Context threading on the RubyVM

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Nagoya Ruby Kaigi 04
Lightning talk

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- A programmer
  - 2006-2012 Faculty
  - 2012-2017 Heroku, Inc.
  - 2017- Cookpad Inc.
- Job: MRI development
  - Core parts
    - VM, Threads, GC, etc

Notice

- This talk is based on the knowledge of computer science, especially interpreter development, CPU architecture and C language. Only one Ruby code here.
- This talk is about the virtual machine development.

Summary

- Introducing “Context threading” to improve VM performance with extension by “tailcall” technique.
- Now we can not observe performance improvements (slightly slows down), but we need to investigate more.

Background
VM instruction dispatch technique

- Token Threading

```
while (1) {
  insn = *pc;                              // fetch
  switch (insn) {                          // dispatch
   case Insn_A: do_a(); break; // execution
   case Insn_B: do_b(); break;
   case Insn_C: do_a(); break;
    …
```

Background
VM instruction dispatch technique

- Direct Threading w/ GCC extension (label as value)

```
Insn_A:
    do_a();    // execution
    goto *pc; // fetch and dispatch
Insn_B:
    do_a();    // execution
    goto *pc; // fetch and dispatch
```

YARV Maniacs 【第 3 回】 命令ディスパッチの高速化
https://magazine.rubyist.net/articles/0008/0008-YarvManiacs.html

Background
Issues

- Indirect branch can hurt “branch prediction”
- Missing branch prediction may have a performance impact.

```
Insn_A:
    do_a();    // execution
    goto *pc; // fetch and dispatch

    // Branch target is decided by a pointer
    // difficult to predict branch prediction
```

Context threading

- Marc Berndl, et.al.: Context Threading: A Flexible and Efficient Dispatch Technique for Virtual Machine Interpreters (2005)
- Remove most of indirect branch to improve branch prediction performance

