Adaptive Multi-Level Compilation in a Trace-based Java JIT Compiler

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Goal

- Balancing steady-state performance and startup performance has been a challenging task for JIT compilers.

Our Goal

*to improve the steady-state performance without hurting startup performance in a trace-based Java JIT compiler*

Our contributions:

1. We show that adaptive multi-level compilation is a practical way to balance the startup time and steady-state performance in a trace-JIT
2. We develop a new technique to efficiently identify hot paths to recompile in a higher optimization level
Background: Trace-based Compilation

- Using a Trace, a hot path identified at runtime, as a basic unit of compilation
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Trace selection: how to form good compilation scope

method entry

method f

if (x != 0)

frequently executed

while (!end)

a hot path

do something

return

rarely executed

A

B

exit

stub

B

exit

stub

A

linear trace

cyclic trace
Background: Trace Selection and Performance

- Steps of trace selection
  1. Identify a hot trace head
     - a target of a backward branch, a exit point of an existing trace
  2. Record next execution path starting from the trace head
  3. Stop recording when the trace being recorded
     - forms a cycle, reaches pre-defined maximum length

- Generating longer traces (compilation scopes):
  😊 yields better steady-state performance
  - more optimization opportunities for compilers
  - smaller trace transitioning overhead
  😞 but it hurts startup performance
  - longer compilation time
  - more duplicated code among traces
Our Approach: Adaptive multi-level compilation for trace-JIT

1. Interpreted execution
   - identify hot paths by counting the execution count for each potential trace head (e.g. loop backedge)

2. Initial compilation for faster startup
   - smaller compilation scope
   - lower optimization level
   - identify really hot paths by using timer-based sampling profiler

3. Upgrade recompilation for higher steady-state performance
   - larger compilation scope
   - higher optimization level

Our focus
Trace selection for upgrade recompilation
**Steps of Our Multi-level Compilation**

- **Source program**
  - Hot path
  - Cold path
  - Trace head

- **We limit the max trace length for faster startup (here 2 BBs)**

- **Initial compilation**
  - Executed by interpreter with monitoring to identify hot path
  - Executed as compiled code with timer-based sampling profiler

- **Linear trace 1**
  - Upgrade recompilation
  - Our focus: Trace selection for upgrade recompilation

- **Linear trace 2**

- **Cyclic trace**

- **Compiled cyclic trace**

- **Compiled linear trace**
An Example of Inefficient Selection for Recompilation

**Badly formed case**

Problem insufficient coverage by recompiled traces

We want to cover the entire hot path by a recompiled trace

**Desired case**

A straight-line hot path

upgrade recompilation

linear trace 1

linear trace 2

linear trace 3

recompiled linear trace

recompiled linear trace

recompiled linear trace
Our Solution: Trace Transition Graph (TTgraph)

- **Trace-Transition Graph (TTgraph)** is a weighted directed graph representing the control flow among traces

  - **Node:** compiled trace
  - **Edge:** transition between two traces
    - weight represents relative frequency

  ➔ We identify the hot paths to recompile using the TTgraph

    - to capture the entire hot path by traversing the edges backward
Steps to Build TTgraph

1. We add an node when a trace is compiled

2. We add an edge between two traces when we link them (trace linking)

3. We increment weight of an edge by timer-based sampling profiler

See the paper for more detail (e.g. how we profile transition and how we employ bursty tracing)
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Recompilation Based on TTgraph

We traverse the hot edges backward to identify the new trace head for recompilation

- we stop the backward traversal when hitting a cyclic trace (our system does not capture cyclic and linear path in one trace)
- If there are multiple hot incoming edges for a node, we track both of them

See the paper for more detail
Performance Evaluation

- **Hardware**: IBM BladeCenter JS22
  - 4 cores (8 SMT threads) of POWER6 4.0GHz
  - 16 GB system memory
- **Our trace-JIT**:
  - Extended IBM JVM for Java 6 (32-bit) to support trace compilation
  - Two optimization levels (both trace selection and code generation), **cold** and **hot**
  - We compare cold only, hot only, and our adaptive multi-level compilation
- **Benchmark**:
  - DaCapo benchmark suite 9.12
Steady-state Performance

always using hot level gives 26% gain in steady state

Our technique achieved 22% gain in steady state
Startup Time (Execution time of first iteration)

- using hot level makes the startup 50% (up to 3x) slower!
- Our technique does not hurt the startup performance!
Improvement by TTgraph-Based Recompilation

The bar chart shows the improvement in peak performance for various applications when using basic recompilation compared to TTgraph-based recompilation. The x-axis represents different applications, and the y-axis shows the relative peak performance, with higher values indicating faster performance. The chart indicates that TTgraph-based recompilation generally results in higher performance compared to basic recompilation.
Summary

- We showed that adaptive multi-level compilation is a practical way to balance the startup time and steady-state performance in a trace-JIT.

- We developed an efficient technique based on TTgraph to identify hot paths. We described the trace selection engine, the timer-based sampling profiler, and the code generator work together for effective recompilation.
Thank you!
Backup
CPU Time Breakdown

Most of the execution time is spent in recompiled code.