Compiler Optimization: Increasing Research Impact

Chris Lattner
LLVM Founder & Architect
CGO 2012 - April 2, 2012

A Disclaimer

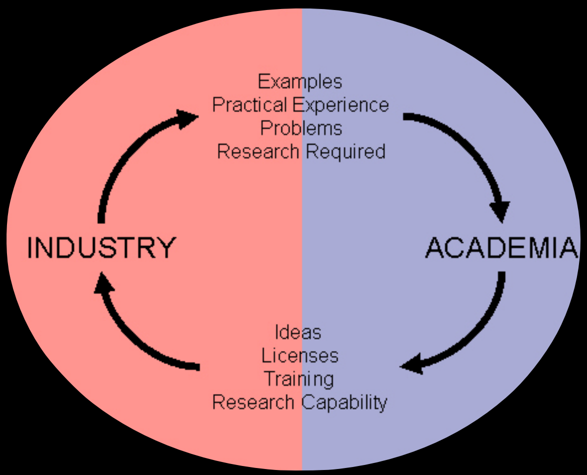
- This talk:
  - is highly biased by personal experiences and opinions
  - plays to broad stereotypes :-)
- Uses code optimization as an example
  - focused on traditional static compilation
  - focused on open source compilers
- Not intended to be new or novel
  - hopefully some tasty food for thought

Roadmap

- Industry vs Academia
- Heroic Optimizations
- Open Problems in LLVM
- Suggestions for the Community

http://llvm.org/

Academia vs Industry



Perspectives on Code Optimization

- How do we speed something up?
- What do we control?

Perspectives - Compiler Academia

- Can't change the benchmark
  - Results on well known benchmarks ⇒ credibility
- Easy (and desirable!) to change the compiler
  - Preferably in novel / publishable ways
  - Quality threshold: enough to run benchmarks

Perspectives - Industry

- "Hard" to change the compiler
  - Compiler engineers are specialized
  - Many competing demands
  - Compiler needs to be ~100% reliable

- Easy to change the application
  - Code changing and evolving rapidly
  - Performance tools are a necessity!

Tradeoffs

- Improving the compiler:
  - Benefits lots of code
  - Expensive

- Improving the application:
  - Only helps one application
  - Cheap

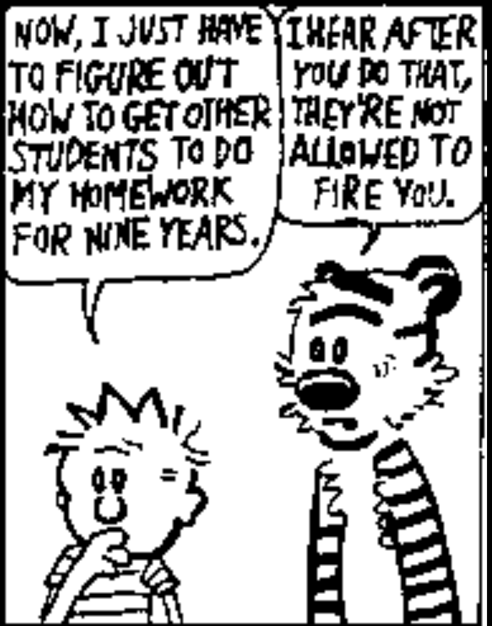
http://llvm.org/


Motivation, Goals,
Results, and Impact:
Academia

Motivation and Goals

- Motivation:
  - Contribution to the field
  - Graduate degree, Tenure, ...

- Goal:
  - Paper publication
  - Novel research contribution
  - Build towards large research goals
  - Future citations



Result and Impact

- Result:
  - "Our optimization speeds up SPECINT2000 by a geometric mean of 10% compared to our baseline"
  - New ideas and algorithms
  - Basis of future work

- Impact:
  - Achieved goal
  - Unclear impact on real-world code
  - Optimization never ships in production compiler


Motivation, Goals,
Results, and Impact:
Industry

Motivation and Goals

- Motivation:
  - "Video playback on widget X is stuttering!"
- Goal:
  - Video decoder runs 25% faster

Result and Impact

- Result:
  - 2%: improved modeling of subregister kill flags
  - 3%: form FMAs more aggressively with -ffast-math
  - 0%: add builtin for "sum of absolute differences"
  - 20%: source changes to video decoder

- Impact:
  - Achieved goal
  - Better video decoder code base
  - Modest compiler improvements:
    - Broad code benefits
    - Composes with future changes
  - Product ships on time

Heroic Optimizations

A random example

"[Our work] improves the performance of many programs from 5% to 20%, improves analyzer and llu-bench by **roughly 2X**, and ft and chomp **more than 10X**."

