Measuring kernel throughput on Blue Gene/P with the Plan 9 research operating system

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Outline

1. Context
2. Where is the time going?
   - Related Work
3. devtrace
4. Using it
5. Summary

Context

- Porting Plan 9 to supercomputers
- Because it's a clean, small system
- Flexibility comes in at user level
- One question of the DOE work: can we remove OS bypass if the kernel is fast enough?
- Simulations said "maybe"

Simulation result

- Using IBM SystemSim, boot Plan 9, and run a program that does a single write
- acid: 0x0119dd39 n = r;==>/9k/port/sysfile.c:790
- acid: 0x0119dd3a n = r;==>k/port/sysfile.c:790
- acid: 0x0119dd3b off = ~0LL;==>9k/port/sysfile.c:792
- acid: 0x0119dd3c off = ~0LL;==>9k/port/sysfile.c:792 etc.
- About 600 ticks
- About 180 lines
- Seemed like it would be quite fast

But not as fast as we want

- On simulation we had thought the path from user to kernel to wire was fast
- Certainly faster than MPI libraries (or so the MPI guys told us)
- Measurement on real hardware showed it was actually slower than sim by too much

Example: global barrier driver

```
dcrput(p->set, 1); /* signal */
```

- That's all there is to it
- Across 128K CPUs, this op takes about 125 ns.
- Other networks are similar
- HPC approach: just let programs do it directly
- Our approach: go through a fast kernel
- But it was not fast enough ... took a significantly longer time
- What's an acceptable time? Has to be well under 1 microsecond

Where is all the time going?

- Did not have a way to trace, function-by-function, where time was spent, and who called whom
- Can do profiling but that is really a "fraction of time spent"
- Hard to see relationships between events
- Profiling is a histogram tool

We would rather see

- Who calls whom
- What fraction of time I spend in “x” before I call “y”
- Not just “how much time spent in “x” and “y”
- Need to see relationships and ordering of calls

Other work

- dtrace[1], dkm, neat hardware hacks[3], kprobes[2], djprobes, jprobes[4], kernel markers, ftrace[http://lwn.net/Articles/270971/]
- First time I saw it was on SunOS ca. 1988, which used a kernel markers like approach
- Kernel markers are a lot of work, requires annotating thousands of points to really get coverage
- My reading: Linux community may find function tracing is "good enough" most of the time (see: ftrace)
- MacOS, however, has adopted dtrace, which is extremely powerful
- dtrace has two modes: enable always-compiled-in function traces, or:
- Rewrite running kernel binary for more complex tracing

