Adaptive Inlining

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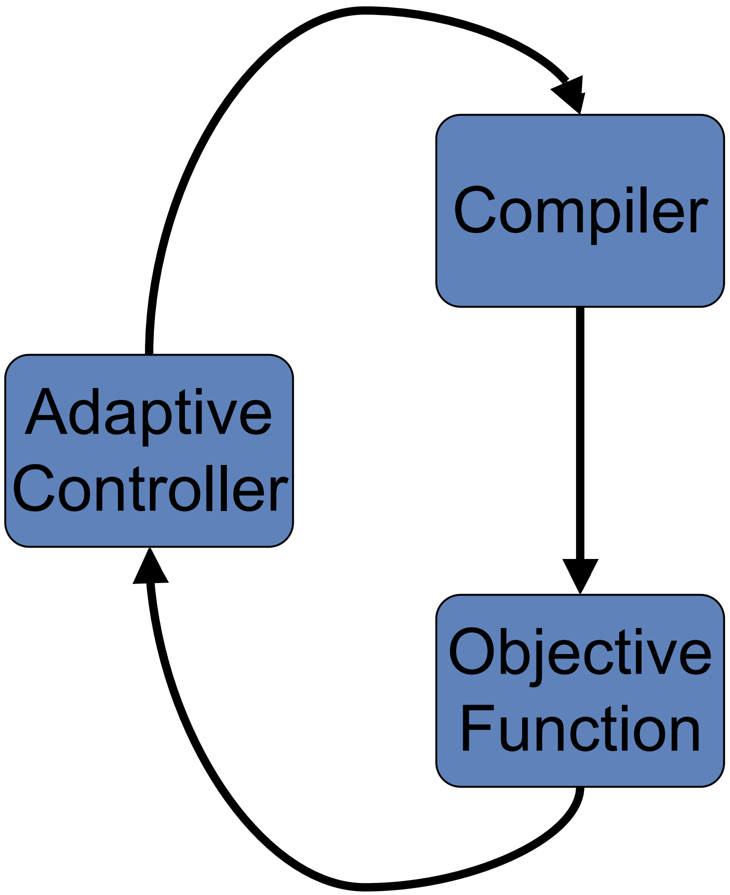
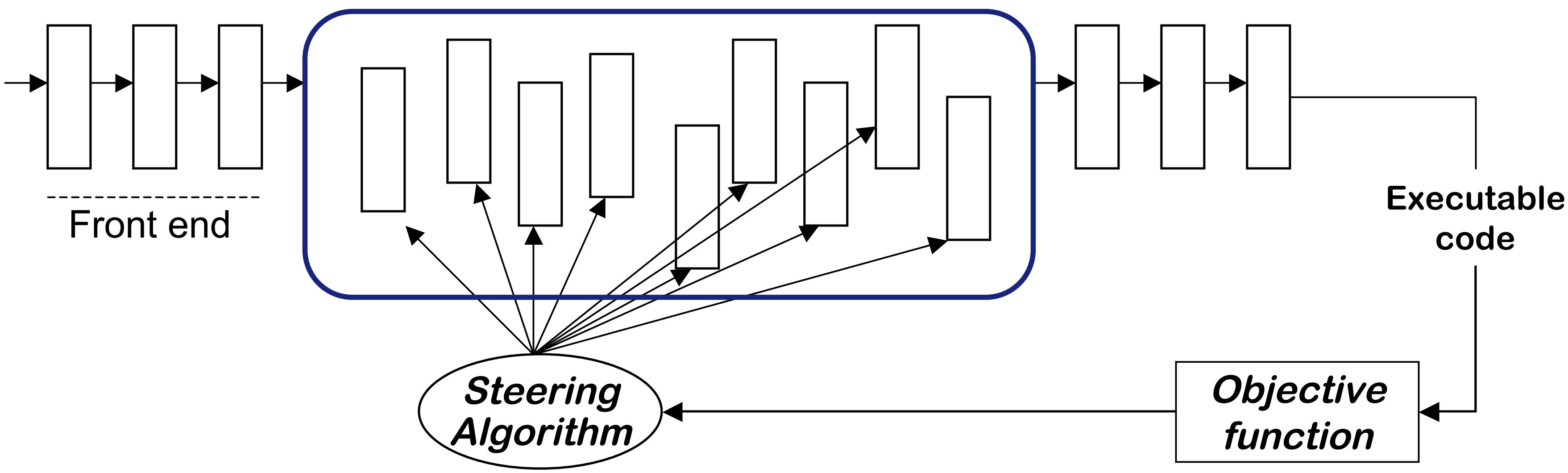
Adaptive Compilation

