# Kernels and Tracing

Lecture 2, Part 1: DTrace

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# Kernels and tracing

- DTrace — Lecture 2, Part 1
- The **probe effect** — Lecture 2, Part 2
- Our lab environment — Lecture 2, Part 3

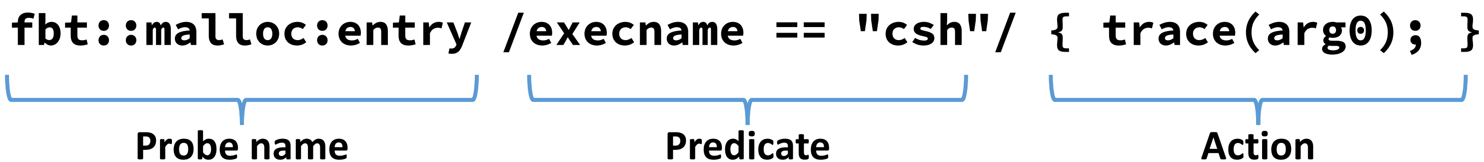
# Dynamic tracing with DTrace

- Bryan M. Cantrill, Michael W. Shapiro, and Adam H. Leventhal. *Dynamic Instrumentation of Production Systems*, USENIX ATC 2004.
  - “Facility for dynamic instrumentation of production systems”
  - Unified and safe **instrumentation** of kernel and user space
  - Zero **probe effect** when not enabled
  - Dozens of **providers** representing different trace mechanisms
  - Tens (hundreds?) of thousands of **instrumentation probes**
  - **D language**: C-like scripting language with **predicates**, **actions**
  - Scalar variables, thread-local variables, associative arrays
  - **Data aggregation** and **speculative tracing**
- First-class feature in: Solaris, Mac OS X, FreeBSD, Windows; third-party Linux module
- Wide influence – e.g., on Linux SystemTap, eBPF
- **Our tool of choice in this course**

# DTrace scripts

- Human-facing, C-like **D Programming Language**
- One or more {**probe name**, **predicate**, **action**} tuples
- Expression limited to control side effects (e.g., no loops)
- Specified on command line or via a `.d` file

| Probe name | Identifies the probe(s) to instrument; wildcards allowed; identifies the provider and provider-specific probe name |
|---|---|
| Predicate | Filters cases where action will execute |
| Action | Describes tracing operations |



# Some FreeBSD DTrace providers

- Providers represent data sources – instrumentation types:

| Provider | Description |
|---|---|
| callout_execute | Timer-driven "callout" event probes |
| dtmalloc | Kernel `malloc()/free()` |
| dtrace | DTrace script events (`BEGIN`, `END`) |
| fbt | Function Boundary Tracing (function prologues, epilogues) |
| io | Block I/O read/write |
| ip,udp,tcp,sctp | TCP/IP events |
| lockstat | Kernel locking primitives |
| proc,sched | Kernel process, scheduling primitives |
| profile | Profiling timers |
| syscall | System-call entry/return |
| vfs | Virtual File System operations |

- Apparent duplication: FBT vs. event-class providers?
  - Efficiency, expressivity, interface stability, portability

# Tracing kernel malloc() calls

- Trace first argument to kernel `malloc()` for `csh`
- NB: Captures both successful and failed allocations

```
# dtrace -n
  'fbt::malloc:entry /execname=="csh"/ { trace(arg0); }'
```

| | |
|---|---|
| **Probe** | Use FBT to instrument `malloc()` function prologue |
| **Predicate** | Limit actions to processes executing `csh` |
| **Action** | Trace the first argument (`arg0`) |

```
CPU     ID                    FUNCTION:NAME
  0   8408                     malloc:entry        64
  0   8408                     malloc:entry      2748
  0   8408                     malloc:entry        48
  0   8408                     malloc:entry       392
^C
```

# Aggregations – summarising traces

- **Aggregations** allow early, efficient reduction
  - Scalable multicore implementations (i.e., commutative)

```
@variable = function(.. args ..);
printa(@variable)
```

| 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 of arguments |
| `lquantize()` | Linear frequency distribution (histogram) |
| `quantize()` | Log frequency distribution (histogram) |

# Profiling kernel malloc() calls by csh

```
fbt::malloc:entry
/execname=="csh"/
{ @traces[stack()] = count(); }
```

| | |
|---|---|
| **Probe** | Use FBT to instrument `malloc()` function prologue |
| **Predicate** | Limit actions to processes executing `csh` |
| **Action** | Keys of associative array are stack traces (`stack()`); values are aggregated counters (`count()`) |

```
^C
              kernel`malloc
              kernel`fork1+0x14b4
              kernel`sys_vfork+0x2c
              kernel`swi_handler+0x6a8
              kernel`swi_exit
              kernel`swi_exit
                3
...
```

