A Dynamic Tool for Finding Redundant Computations in Native Code

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Motivation

- Compiler optimizations do not always deliver their full performance potential
  - Complicated interactions between optimizations
  - Unforeseen interactions with the target architecture
- Compiler engineers spend significant portion of their time tuning optimizations
  - Focus on hot-code of specific application
  - Use HW profile to assist identifying inefficiencies in the generated code

Could we build a new tool to helps assess the quality of compiler optimizations?

Why use Dynamic Analysis?

Dynamic

Pros

- handles indirect jump, and dynamically loaded libraries
- Observes the same address and value as they run
- Simple verification technique

Cons

- Unexecuted path/code are not analyzed
- High runtime overhead but can be made reasonable

Static

Cons

- Indirect jump and DLLs are a problem
- Values cannot be observed. Symbolic analysis is conservative and limited.
- Require multiple analysis to be effective – e.g. alias analysis, symbolic, range and control-flow, call graph.

Pros

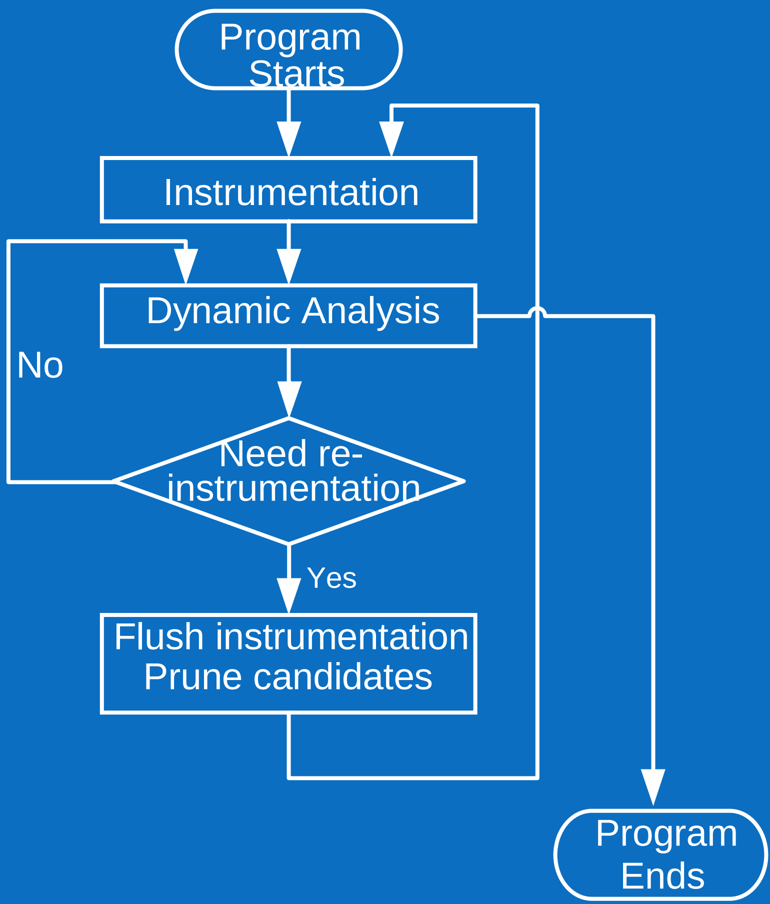
- All execution paths are covered
- No runtime overhead

Performance Opportunity Finder (POF)

- POF identifies potentially redundant computations
  - that require contextual analysis relevant to (global/interprocedural) compiler optimization
    - Redundant sign/zero extensions
    - Redundant constant spills
    - Missing copy/constant propagations
- POF is implemented using Intel's PIN* dynamic instrumentation framework
  - POF uses program execution contexts (register/memory value) and program execution paths
  - POF determines invariants associated with redundant computations

*http://rogue.colorado.edu/pin

How POF Works?



1. Instrumentation: Performs (dynamic) instrumentation on candidate instructions associated with redundant computation patterns

2. Dynamic Analysis: Checks if invariants on the patterns are satisfied during the program execution.

3. (Re-instrumentation): Unnecessary instrumentation is removed.