- Iterative process
  - Compile with initial set of decisions
  - Evaluate code
  - Use previous decisions and results to guide new decisions
  - Repeat until…



Prior Work on Adaptive Compilation

- Big focus on order of optimizations
  - Intermediate optimizations can be applied in any possible order
  - Historically, the compiler writer selects a single, universal sequence of optimizations
  - Different sequences perform better for different programs
  - Use adaptive techniques to find a good sequence for a specific program (LACSI '04)



Single-optimization adaptive techniques

- Can we use adaptive techniques to improve the performance of individual optimizations?
  - Need "flexible" optimizations
    - Expose a variety of decisions that impact the optimization's performance
    - Different sets of decisions work better for different programs
  - Need to understand how to explore the space of decisions
- We examine procedure inlining
  - A poorly understood, complex, problem
    - Many different approaches and heuristics have been used
    - Mixed success that varies by input program
    - Potential for major improvements

Procedure Inlining

- Procedure inlining replaces a call site with the body of the procedure
- Wide variety of effects
  - Eliminates call overhead
  - Increases program size
  - Enables other optimizations
  - Changes register allocations
  - Cache performance
- Decisions are not independent

```
int f() {
  int a = g(1);
  return a;
}

int g(x) {
  if (x == 0)
    return 0;
  else
    return x+1;
}
```

```
int f() {
  int a;
  if (1 == 0)
    a = 0;
  else
    a = 1 + 1;
  return a;
}

int g(x) {
  if (x == 0)
    return 0;
  else
    return x+1;
}
```

```
int f() {
  return 2;
}
```

Building the Inliner

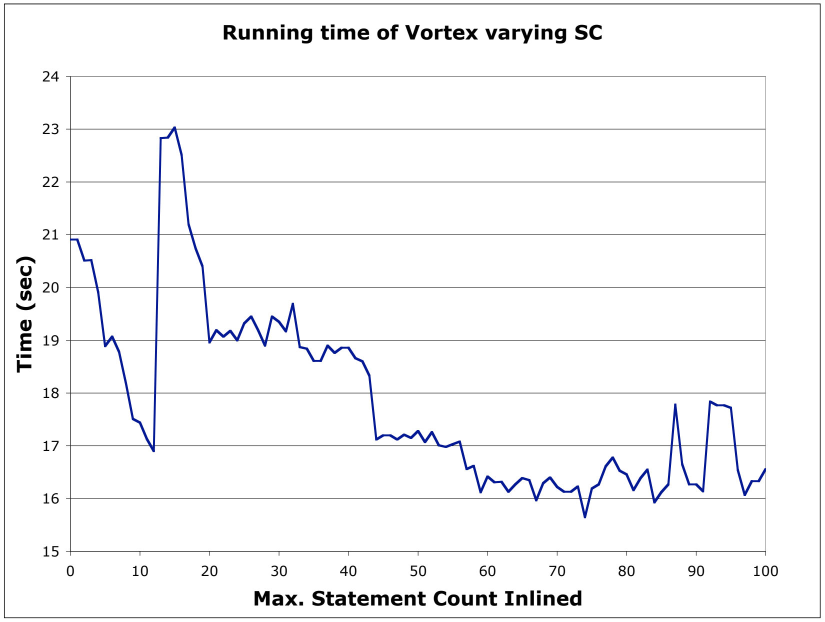
- Built on top of Davidson and Holler's INLINER tool
  - Source-to-source C inliner
  - Need to modernize for ANSI C
- Parameterize the inliner
  - Find parameters that can positively impact inlining decisions
  - Group parameters together in condition strings
    - Specified at the command line
    - Use CNF
    - Example: inliner -c "sc < 25 | lnd > 0, sc < 100" foo.c