Some tracing issues

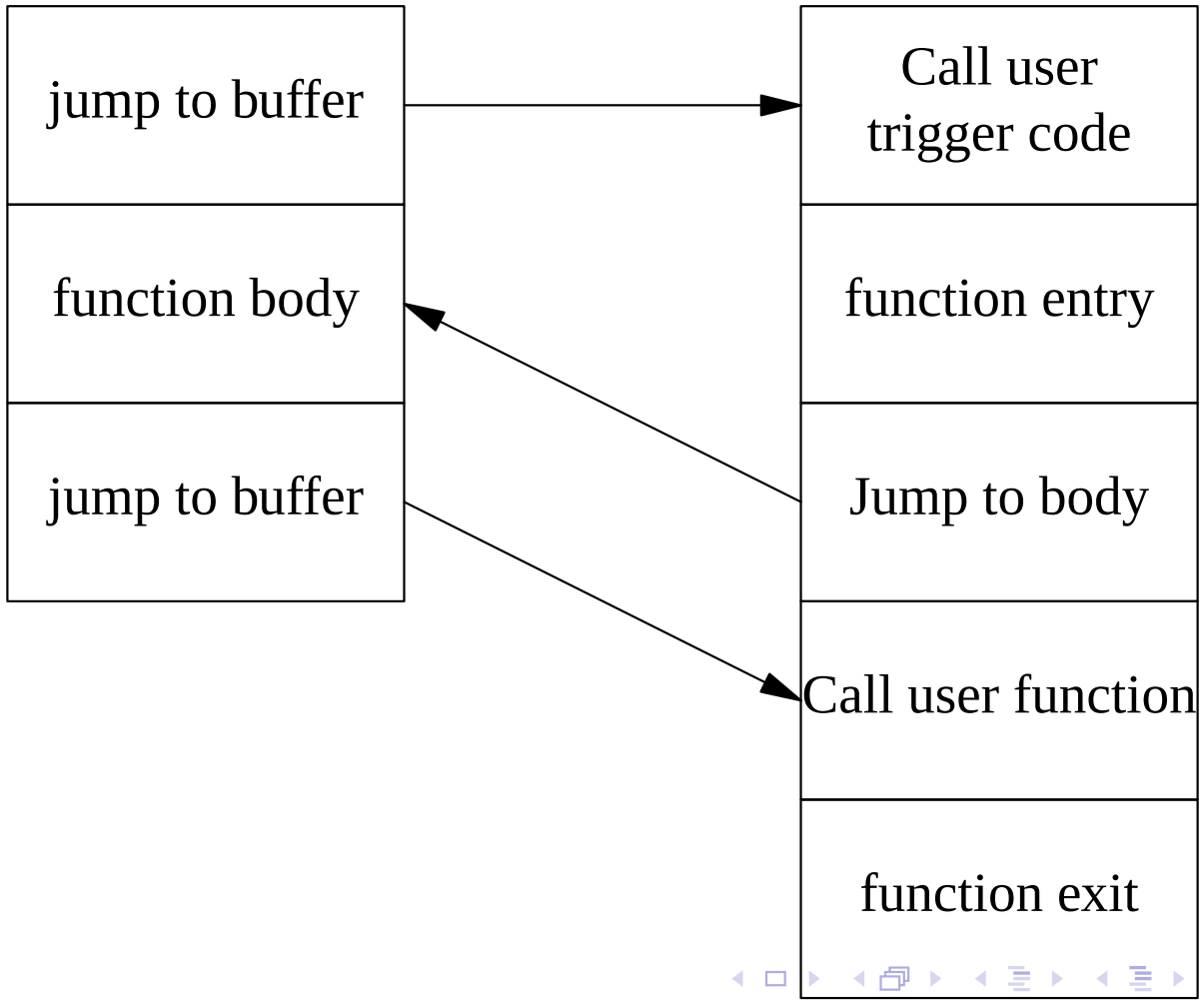
- The obvious one: overhead
- Hence terms like “invasive” and “sample-based”
- The less obvious one: you just changed a kernel binary
- Was that safe?
- Do all the CPUs know?
- When is it safe to change it back? (answer: maybe never)
- SMP issues

Starting from earlier Dynamic Kernel Modifier work (2001?)

- Code rewriting at runtime
- Modify code by moving blocks and replacing them with jumps
- Given an address, rewrite the code at that address to jump to a "logger"
- If you know entry and exit addresses, you can trace a function
- Gets a little tricky if you don't want to write an object-code-understander-relocater for CISC – and I don't
- I only moved code known to be "safe" to move, i.e. register-register moves etc.
- See paper for details
- GCC function prologues are only a few specific types, so was easy – and you only need to move 5 bytes, around instruction boundaries
- 8c is not so gentle

DKM code inserted

Rewritten code with entry, exit modified



The fun bits

- Relocated code has to be position-independent
- There is stack fixup:
- Have to maintain the stack correctly so calls from this function work
- Have to ensure that the function, on exit, returns to the jump to your exit code
- i.e. we don't rewrite the exit code, we only rewrite the entry code
- It gets messy but it's doable
- And it's fun to disable gettimeofday() and watch how things slowly fall apart ...

Version 1 (Aki and Ron)

- Ron did an early cut based on the Dynamic Kernel Modifier work from 2001
- At IWP9 2, Aki adapted it to the Power PC on Jim's desk
- We then further took it over to Blue Gene/P

IWP9 2 work

- Short form: on PPC it was pretty high overhead (although object-code-understander was not an issue)
- Worse, it required rewriting bits of the kernel memory image at run time
- Even worse, there is never a guarantee that you know when you can turn it off[4]
- Much less turn it on: are you *sure* that core 1 is not running code while you are busy rewriting it?
- You can't ensure it by just making sure you write less than one cache line of code!