4. At program exit, reports the locations (virtual addresses) of redundant computations and how many times they execute.

(Potentially) Redundant Computation Patterns

- Redundant Sign/Zero Extension
  - Instruments every: ***movsx/movzx dst, src***
  - Check whether the value of ***src*** *register* is already sign/zero extended in its super register

- Redundant Constant Spill
  - Instruments every: ***mov [esp + offset], src***
  - Check whether the value of ***src*** is the same over the execution

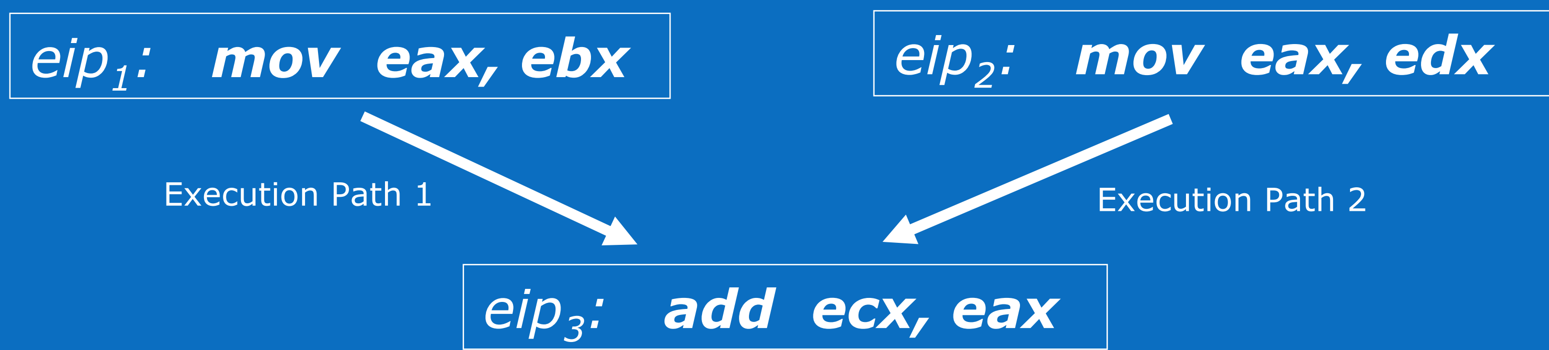
Missing Copy/Constant Propagation

def:	***mov dst, src / mov dst, const***
	⋮
use:	***inst … dst …***

- Check if neither ***dst*** nor ***src*** is defined along any possible path between the *def* and *use* sites
  - Potentially, all instructions having register operands need to be instrumented.
- Basic-block level instrumentation for efficiency
  - Initially summary information (Uses/Defs) is built for each basic block using a bit vector representation.
  - POF propagates summary information at each basic block entrance during execution.

Missing Copy/Constant Propagation (Cont.)

- Data flows along the actual execution path
  - No control flow/call graphs are required.
- POF Handles control-flow merge



  - A copy pair **(*eax, ebx*)** is created.
  - A missing copy propagation from *eip*$_1$ to *eip*$_3$ is identified.
  - Another copy pair ***(eax, edx)*** is created.
  - The missing copy propagation is invalidated.

Reducing POF's Runtime Overhead

- Static instrumentation removal
  - If a benchmark has several input scenarios, POF skips instrumentation on instructions that were proven to be *non-redundant* in the previous execution.

- Dynamic instrumentation removal
  - POF investigates how instructions become *non-redundant*, and decides when to re-instrument the binary
    - If the number of instructions that dynamically become non-redundant exceeds a certain number, POF flushes out all previous instrumentations and re-instruments only remaining candidates.