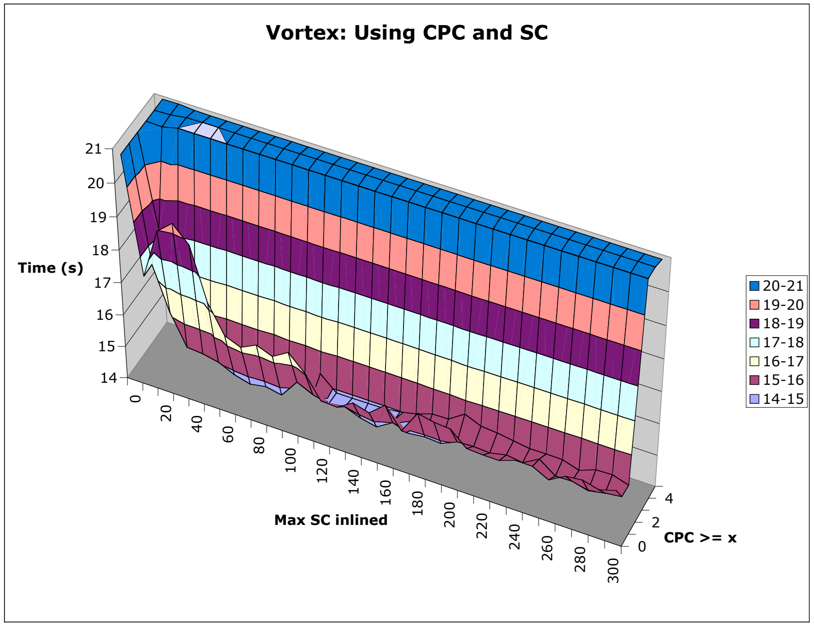
Condition String Properties

- Statement count
- Loop nesting depth
- Static call count
  - If the static call count is one, inlining can be performed without increasing the code size
- Constant parameter count
  - Used to estimate the potential for enhancing optimizations
- Calls in the procedure
  - Introduced as a method for finding leaf procedures
- Dynamic call count

Preliminary Searches

- Perform one and two dimensional sweeps of the space
  - Get an idea of what the space looks like
  - Determine which parameters have a positive impact on performance





Results of Preliminary Searches

- Provided insight into the value of certain parameters
  - Calls in a procedure (CLC) and constant parameter count (CPC) proved very effective
  - Parameter count (PC) had little effect
- A hill climber is a good method for exploring the space
  - Relatively smooth search space
  - Was effective for optimization ordering work
- Bad sets of inlining decisions are expensive
  - Example: "clc < 3" provides great performance for Vortex, "clc < 4" exhausts memory during compilation
  - Unavoidable to some extent

Constraining the Search Space

- Search space is immense
  - Many possible combinations of parameters
  - A large number of possible values for certain parameters
- Need to constrain the search space
  - Eliminate obviously poor sets of decisions
    - Often the most time consuming as well
  - Make the search algorithm more efficient
- Fix the form of the condition string:

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

  - Constrains the number of combinations and eliminates foolish possibilities
  - Still need to constrain the values of the individual parameters

Constraining Parameters

- Need reasonable minimum and maximum values
  - Easy case: parameters that have a limited range regardless of program (CPC & CLC)
  - Hard case: parameters that need to vary based on the program
    - General idea
      - minimum value: no inlining will occur from the parameter
      - maximum value: maximal amount of inlining
    - Statement count
      - Set minimum value to 0
      - Begin with a small value and increase until an unreasonable amount of inlining occurs for maximum value
    - Dynamic call count
      - Set maximum value to the highest observed DCC
      - Repeatedly decrease to find minimum value

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Constraining Parameters

- Need reasonable granularity for the range of parameters
  - Some parameters can have extremely large ranges
  - Linear distribution of values doesn't work well
    - Not uniform spaces
    - Want a smaller step value for smaller values
  - Purely quadratic has problems as well
    - Values too close at the low end
- Have a fixed number of ordinals for large ranges (20)
- Use quadratic equation with linear term to get value

Building the Hill Climber

- Each possible condition string is a point in the search space
  - Neighbors are strings with a single parameter increased or decreased by one ordinal (14 neighbors for each point)
- Hill climber descends to a local minimum
  - Examine neighbors until a better point is found and descend to that point
  - Evaluate points using a single execution of the code
    - Experiments show a single execution to be sufficient
  - Cutoff bad searches
- Perform multiple descents from random start points
- Try using limited patience
  - Only explore a percentage of the neighbors before giving up
  - Tradeoff the quality of a descent for the ability to perform more

Selection of Start Points

- Problem: Many possible start points are unsuitable
  - Massive amounts of inlining occur
  - Parameter bounds are designed to be individually reasonable but the combination can be unreasonable
- Solution: Limit start points to a subset of the total space
  - Require start points to have the property:

    $$p_a^2 + p_b^2 + \dots < (\text{max. ord})^2$$

  - Much more successful in finding start points
  - Creates tendancy to go from less inlinining to more inlining
    - Faster searches
    - Prioritizes solutions with less code growth