Version 2 goals

- Easily build into kernel
- Easy to control
- Can reliably turn tracing on and off
- No kernel rewrite

Devtrace in a nutshell

- Plan 9 style text control
- Textual output
- No kernel rewriting
- Tracing on/off is always safe
- Logic analyzer style interface
- Not as powerful as dtrace
- Not as informative as ftrace (I think?)
- Ftrace info can be added
- Could produce dtrace format data for dtrace function processing

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We use -p infrastructure

- When you invoke ?l with -p, functions look like this:

```
0x00001020 CALL _profin(SB) f+0x5
 0x00001025 MOVL a+0x0(FP),AX f+0x9
 0x00001029 ADDL $0x5,AX f+0xc
 0x0000102c CALL _profout(SB) f+0x11
 0x00001031 RET
```

- profin/out give you arbitrary hooks
- Call sequence only lets you see the pc, no args
- Just gets a histogram, no time relationships

We just define our own profin

```
TEXT _profin(SB), 1, $0
TESTL probeactive(SB), AX
JZ inotready
MOVL 4(SP),AX
PUSHL AX
MOVL 4(SP),AX
PUSHL AX
CALL profin(SB)
POPL AX
POPL AX
inotready:   RET
```

and profout ...

```
TEXT _profout(SB), 1, $0
PUSHL AX
TESTL probeactive(SB), AX
JZ notready
MOVL 4(SP),AX
PUSHL AX
CALL profout(SB)
POPL AX
notready:   POPL AX
RET
```

A few details

- The stack frame already has some things you want
- Caller PC and some args
- Also, on some machines, one register has the "first parameter"
- Problem is to get them into a machine-independent format
- On x86, can trash ax on entry; must save it on return
- on PPC, must save it in both directions
- Finally, it's important to disable tracing on certain functions
- Such as profin assembly and C code
- And anything the profin C code calls

Building into your kernel

- contrib/rminnich/9.probe
- Bind these directories over your /sys/src/9
- Note I left v1 code in there for your viewing pleasure
- mk 'CONF=pcprcpf'
- boot kernel and you're ready to try it out

Trying it out

- See the 'probeit' file in 9.probe

```
#!/bin/rc nm pc/9pcprcpf | grep $1 |
awk '{print "probe 0x" $1 " new "$3}'
> /dev/probectl
```

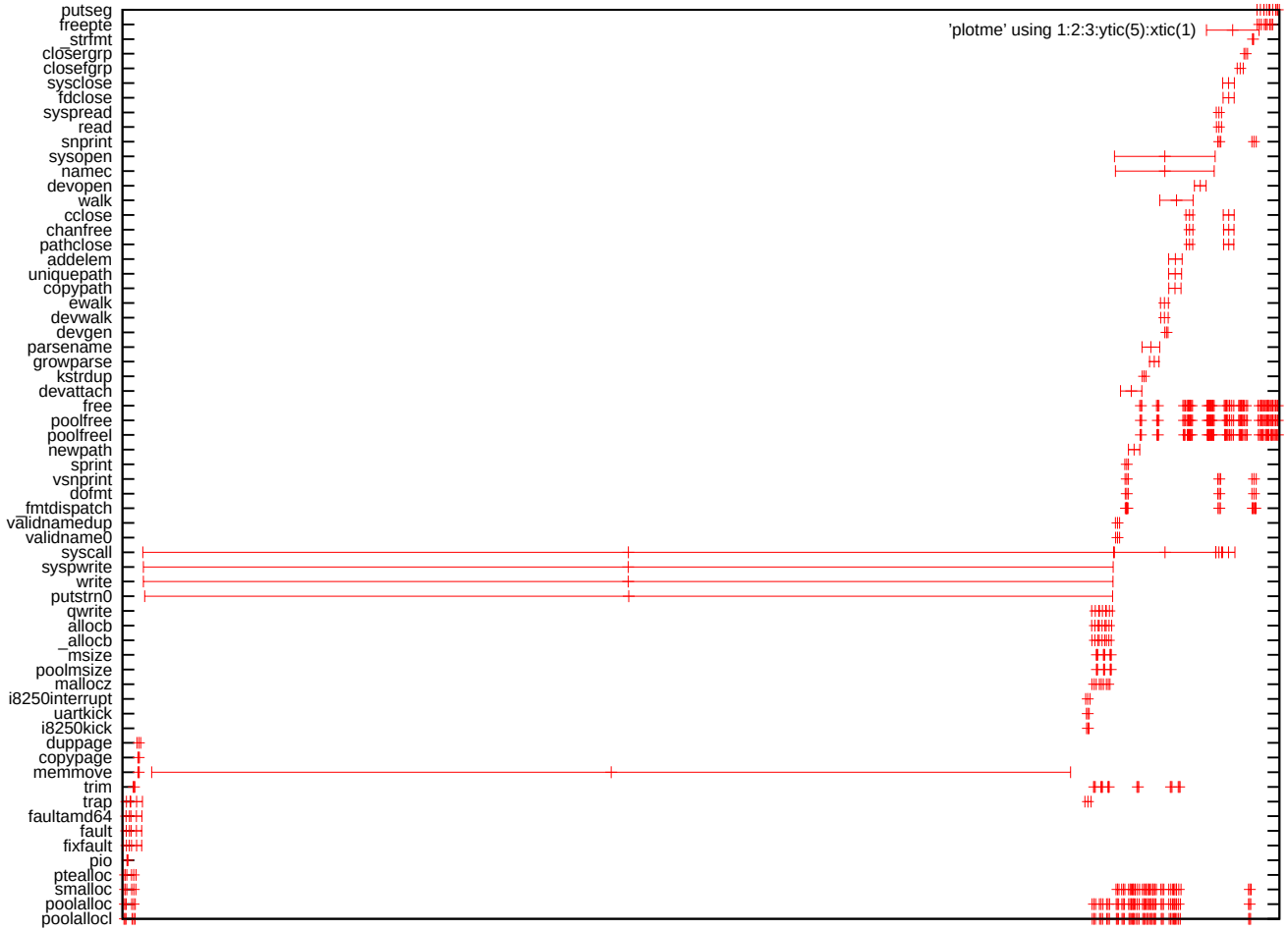
- That script will set up tracing for one symbol at entry
- Example in 'probeit' shows a real trace
- Probing syschdir and namec
- Showing arguments and so on