"Automatic Pool Allocation: Improving Performance by Controlling Data Structure Layout in the Heap"
Chris Lattner and Vikram Adve
PLDI 2005

What is a heroic optimization?

- Success leads to a dramatic performance effect
  - Failure implies no performance change or a loss

- Anything relying on heroic analysis:
  - Shape analysis transformations
  - Restructuring optimizations for cache
  - Auto-parallelization
  - Many SPEC hacks :-)

What's the problem?

- App performance swings wildly as code changes
  - Small changes to an app can "break" optimization
    - e.g. one new alias introduced
  - How does a developer predict or control this?

- Often unrealistic assumptions:
  - e.g. requires the "whole program"

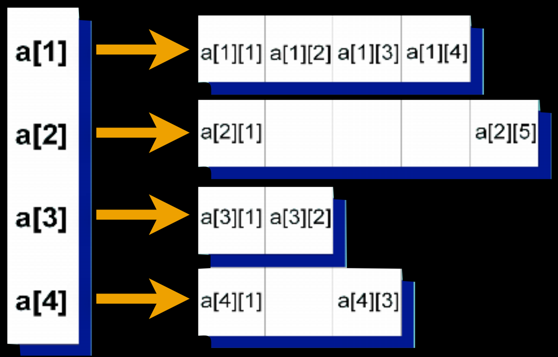
- Difficult to justify in production setting
  - Hard to qualify correctness
  - "Kicks in" in limited situations

When can it make sense?

- Code you can't (or don't want to) change
  - Benchmark hacks (aka Marketing :-)
  - Legacy code - e.g. dusty deck Fortran

- Optimizing common idioms
  - Pattern matching loops to memset/memcpy

- Overcoming source language limitations:
  - e.g. 1D arrays in Java



Solving the Transparency Problem

- Look to auto-vectorizers for inspiration:
  - Report what optimizations happened
  - Report why an expected optimization failed

- Hard problems:
  - Optimizations happen on IR, not source code
  - Some concepts are very abstract!

Better Programming Languages?

- Abstract away details, not algorithmic issues:
  - Good: register allocation, inst selection, scheduling
  - Bad: cache behavior, vectors vs scalars, parallelism
- Provide abstractions for architecture portability:
  - Allow reasoning about memory hierarchy
  - Allow expressing intentions of how code is run
- Need to verify that the “right thing” happens

What about Performance Tools?

- Explain how to restructure code for performance
  - Instead of automatically fixing it during compilation

- Benefits:
  - Communicate to the developer in terms of source code
  - Compile time doesn't matter for off-line tools
  - Less fragile as code evolves

- Challenges:
  - Need to reimplement most analyses
  - Source level is more complex than IR

Other Challenges

- Many people don't want to look at assembly
  - higher level way to reason about code execution?
  - still need to see what happens after optimization
- Distributed performance problems
  - Small slowdown, spread across the entire app
  - No hot spot, no obvious way to find the culprit
  - Extremely common in C++ and OO apps

Some Open Problems in LLVM

Instruction Selection for Vector Shuffles


```
shufflevector %V1, %V2, <i32 3, i32 7, i32 7, i32 4>
```

- Shuffles critical for OpenGL / CL and vectorization
  - Produce vector from two inputs
  - Allows “don’t care” elements in the result

Instruction Selection for Vector Shuffles


```
shufflevector %V1, %V2, <i32 3, i32 7, i32 7, i32 4>
```

PowerPC Altivec Example

```
li r8, lo16(LCPI0_0)
lis r7, ha16(LCPI0_0)
lvx v2, r7, r8
vperm v2, v4, v3, v2
```