# D Intermediate Format (DIF)

```
# dtrace -Sn
  'fbt::malloc:entry /execname == "csh"/ { trace(arg0); }'
```

Predicate

```
DIFO 0x0x8047d2320 returns D type (integer) (size 4)
OFF OPCODE      INSTRUCTION
00: 29011801    ldgs DT_VAR(280), %r1           ! DT_VAR(280) = "execname"
01: 26000102    sets DT_STRING[1], %r2          ! "csh"
02: 27010200    scmp %r1, %r2
03: 12000006    be   6
04: 0e000001    mov  %r0, %r1
05: 11000007    ba   7
06: 25000001    setx DT_INTEGER[0], %r1         ! 0x1
07: 23000001    ret  %r1

NAME              ID   KND SCP FLAG TYPE
execname          118  scl glb r    string (unknown) by ref (size 256)
```

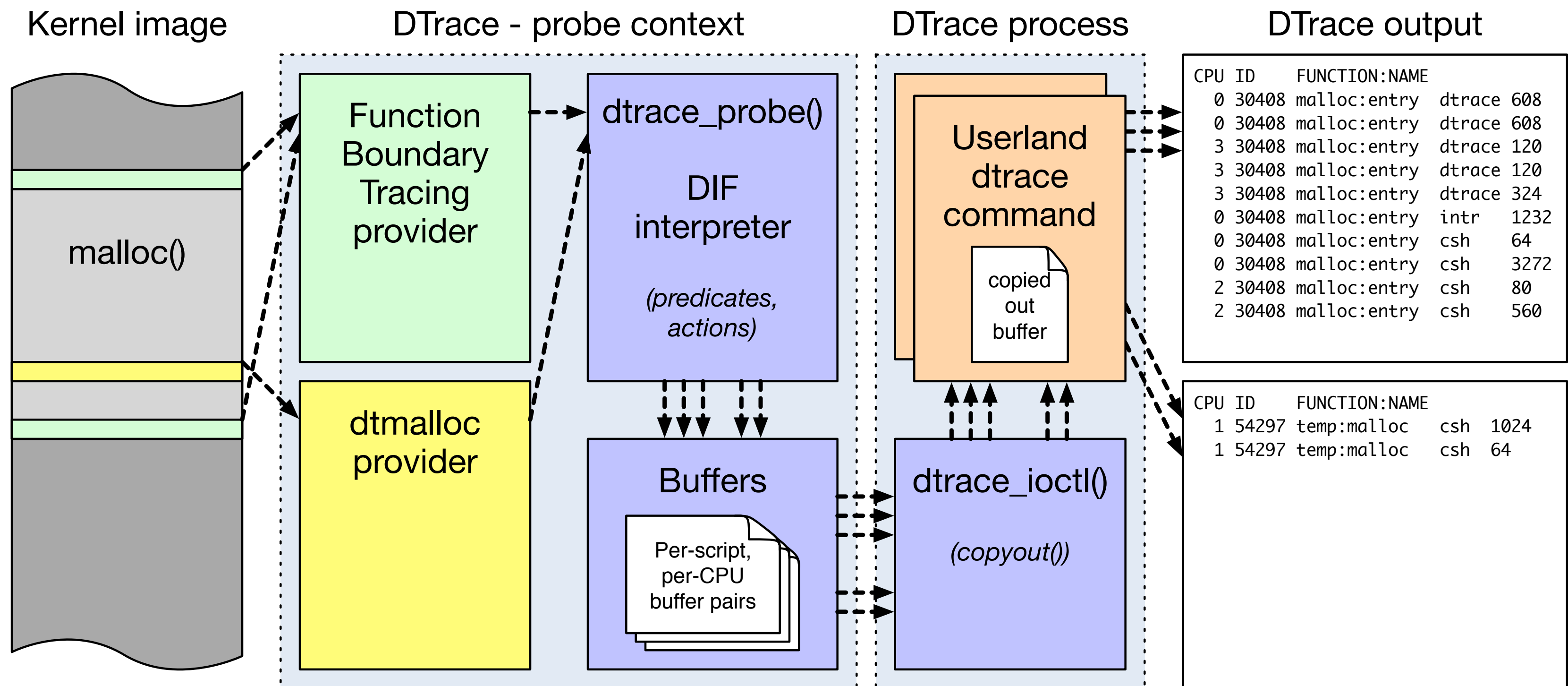
Action

```
DIFO 0x0x8047d2390 returns D type (integer) (size 8)
OFF OPCODE      INSTRUCTION
00: 29010601    ldgs DT_VAR(262), %r1           ! DT_VAR(262) = "arg0"
01: 23000001    ret  %r1

NAME              ID   KND SCP FLAG TYPE
arg0              106  scl glb r    D type (integer) (size 8)
```

# DTrace: Implementation

```
dtrace -n 'fbt::malloc:entry { trace(execname); trace(arg0); }'
```




```
dtrace -n 'dtmalloc::temp:malloc /execname=“csh”/ { trace(execname); trace(arg3); }'
```