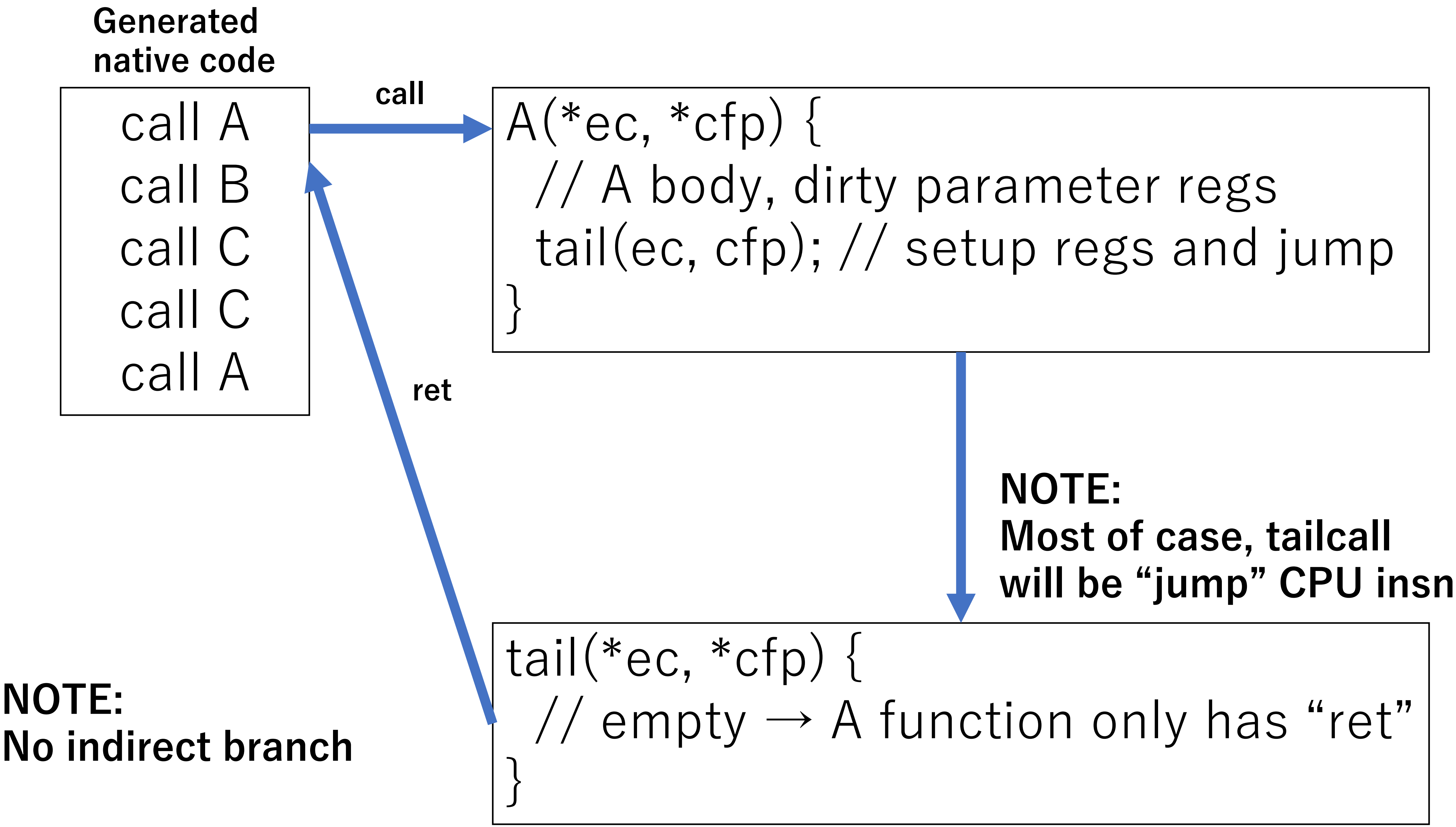
Context threading

- Basic idea: Use call instruction (= subroutine threading)
  - Bytecode: [A, B, C, C, A]
    → Generate native "call" sequence
    [call A, call B, call C, call C, call A] with machine code.
    NOTE: there are more techniques on CT, but eliminate them here.
- Advantage:
  - Similar to JIT idea. But JIT needs machine code knowledge.
  - CT only needs limited knowledge (call instruction).
  - "call A" instruction is not indirect branch because the destination is determined. We can increase instructions number more.
  - The call/return pair has been optimized by CPU (call stack cache).

Context threading
Problem

- How to eliminate parameter setup code?
  - The sequence should be [call A, call B, …]
  - Instructions should communicate each other with parameters
  - How to setup function parameters (rdi, rsi, … on x86_64)?
  - Original CT (subroutine threading) only support a labels in a function (calling labels directly)

    → Maybe we don’t need to setup function parameters.
- Disadvantage:
  - We can’t add new instructions outside of the function.
  - The setup time of the function can be grow.
  - “perf” only shows the function’s time.


Generated native code
call A
call B
call C
call C
call A
call
ret
A(*ec, *cfp) {
// A body, dirty parameter regs
tail(ec, cfp); // setup regs and jump
}
NOTE:
Most of case, tailcall will be “jump” CPU insn
tail(*ec, *cfp) {
// empty → A function only has “ret”
}
NOTE:
No indirect branch

Measurement

```
i=0
while i< 100_000_000 # 100M iterations
  i = i + 1
end
# Impl. is not
# completed.
```

```
0000 putobject_INT2FIX_0_
0001 setlocal_WC_0                    i@0
0003 jump                             17
0005 putnil
0006 pop
0007 jump                             17
0009 getlocal_WC_0                    i@0
0011 putobject_INT2FIX_1_
0012 opt_plus                         <callinfo!mid:+, argc:1, ARGS_SIM
0015 setlocal_WC_0                    i@0
0017 getlocal_WC_0                    i@0
0019 putobject                        100
0021 opt_lt                           <callinfo!mid:<, argc:1, ARGS_SIM
0024 branchif                         9
0026 putnil
0027 nop
0028 leave
```

Result

	Execution time (sec)
Direct threading (Current)	1.26
Context threading (Proposal)	1.31

Congratulation! Your Ruby is fast!!

- [Small benchmark] → NO prediction misses on recent CPUs.
- So many prologue/epilogue code than my expect.
- “call/return” pair is expensive than my expect.

Remaining issues

- Memory management
  - We need to manipulation page protection (allowing execution) so that we can't use "malloc/free" library functions.
  - On x86_64 CPU, "call" instruction should be 32 bit relative address so that code are should be near to instruction functions (A, B, …).
- Verbose VM virtual registers manipulation
  - Stack caching can have an affinity because we can pass TOS values with function parameters.
- Not only "call", but other asm is needed to improve more.
  - Maintenance issue.
  - Portability issue.

Summary

- Introducing “Context threading” to improve VM performance with extension by “tailcall” technique.
- Now we can not observe performance improvements (slightly slows down), but we need to investigate more.

Thank you for your attention

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