Constant Pool Load

```
vmrglw v3, v3, v2
vmrglw v3, v3, v3
vsldoi v2, v3, v2, 4
```

Better: Three Shuffles

“Perfect” Shuffle

- Precomputed table of shuffles
  - 4 Elements: 9*9*9*9=6561 entries * 4 bytes = 26K
  - Code generator indexes into table to emit code

```
...
2297907567U, // <3,7,7,3>: Cost 3 vmrglw <2,6,3,7>, <3,2,7,3>
2637729078U, // <3,7,7,4>: Cost 3 vsldoi,4 <3,3,7,7>, V2
3371649312U, // <3,7,7,5>: Cost 4 vmrglw <2,6,3,7>, <3,1,7,5>
...
```

```
%result = vsldoi %tmp1, %V2, 4
```

```
%result = shuffle %V1, %V2, <3,7,7,4>
```

"Perfect" Shuffle

- Precomputed table of shuffles
  - 4 Elements: 9*9*9*9=6561 entries * 4 bytes = 26K
  - Code generator indexes into table to emit code

```
...
3371648548U, // <3,3,7,6>: Cost 4 vmrglw <2,6,3,7>, <2,1,3,6>
1224165306U, // <3,3,7,7>: Cost 2 vmrglw <2,6,3,7>, <2,6,3,7>
1224165306U, // <3,3,7,u>: Cost 2 vmrglw <2,6,3,7>, <2,6,3,7>
...
2297907567U, // <3,7,7,3>: Cost 3 vmrglw <2,6,3,7>, <3,2,7,3>
2637729078U, // <3,7,7,4>: Cost 3 vsldoi,4 <3,3,7,7>, V2
3371649312U, // <3,7,7,5>: Cost 4 vmrglw <2,6,3,7>, <3,1,7,5>
...
```

```
%tmp1 = vmrglw %tmp2, %tmp2
%result = vsldoi %tmp1, %V2, 4
```

```
%result = shuffle %V1, %V2, <3,7,7,4>
```

http://llvm.org/

"Perfect" Shuffle

- Precomputed table of shuffles
  - 4 Elements: 9*9*9*9=6561 entries * 4 bytes = 26K
  - Code generator indexes into table to emit code

```
...
1256575800U, // <2,6,3,6>: Cost 2 vmrglw V1, <6,6,6,6>
135056694U,  // <2,6,3,7>: Cost 1 vmrglw V1, V2
135056695U,  // <2,6,3,u>: Cost 1 vmrglw V1, V2
...
3371648548U, // <3,3,7,6>: Cost 4 vmrglw <2,6,3,7>, <2,1,3,6>
1224165306U, // <3,3,7,7>: Cost 2 vmrglw <2,6,3,7>, <2,6,3,7>
1224165306U, // <3,3,7,u>: Cost 2 vmrglw <2,6,3,7>, <2,6,3,7>
...
2297907567U, // <3,7,7,3>: Cost 3 vmrglw <2,6,3,7>, <3,2,7,3>
2637729078U, // <3,7,7,4>: Cost 3 vsldoi,4 <3,3,7,7>, V2
3371649312U, // <3,7,7,5>: Cost 4 vmrglw <2,6,3,7>, <3,1,7,5>
...
```

```
%tmp2 = vmrglw %V1, %V2
%tmp1 = vmrglw %tmp2, %tmp2
%result = vsldoi %tmp1, %V2, 4
```

