Improving Code Quality

Developing & Deploying New Ideas

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Background

- Our group is funded under both performance & components
  - Better compiler techniques for microprocessor based systems
  - Automatic application tuning through adaptive compilation
- Focus on development & deployment
  - Invent new code optimization techniques
    - Improve runtime performance
    - Broaden suite of codes that achieve “good” performance
  - Transfer technology into important compilers
    - Widely used open source systems & vendor compilers
    - Model implementations to guide commercial
- Three examples
  - Instruction mix, register allocation, adaptive inline substitution

Changing Instruction Balance

Motivation: Some of the performance critical loops in Sweep3D have a low ratio of useful (floating point) ops to total ops

Question: Can we transform them to improve performance?

- Mellor-Crummey rewrote loops in SAGE to cure similar problems
- Can we develop automated techniques to achieve similar results that are suitable for use in compilers such as gcc or Intel's compilers?
  - Low-level automatic techniques would help a variety of codes

- Launched a study that tried novel combinations of
  - Algebraic reassociation
  - Strength reduction
  - Code motion
- We have not had much success
  - Subject of continuing research

Based on prior experience, we believed that we could reduce the overhead from addressing & control flow

Register Allocation

Motivation: High-quality register allocation plays a critical role in single-processor performance

— Open-source systems have a history of using weak algorithms

Goal: Move best practices into important open-source systems

— Direct performance benefits for most programs

Activities in the Last 18 Months

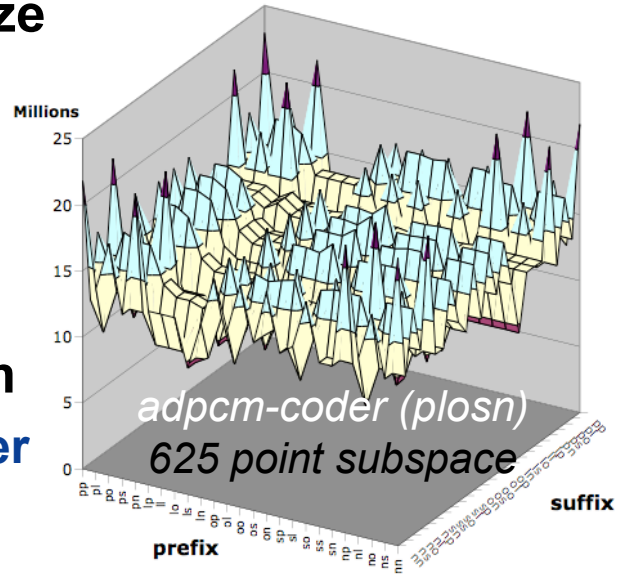
- Advised implementor of gcc's "new-ra"
  — Uses many of our algorithms & data structures
- Built two new global allocators for LLVM
  — LLVM is a strong contender for next-generation gcc backend
  — Implementations show how to adapt allocators for x86 ISA
  — IP issues complicate the distribution process (*working on it*)
- Made fundamental algorithmic improvements
  — Better coalescing, faster graph updates for JIT environments

Adaptive Compilation (*Background*)

- Today's compilers apply fixed set of passes in a fixed order
  - — No relationship to mathematical notion of optimization
- Our systems look for "good" optimization sequences
  - — Feedback-driven search over large, complex spaces
  - — 20 to 40% improvement over fixed sequence optimizers
  - — Reduced cost for "good" sequence from 20,000 evaluations to ≤ 250

1 trillion points of interest

- Developed search techniques that capitalize on properties of the search spaces
  - — Large scale studies to learn properties
  - — Efficient searches for different cost points
  - — Randomized restart avoids local minima
- Sequence finding is a hard search problem
  - — Finding loop blocking factors is much easier
- Spawned interest in academia & industry



New techniques ⇒ new tools

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Adaptive Inline Substitution

- **Inline substitution is a well-known transformation**
  - — Replace procedure call with body of called procedure
  - — Eliminates overhead & creates larger scope for optimization
  - — Important in OO languages, also improves C or FORTRAN
- **Difficult problem is deciding which call sites to inline**
  - — Decisions interact with each other
  - — Profitability depends heavily on context
  - — Underlying graph changes as decisions are made