Experiments

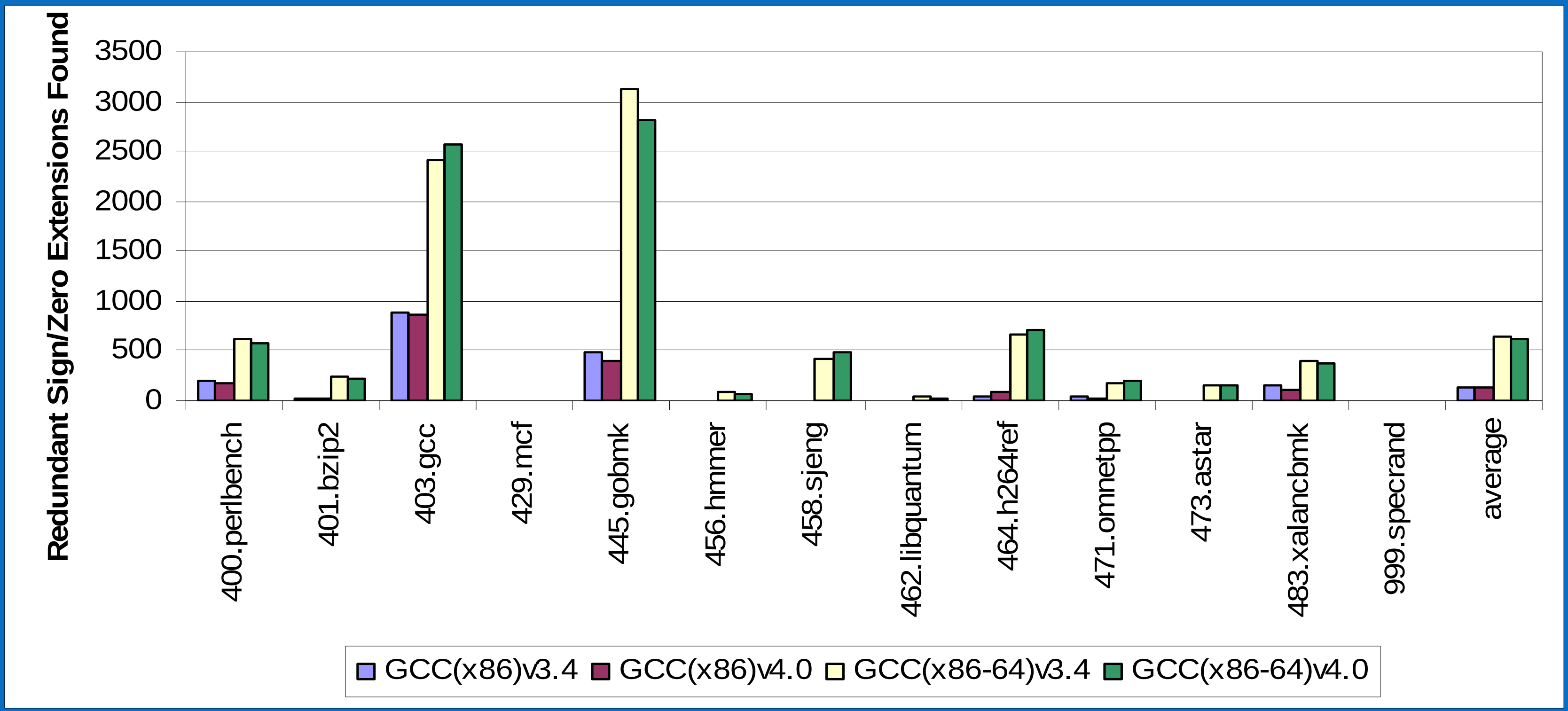
- Hardware
  - Intel® Core™ 2 Duo 2.4GHz 4MB L2, FSB 1066MHz, 2GB memory
  - BIOS version/date: Intel Corp CO96510J.86A.2254.2006.0316.1743 3/16/2006
  - SUSE™ Linux* 10.0 with kernel 2.6.5

- Software Configuration
  - Benchmarks: SPEC® CPU2006 (CINT)
  - Compilers:
    - GCC version 3.4 and version 4.0 for IA-32(x86) and Intel® 64(x86-64) respectively (/O2)

- Evaluate the code generated by compilers
  1. Static counts: Number of redundant computations found in the binary
  2. Hot-score [%]= $D / D_{hottest}$