Output

```
E f01b626e 000000226c00e7d4 00009ed0 00000000 00000000 0
```

- E or X
- PC
- Time in ticks
- PID
- Three args for E; return value for X
- Fixed, easy to parse format

Viewing it


'plotme' using 1:2:3:ytic(5):xtic(1)
putseg
freepte
strfmt
closergrp
closefgrp
sysclose
fdclose
syspread
read
snprint
sysopen
namec
devopen
walk
cclose
chanfree
pathclose
addelem
uniquepath
copypath
ewalk
devwalk
devgen
parsename
growparse
kstrdup
devattach
free
poolfree
poolfreel
newpath
sprint
vsnprint
dofmt
fmtdispatch
validnamedup
validname0
syscall
syspwrite
write
putstrn0
qwrite
allocb
_allocb
_msize
poolmsize
mallocz
i8250interrupt
uartkick
i8250kick
duppage
copypage
memmove
trim
trap
faultamd64
fault
fixfault
pio
ptealloc
smalloc
poolalloc
poolallocl

What we learned

- We were able to measure where the time was spent
- There were some real time-wasters (incref/decref)
- There were some problems hard to see a way around (okaddr, fdtochan)
- We could go to elaborate and complex translation and other caching to try to shorten time
- But that seems the wrong path

Summary

- devtrace can let you see where the time is going
- Simple textual control and data interface
- You can see relationships between calls
- Exploits existing profiling architecture
- Thanks to SP9SSS for help and advice

Can we make it less intrusive?

- Yes. And safer.
- Consider this code:

```
a: JMP 2f

    call profin
    2: ...
```

- It becomes:

```
    EB05       a: jmp 2f
    E8F9FFFFFF call profin
C3             ...
```

- So, actually, we can change one byte and enable/disable profiling on this function

Exit

```
ret
call profout
ret
```

- Same deal: NOP and RET are same size, one byte
- So one-byte change can enable/disable profout in this function
- And it's easy to find the code signature!

Have to modify 8l

- 8l builds "instructions" (prg()) as part of creating linked binary
- They form a linked list
- if profiling is enabled, 8l does a final-pass walk of list and inserts calls to profin/profout on function entry/exit
- How do you know what is entry/exit?
- prg() struct is marked as such
- So, given this least, need only modify how code is inserted
- In code shown below, we have the current entry/exit pointed to by 'p'

Modifying 8l

- Copy doprof() in obj.c to doprof2

```
q = prg();
q2 = prg();
q->line = p->line;  q->pc = p->pc;
q->link = p->link;  p->link = q2;
q2->link = q;
q2->line = p->line; q2->pc = p->pc;
q2->as = AJMP; q2->to.type = D_BRANCH;
q2->to.sym = p->to.sym; q2->pcond = q->link;
p = q;
p->as = ACALL;  p->to.type = D_BRANCH;
p->pcond = ps2;  p->to.sym = s2;
```

Return case

```
/*    * RET    */
q = prg();
q->as = ARET;  q->from = p->from;  q->to = p->to;  q->li
/*    * JAL
profout    */  p->as = ACALL;  p->from = zprg.from;  p->t
p = q;
```

For Further Reading I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