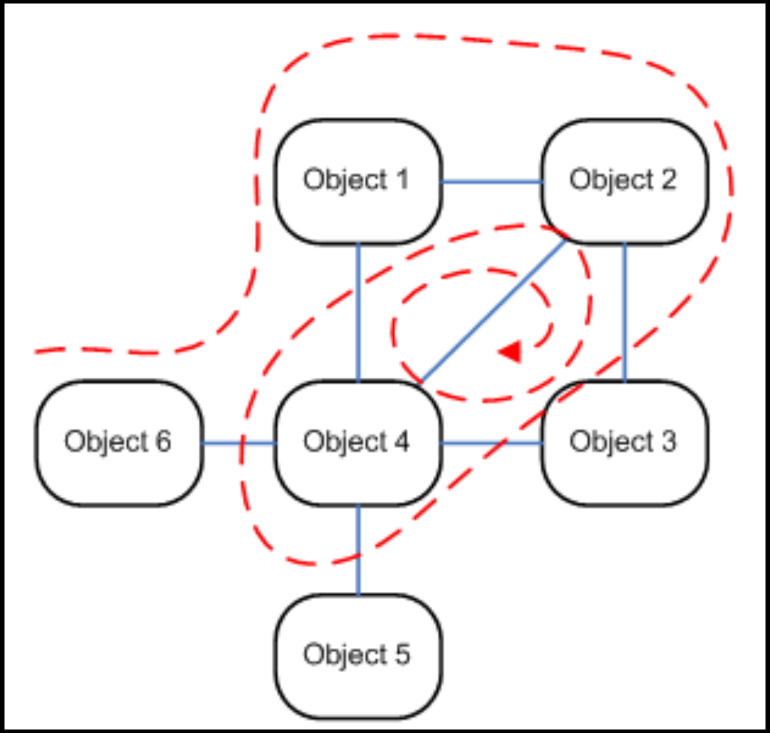
```
%result = shuffle %V1, %V2, <3,7,7,4>
```

Perfect Shuffle Problems

- More than 4 elements:
  - 8 Elements: 9^8 table entries = 172MB
  - 16 Elements: 9^{16} table entries = 1.8e15 entries
- X86 Code Generation:
  - One table per SSE level prohibitive
  - Some operations can fold memory loads
- End result:
  - A pile of heuristics and hacks

Interprocedural Alias/ModRef Analysis

- Obviously, a very well explored area
- Remains very difficult to **use** in practice



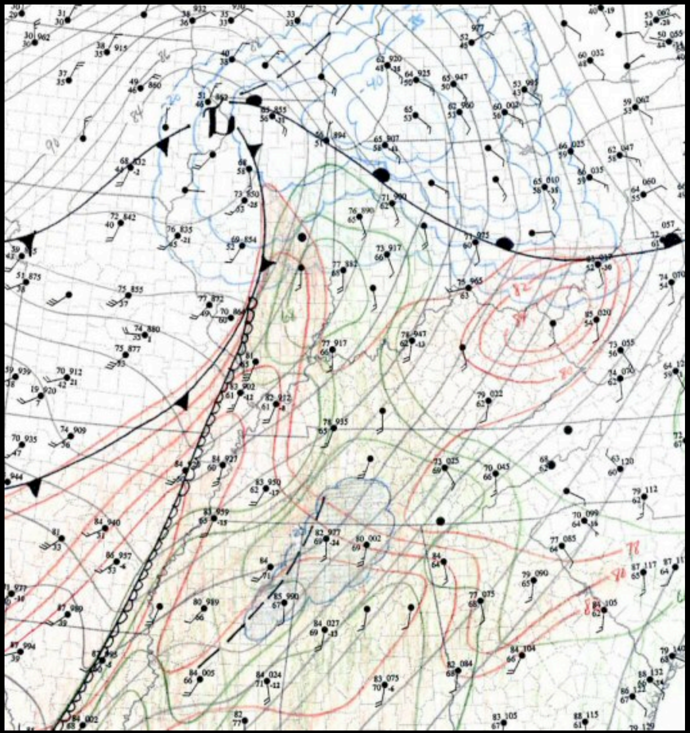
LLVM AA Challenges

- Don't want to recompute it for every optimization
  - Compute once early on, and update it
  - ... Optimizations must update Alias Analysis
- Want flexibility for different AA implementations
  - Allow easy experimentation
  - Willing to limit to flow-insensitivity

LLVM Alias Analysis Needs

- Really need an “Alias Analysis IR API”
  - Abstraction between clients and implementations
  - Must be efficient (no parallel data structures)