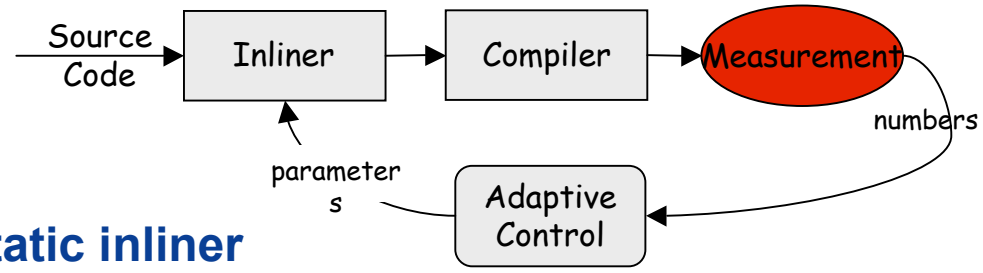
And, inlining can have negative side effects

- **Current state of the art for the decision procedure**
  - — A single heuristic applied at each call site in each application
  - — We have shown that program-specific inlining heuristics can produce significantly better code than any general scheme

Adaptive Inline Substitution

Inline substitution is a natural application for adaptive behavior

- **Built a demonstration system for ANSI C programs**
  - — Analyzes whole program and collects data on program properties
    - Nesting depth, code size, constants at call, call frequency, etc.
    - Experimented with 12 properties in Waterman's thesis
  - — Apply tunable heuristic at each call site
    - Compare actual values against parameter values
    - Use search to select best parameter values
  - — Produce transformed source
  - — Compile, run, evaluate



  - — Improvements of 20% over static inliner and 30% over original (PowerPC & Pentium)
  - — Heuristics vary by application and by target architecture

Adaptive Inline Substitution

Key design issues

- **Finding a good way to parameterize the problem & the software**
  - — Takes a "*condition string*" in CNF where each clause is a program property and a constant, e.g.,

    inliner -c "sc < 25 | lnd > 0, sc < 100" foo.c

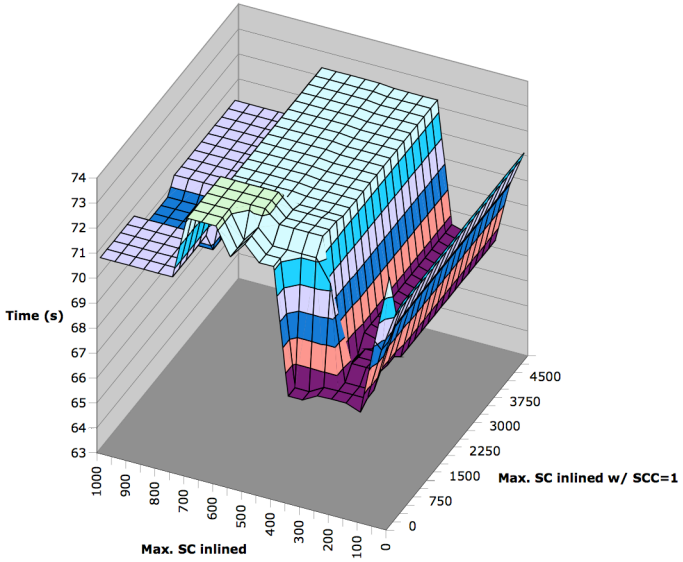
  - — Search produces a condition string that can be used repeatedly
- **Search space is huge**
  - — Range of values depends on input program
    - – Estimate the range & discretize it into 20 intervals
  - — Condition string syntax admits too many choices
  - — Designed a single format for condition strings in our experiments

    sc < A | sc < B, lnd > 0 | sc < C, scc = 1 |
    clc < D | cpc > E, sc < F | dcc > G