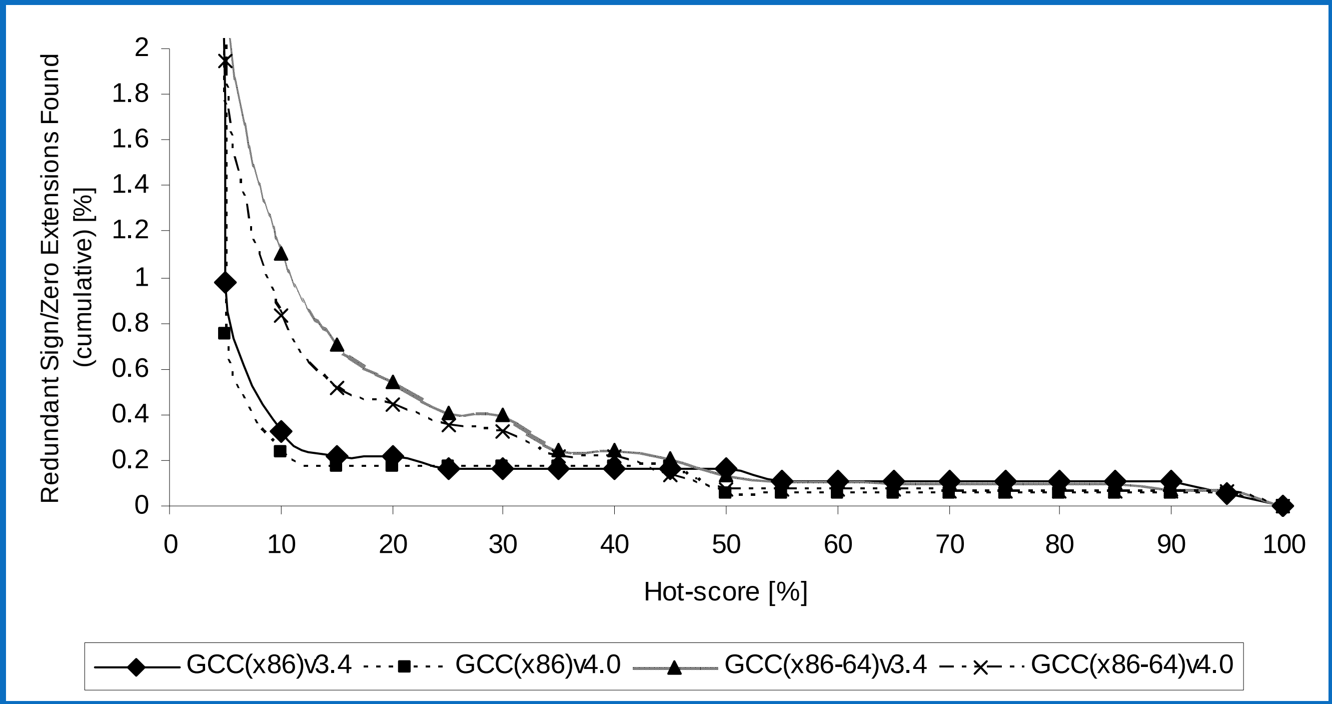
     where D is the number of times the redundant instructions execute, and $D_{hottest}$ is the number of times the hottest instruction executes.