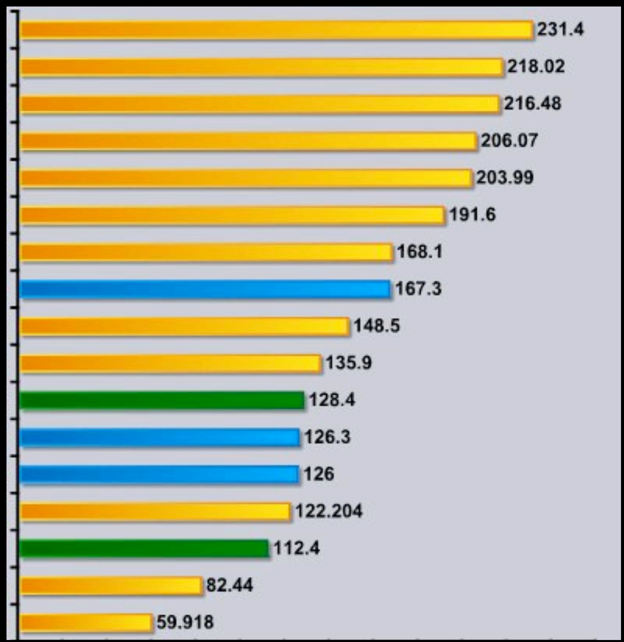
- Should support full generality:
  - Alias queries
  - Mod/Ref queries
  - Pointer capture analysis
  - Type-Based alias analysis



Some Suggestions & Comments

Reproducibility/Believability of Results

- Results vary widely with:
  - Target Architecture & Source Language
  - Compiler Infrastructure
  - Quality of Implementation
  - Benchmark set



http://llvm.org/

Reproducibility of Results: Wishlist

- Use a specific version of a **well known** compiler:
  - “LLVM 3.0”, “GCC 4.7”, ”GHC 7.4.1” ...
  - Avoids measuring artifacts of an immature foundation

- Measure, measure, measure:
  - Dynamic performance, static metrics
  - Code size, compile time

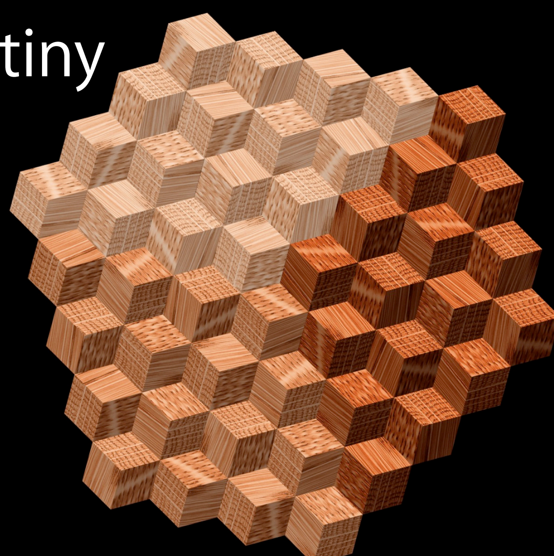
- Publish implementation and dataset:
  - github link in your paper!
  - No need for it to be production quality

Empirical Meta-Comparison Studies

- Solutions to important problems have:
  - multiple different algorithms
  - many implementation refinements
  - different tradeoffs (e.g. analysis time vs quality)

- Need more studies to *fairly* compare these:
  - ideally by third parties
  - code and dataset made available for scrutiny
  - as apples-to-apples as possible

- Obvious "citation bait"!



Use LLVM!

- LLVM advantages:
  - Well known, mature, and robust
  - Widely used in both industry and academia
  - Modular code base with modern design
  - Spans the entire toolchain:
    - assembler to compiler, runtime, and debugger

- Other advantages:
  - Great basis to measure and share reproducible results
  - Blog is a great platform to advertise **your** work
  - LLVM experience is very useful in the job market

http://llvm.org/

Wrap up

- Industry and Academia work differently
  - Different goals lead to different results

- Helping humans write better code is useful
  - Just as much as doing it automatically in a compiler

- LLVM is a fantastic foundation for research:
  - Mature, well known, widely used
  - Easy to work with and change
  - Lots of hard problems left!

http://llvm.org/