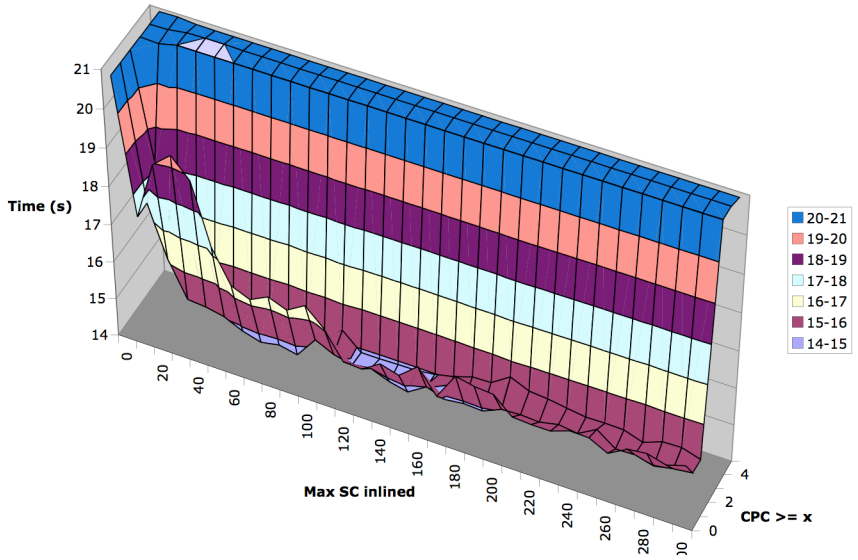
    } Fixes the search space's "shape"

Adaptive Inline Substitution

Search spaces are much smoother than in sequence finding problem



bzip, varying sc and sc for single-call procedures



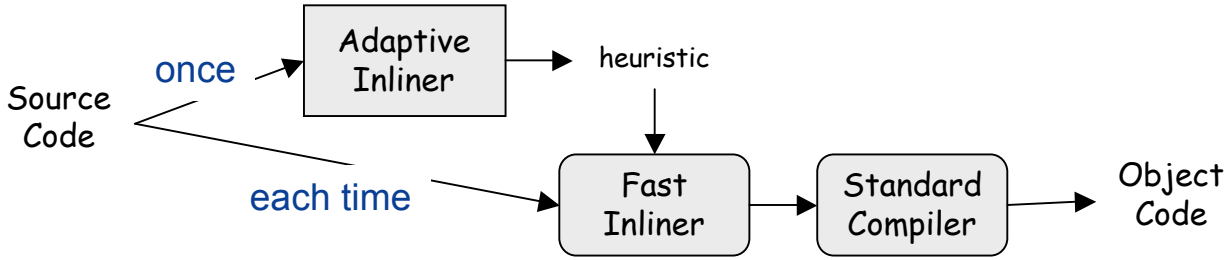
vortex, varying sc and constants per call

- **Designed search techniques for these spaces**
  - **—Impatient hill-climber and random restart**
- **And validated them experimentally**

Adaptive Inline Substitution

How can we deploy these results?

- **Source-to-source inliner**
  - — Runs for a while and produces a CNF expression that describes a program-specific heuristic
  - — Use the inliner on subsequent compilations with that heuristic
    - – If code properties change "enough", re-run the search



- **Tools**
  - — We are implementing these ideas in Rose and in Phoenix
  - — For FORTRAN 90, we are looking for a front end (*build one?*)
  - — Expect to have (& distribute) working tools later this year

Adaptive Optimization

Further work with adaptive inlining

- **Robust implementations applied to large programs**
- **Experiment with other properties** (***obj. code size***)

Apply knowledge & insight to other hard problems

Attack on instruction balance

- **Expression refactoring**
  - — **Balance for ILP, depth for registers, affinity for folding & CSE**
  - — **Another extremely complex problem**
- **Register allocation**
  - — **Reformulate coalescing, recoloring, rematerialization, lr splitting**
  - — **Evaluate variants on same optimized code & interference graph**

Key issues

- — **Developing expressive parameterizations**
- — **Designing effective search strategies**

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Summary

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- Transfer technology into important compilers
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  - — Model implementations to guide commercial
  - — Ph.D. students into industrial compiler groups

Students & Papers

Students

—Alex Grosul, Ph.D. (Search techniques for sequence finding) May 2005

—Todd Waterman, Ph.D. (Adaptive inline substitution), January 2006

Publications

— "ACME: Adaptive Compilation Made Easy", *ACM Conference on Languages, Compilers, and Tools for Embedded Systems (LCTES),* June 2005 (Cooper, Grosul, Harvey, Reeves, Subramanian, & Torczon)

— "Improved Passive Splitting", *Int'l Conference on Programming Languages and Compilers*, June 2005 (Cooper & Eckhardt)

— "Revisiting Graph-coloring Register Allocation: A Study of the Chaitin-Briggs and Callahan-Koblenz Algorithms", *18th International Workshop on Languages and Compilers for Parallel Computing (LCPC)*, October 2005 (Cooper, Dasgupta, Eckhardt)

— "Adaptive Inlining", *in review*

— Plus, two Ph.D. theses

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