEBUG_ADDR_MAP=false
DEBUG_BANKSTATE=false
DEBUG_BUS=false
DEBUG_BANKS=false
DEBUG_POWER=false
VIS_FILE_OUTPUT=true
VERIFICATION_OUTPUT=false
NUM_RANKS=8
!!DEVICE_INI
NUM_BANKS=8
NUM_ROWS=8192
NUM_COLS=1024
DEVICE_WIDTH=16
REFRESH_PERIOD=7800
```

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For more information on MARSSx86 visit
http://marss86.org/~marss86/index.php/Home

For more information on DRAMSim2 visit
http://www.eng.umd.edu/~blj/dramsim/

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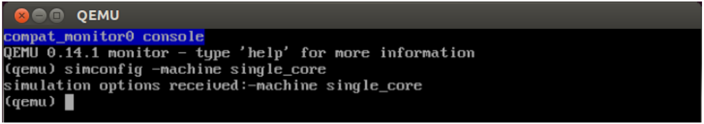
Backup Slides

- The following command requires display redirection (ssh -X option)
    - If using Ubuntu do not need anything additional
    - If using MacOS need to install xQuartz
- Run MARSSx86 with the following command (with graphics, display redirection required):

```
$ ./qemu/qemu-system-x86_64 -m 4G -drive file
    =/hometemp/userXX/micro2014.qcow2,cache=
    unsafe -simconfig /hometemp/userXX/
    micro2014.simcfg
```

Running MARSSx86

- QEMU has a control console that you can switch to with: Ctrl+Alt+2 (only with graphics mode)
- In the control console you can modify the simulation environment.
    - For example you can switch the machine being simulated:



- Press ctrl+alt+1 to go back to the virtual machine console.