Redundant Sign/Zero Extension



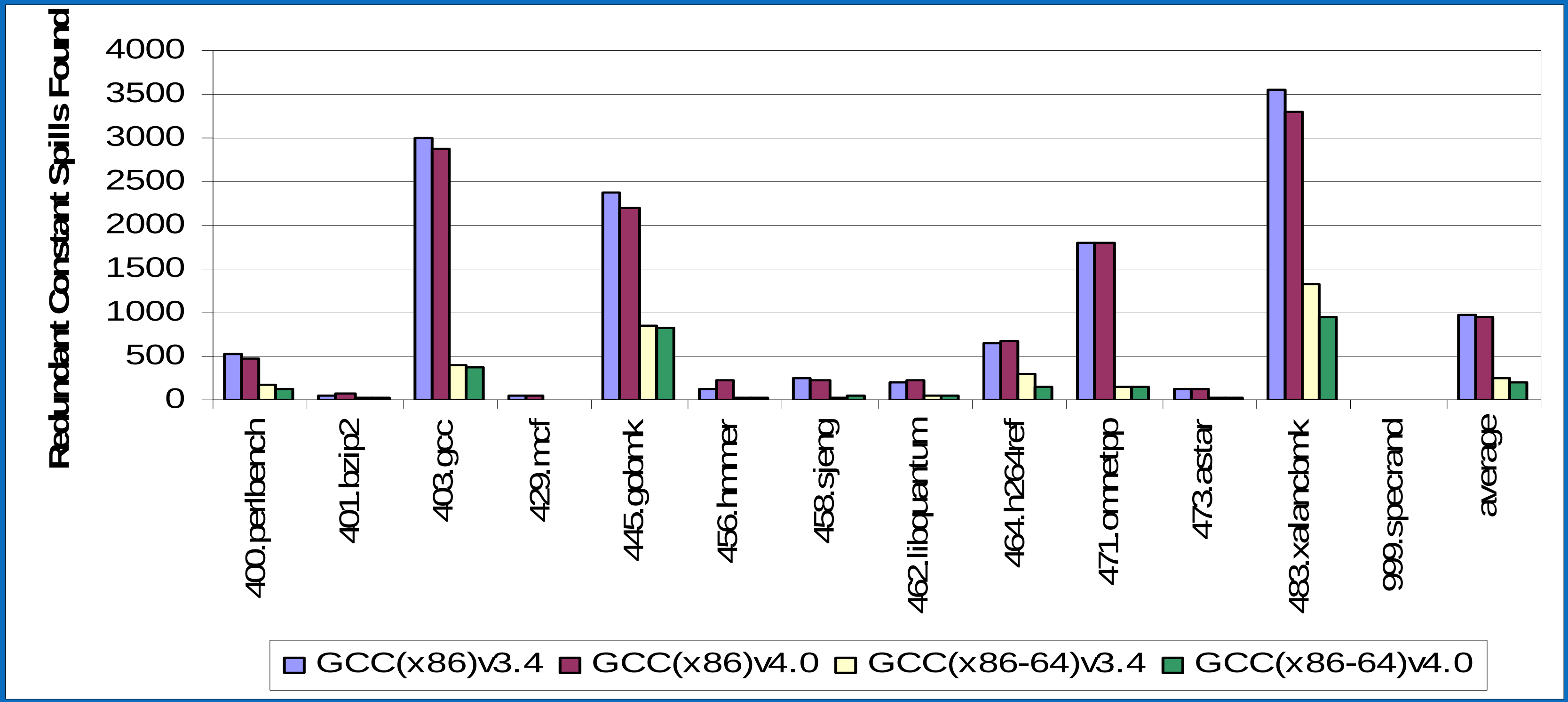
- In 403.gcc and 445.gobmk, there are two consecutive zero-extended moves (*movzx EAX, byte ptr [EBX] … movzx EAX, AL*)
- Overall, x86-64 compilers have more redundant sign/zero extensions than x86 compilers.

Redundant Sign/Zero Extension



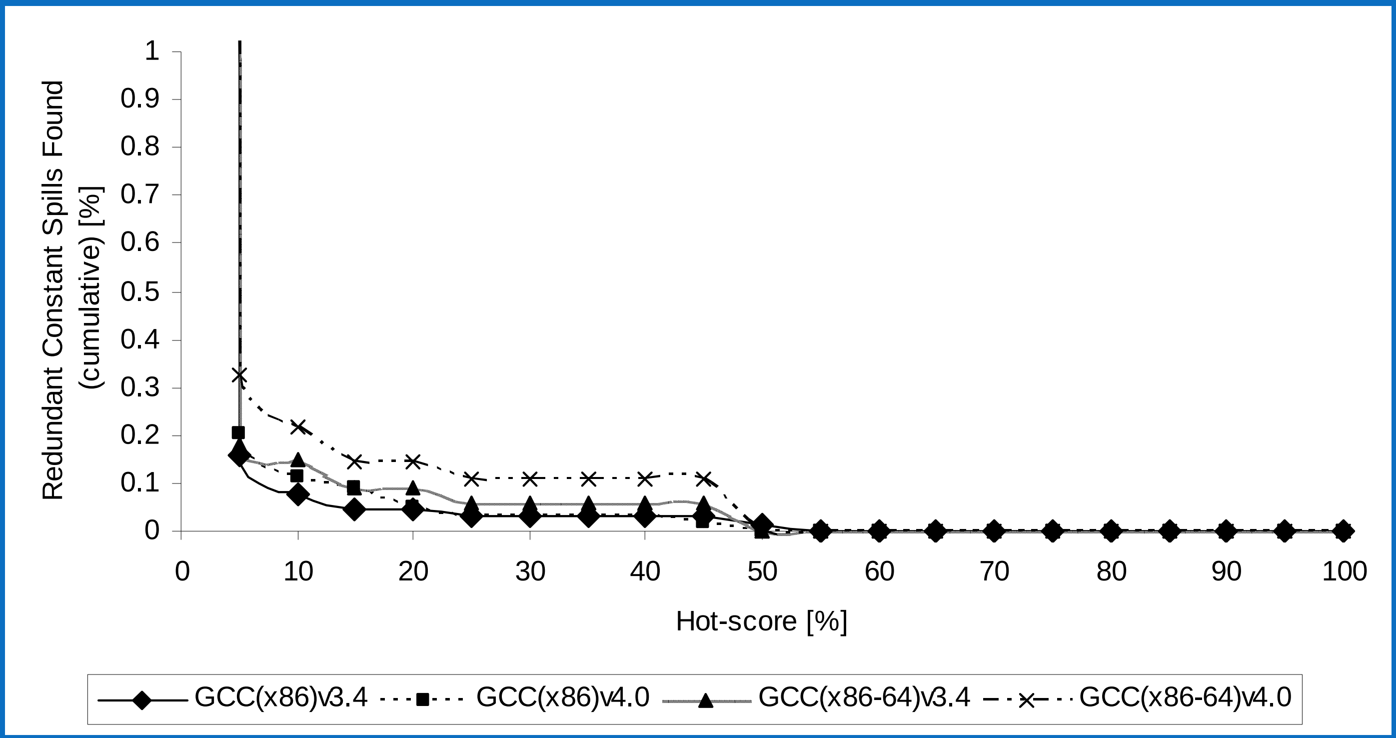
- No more than 2% of redundant sign/zero extensions have only 5% Hot-score – most redundant computations are not in the hot path.
- Relatively, x86-64 compilers have higher Hot-scored redundant sign/zero extensions than x86.