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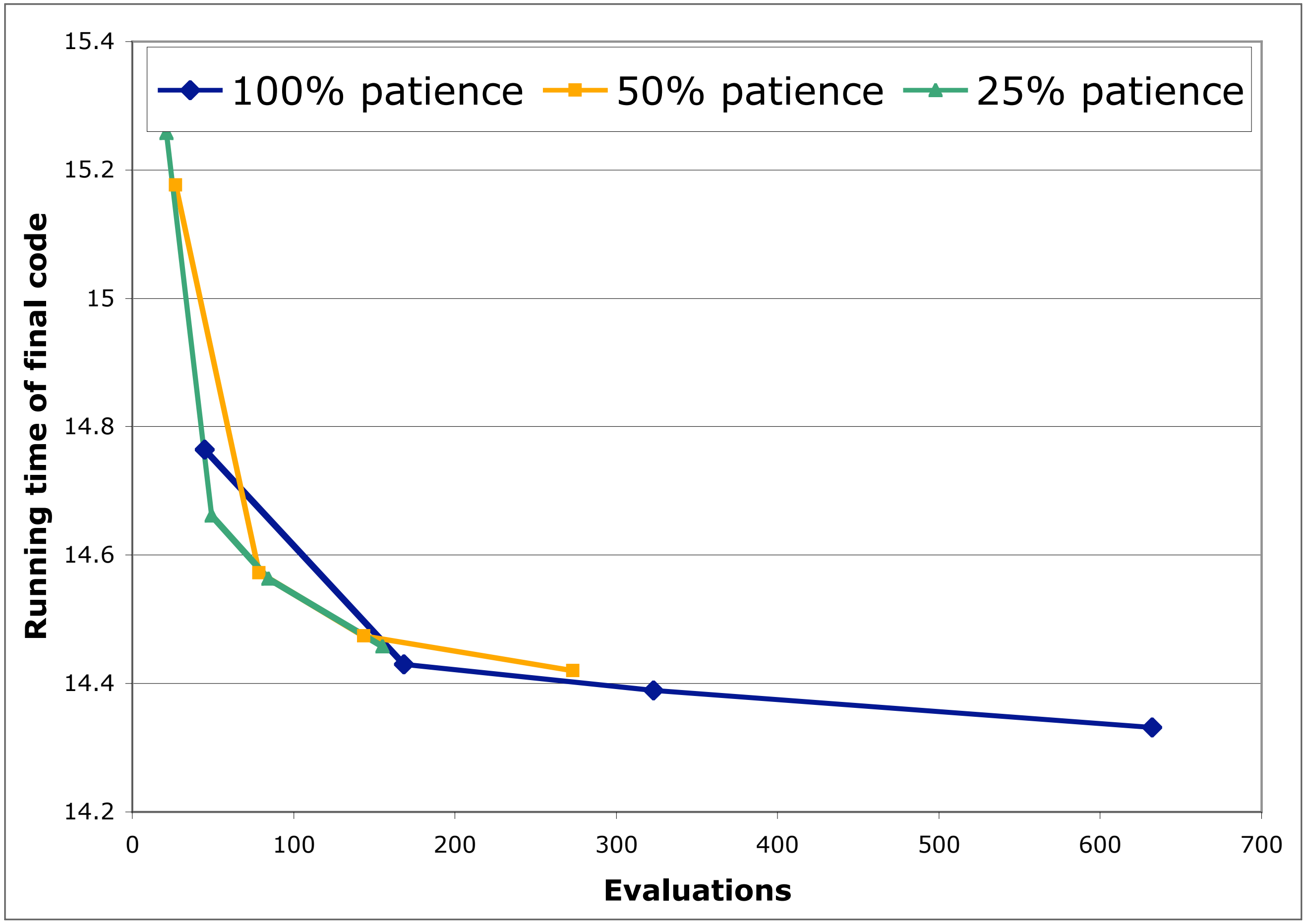
Experimental Setup

- Used a 1 GHz G4 PowerMac
  - Running OS X server
  - 256kB L2 cache, 2MB L3 cache
- Tested using several SpecINT C benchmarks
  - Vortex - object oriented database program
  - Bzip2, Gzip - compression programs
  - Parser - recursive descent parser
  - Mcf - vehicle scheduling

