L41: Lab 1 - I/O

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- Introduce the BBB and DTrace
- Explore user-kernel interactions via syscalls and traps
- Learn a bit about POSIX I/O
- Measure the probe effect

The benchmark

```
[guest@beaglebone ~/io]$ ./io-static
io-static -c|-r|-w [-Bdqsv] [-b blocksize] [-t totalsize] path

Modes (pick one):
    -c                  'create mode': create benchmark data file
    -r                  'read mode': read() benchmark
    -w                  'write mode': write() benchmark

Optional flags:
    -B                  Run in bare mode: no preparatory activities
    -d                  Set O_DIRECT flag to bypass buffer cache
    -q                  Just run the benchmark, don't print stuff out
    -s                  Call fsync() on the file descriptor when complete
    -v                  Provide a verbose benchmark description
    -b blocksize        Specify a block size (default: 16384)
    -t totalsize        Specify total I/O size (default: 16777216)
```

- Simple, bespoke I/O benchmark: `read()` or `write()`
- Statically or dynamically linked
- Adjust buffer sizes, etc.
- Various output modes.

The benchmark (2)

- Three operational modes:

  Create (`-c`) Create a new benchmark data file

  Read (`-r`) Perform `read()`s against data file

  Write (`-w`) Perform `write()`s against data file

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- Adjust I/O parameters:

  Block size (`-b`) Block size used for each I/O
  Total size (`-t`) Total size across all I/Os
  Direct (`-d`) Use direct I/O (bypass buffer cache)
  Sync (`-s`) Perform `fsycnc()` after I/O loop
  Bare (`-B`) Don't synchronise cache (etc) on start (whole-program testing)

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- Output flags:

  Quiet (`-q`) Suppress all output (whole-program tracing)
  Verbose (`-v`) Verbose output (interactive testing)

The benchmark (3)

```
[guest@beaglebone ~/io]$ ./io-static -v -d -w /data/iofile
Benchmark configuration:
  blocksize: 16384
  totalsize: 16777216
  blockcount: 1024
  operation: write
  path: /data/iofile
  time: 58.502746875
280.06 KBytes/sec
```

- Use verbose output
- Bypass the buffer cache
- Write to the previously created file `/data/iofile`
- Use default buffer size (16K) and total I/O size (16M)

Exploratory questions

- Baseline benchmark performance analysis:
  - How do `read()` and `write()` performance compare?
  - What is the performance impact of the buffer cache? Consider both `-d` and `-s`.
  - What proportion of time is spent in userspace vs. the kernel?
  - How many times are system calls invoked during the I/O loop?
  - What is the role of traps in execution of the I/O loop?
  - How does work performed in just the I/O loop compare with whole-program behaviour?

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- Probe effect and measurement decisions
  - How does performance change if you insert system-call or trap probes in the I/O loop?
  - What sources of variance may be affecting benchmark performance, and how can we measure them?

Experimental questions for the lab report

- With respect to a configuration reading from a fixed-size file through the buffer cache:
  1. How does changing the I/O buffer size affect I/O-loop performance?
  2. How does static vs. dynamic linking affect whole-program performance?
  3. At what file-size threshold does any performance difference between static and dynamic linking fall below 5%? 1%?

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- Run the benchmark to gather initial measurements
- Explore through system-call/trap tracing and profiling
- Use various configurations (e.g., I/O on `/dev/zero`) to explore kernel code-path behaviour

DTrace scripts

- Human-facing C-like language
- One or more {*probe name*, *predicate*, *action*} tuples
- Expression limited to control side effects (e.g., no loops)
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```
fbt::malloc:entry /execname == "csh"/ { trace(arg0); }
```

probe name Identifies the probe(s) to instrument; wildcards allowed; identifies the *provider* and a provider-specific *probe name*

predicate Filters cases where action will execute

action Describes tracing operations

Some kernel DTrace providers in FreeBSD

Provider	Description
`callout_execute`	Timer-driven callouts
`dtmalloc`	Kernel `malloc()`/`free()`
`dtrace`	DTrace script events (`BEGIN`, `END`)
`fbt`	Function Boundary Tracing
`io`	Block I/O
`ip`, `udp`, `tcp`, `sctp`	TCP/IP
`lockstat`	Locking
`proc`, `sched`	Kernel process/scheduling
`profile`	Profiling timers
`syscall`	System call entry/return
`vfs`	Virtual filesystem

Aggregations

Aggregation	Description
`count()`	Number of times called
`sum()`	Sum of arguments
`avg()`	Average of arguments
`min()`	Minimum of arguments
`max()`	Maximum of arguments
`stddev()`	Standard deviation ofnts
`lquantize()`	Linear frequency distribution (histogram)
`quantize()`	Log frequency distribution (histogram)

- Often we want summaries of events, not detailed traces
- DTrace allows early, efficient *reduction* using aggregations
- Scalable multicore implementations (i.e., commutative)
- `@variable = function()`
- `printa()` to print

Counting kernel `read()` system calls

```
[guest@beaglebone ~/io]$ ./io-static -q -r /data/iofile
```

```
root@beaglebone:/data/io # dtrace -n
  'syscall::read:entry
  /execname=="io-static"/
  {@reads = count(); }'
```

Probe Trace the `read` system call

Predicate Limit actions to processes executing `io-static`

Action Count the number of probe fires

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Probe Trace the `read` system call

Predicate Limit actions to processes executing `io-static`

Action Count the number of probe fires

```
dtrace: description 'syscall::read:entry ' matched 1 probe
dtrace: buffer size lowered to 2m
dtrace: aggregation size lowered to 2m
^C

                1024
```

A few cautions

Copy key scripts and data files to/from your workstation

- The SD cards seem a bit fragile during poweroff – make sure you shut down safely using the Lab Setup instructions
- We have spare imaged SD cards if you need them
- We may replace your SD cards for future labs

A few other useful things

- Work in pairs for the lab (reports must be written separately)
- Log in as `guest` on the console to set up an SSH key
- Otherwise, log in as `guest` via SSH
- Copy the lab bundle (see handout) to the BBB, and test
- In one terminal, `su` to `root` to run `dtrace`
- Then you will likely want multiple SSH sessions open
- The kernel source code is in `/usr/src/sys`
- Start with something simple – e.g., DTrace `hello world`
- Do not hesitate to ask for help if you need a hand!