Redundant Constant Spill



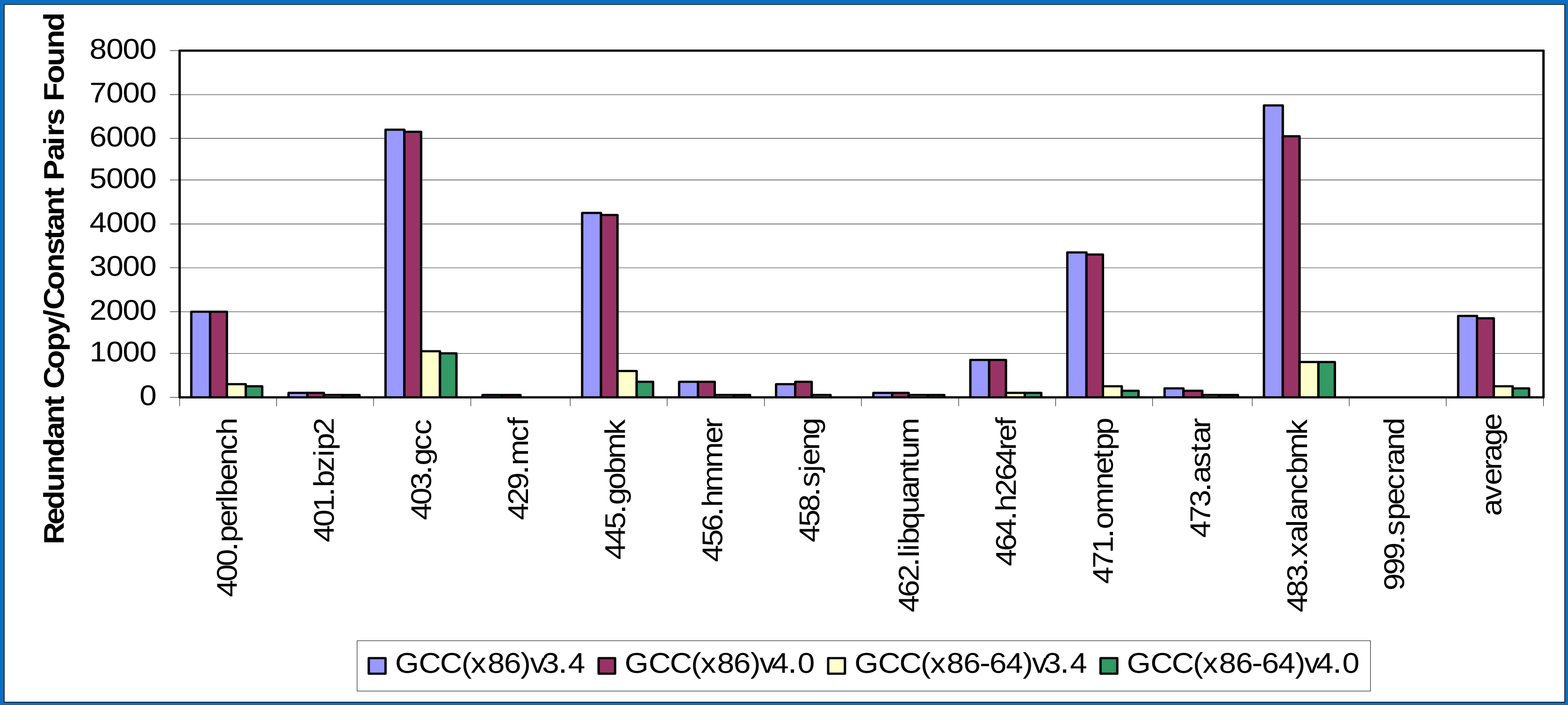
- Overall, x86 compilers have more redundant constant spills than x86-64 compilers.
- This happens because register pressure is higher in x86 compilers.