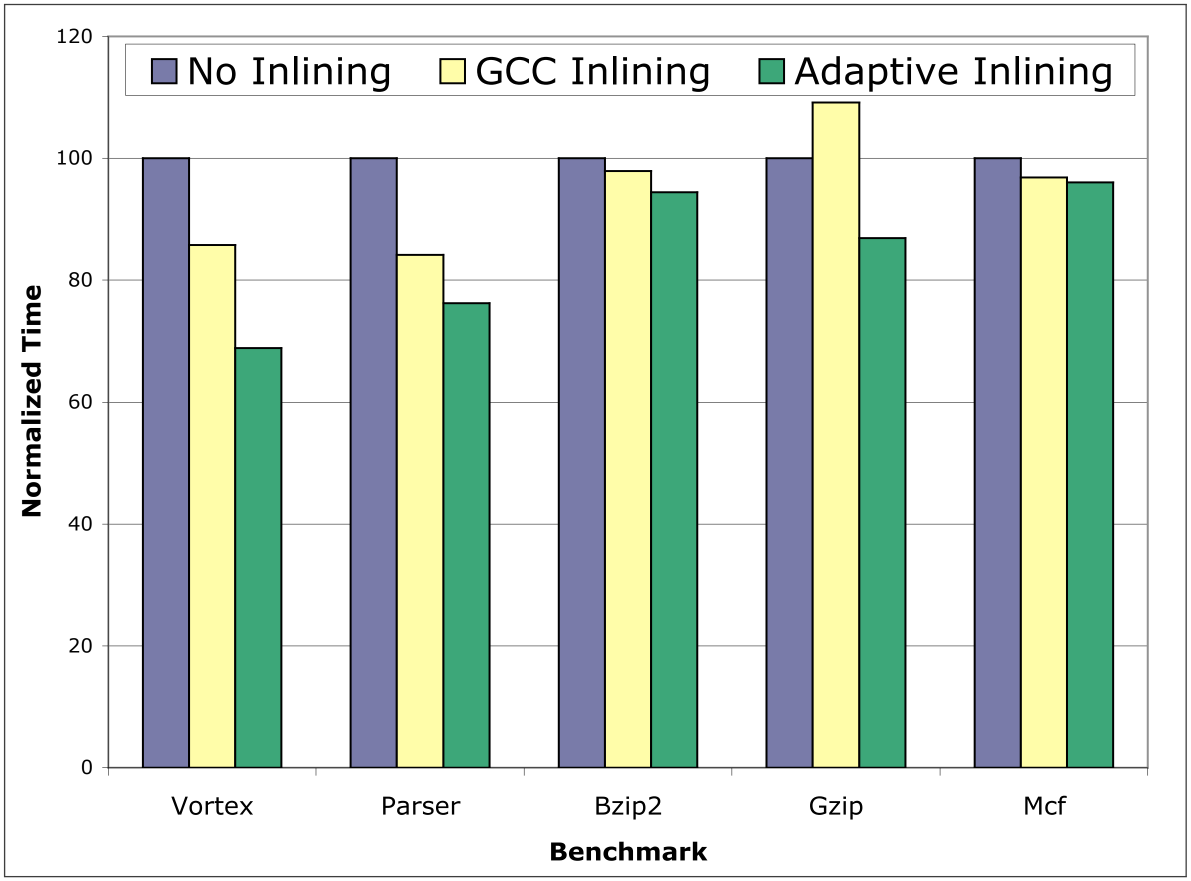
Changing Patience

- **Comparison using HC with varying levels of patience on Vortex**



Normalized Execution Time

- ***Comparison of HC with 5-descents and 100% patience against no inlining and the GCC inliner***



Descents Chosen

- Percentage each neighbor was chosen when a downward step was found by the hill climber

Step	Vortex	Parser	Bzip2	Gzip	Mcf
SC Increased	7.88%	11.17%	15.74%	16.56%	9.30%
SC Decreased	9.07%	19.68%	21.30%	15.95%	22.10%
Loop SC Increased	8.11%	10.64%	0.93%	2.45%	1.16%
Loop SC Decreased	8.35%	8.51%	1.85%	5.52%	3.49%
SCC SC Increased	13.60%	10.11%	23.15%	6.75%	20.93%
SCC SC Decreased	5.25%	8.51%	12.04%	7.36%	34.88%
CLC Increased	3.82%	4.26%	8.33%	6.13%	2.33%
CLC Decreased	3.82%	2.12%	2.78%	0.61%	2.33%
CPC Increased	3.58%	5.32%	2.78%	6.13%	2.33%
CPC Decreased	4.06%	1.59%	4.63%	14.72%	1.16%
CPC SC Increased	6.44%	3.19%	0.00%	4.91%	0.00%
CPC SC Decreased	3.34%	0.53%	0.00%	2.45%	0.00%
DCC Increased	18.85%	4.26%	1.85%	0.61%	0.00%
DCC Decreased	3.82%	10.11%	4.63%	9.82%	0.00%

Conclusions

- Adaptive Inlining
  - Gets consistent improvement across programs
    - Magnitude limited by opportunity
  - Static techniques cannot compete
    - Results suggest against a universal static solution
- Adaptive Compilation
  - Design the optimization to expose opportunity for adaptivity
  - Understand the search space
  - Build the adaptive system accordingly