Redundant Constant Spill



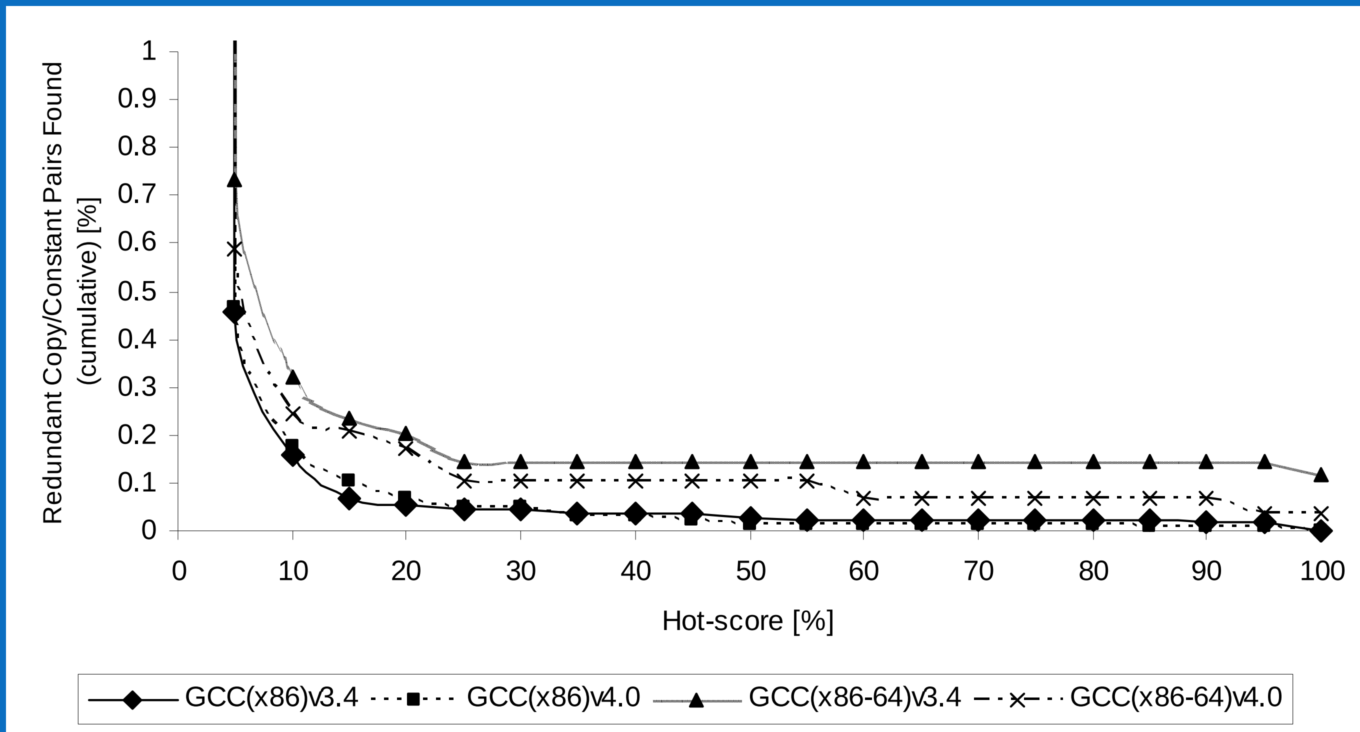
- Hot-scores for all redundant constant spills do not exceed 55[%].
- Relatively, x86-64 compilers have higher Hot-scored redundant constant spills than x86 compilers.

Missing Copy/Constant Propagation



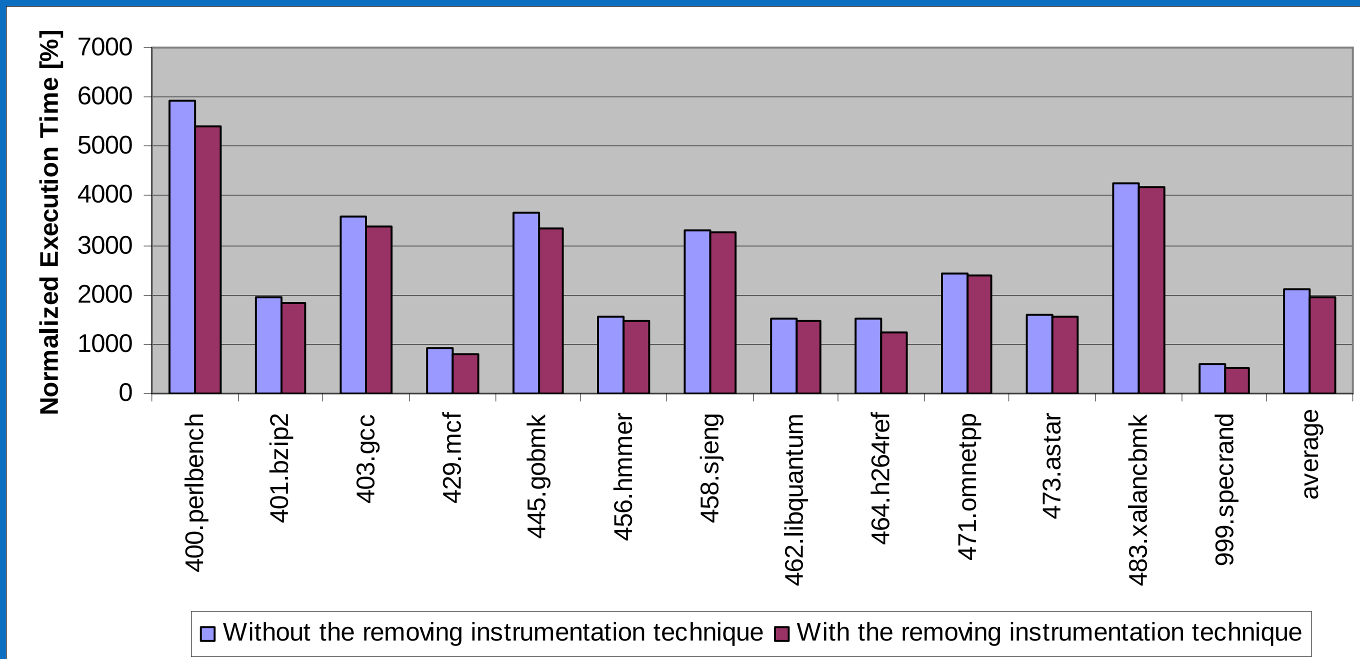
- Counts def sites (instructions associated with copy pairs).
- Overall, x86 have more missing copy/constant propagations than x86-64 compilers.

Missing Copy/Constant Propagation



- Relatively, x86-64 compilers have higher Hot-scored redundant copy/constant pairs than x86 compilers.
- There is little difference between version 3.4 and 4.0 for x86 compilers.

POF Execution Time Relative To the Original Run



- Average of three execution time of all runs of the reference input data sets with all patterns enabled
- Overhead is affected by the number of redundant computations found.
- POF has an average of 19X slowdown relative to the original run.

Conclusion & Next Steps

- POF is an original tool to help assess the quality of compiler optimizations
  - Our first implementation supports three patterns
  - Using various GCC compilers, we have performed a comparative study on the redundant computations.
- Future work
  - Add more redundant computation patterns for both architecture-independent/dependent optimizations.
  - Generalize a pattern description rule
  - Share POF with compiler developers and see how effectively they fix deficiencies in compiler optimizations

Acknowledgement

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