IMPROVING PROGRAMS THROUGH SOURCE CODE TRANSFORMATIONS

Dissertation Proposal

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Beyond Functional Correctness

- Software development involves ***tradeoffs***.
  - “Fast, good, or cheap. Pick any two.”
  - Time vs. memory.
  - Maintainability vs. efficiency.
  - …


OPTIONS
LB
CAMERA
CONTROLS
VIDEO
AUDIO
MISC
RB
WINDOW SETTINGS
RESOLUTION
1920 x 1080 16:9
WINDOWMODE
Fullscreen
VERTICAL SYNC
APPLY
BASIC SETTINGS
ANTI ALIAS
FXAA High
RENDER QUALITY
High Quality
RENDER DETAIL
Custom
SAFE ZONE RATIO
1.00
ADVANCED SETTINGS
TEXTURE DETAIL
High Quality
WORLD DETAIL
High Quality
HIGH QUALITY SHADERS
AMBIENT OCCLUSION
DEPTH OF FIELD
BLOOM
LIGHT SHAFTS
LENS FLARES
DYNAMIC SHADOWS
MOTION BLUR
WEATHER EFFECTS


LEAGUE of LEGENDS

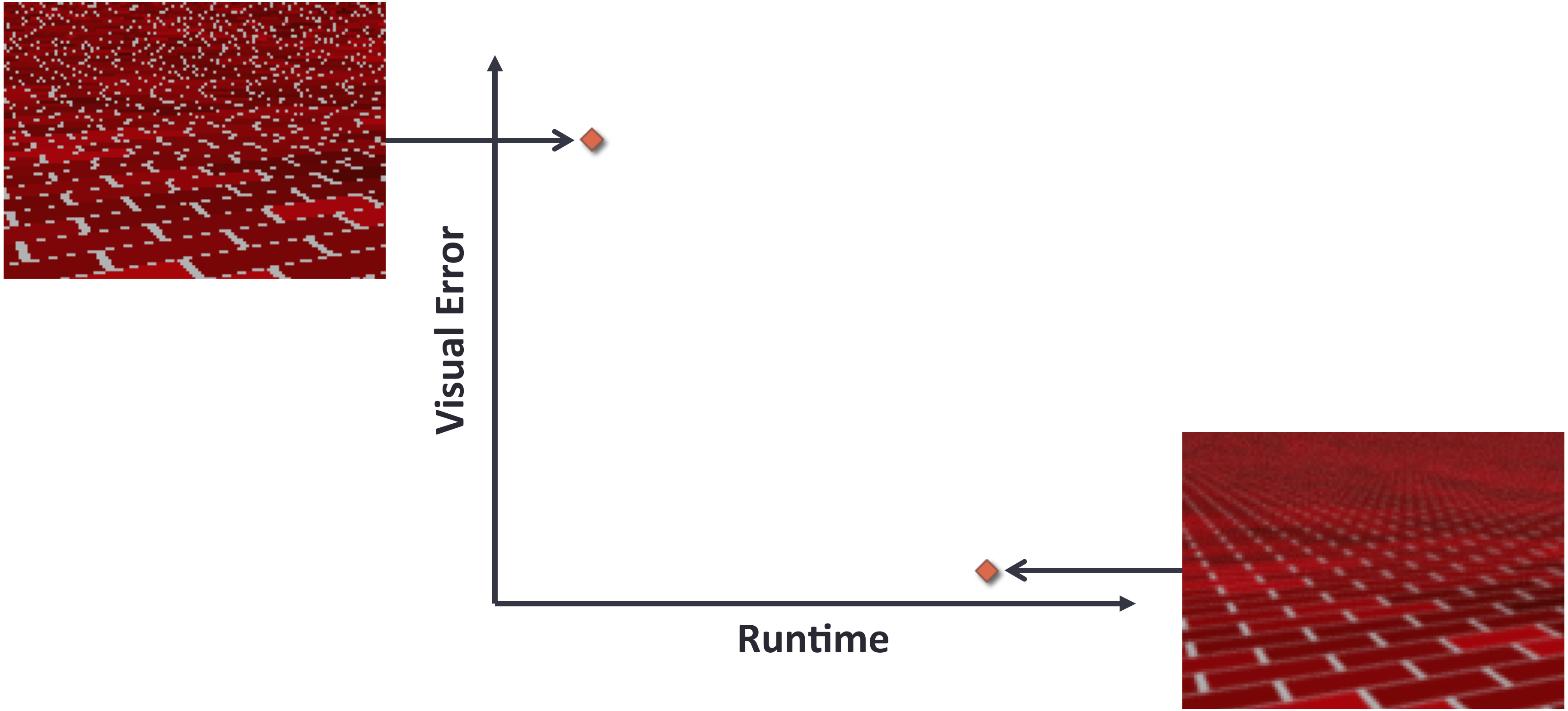

LEAGUE of LEGENDS

```c
float Q_rsqrt( float number )
{
	long i;
	float x2, y;
	const float threehalfs = 1.5F;

	x2 = number * 0.5F;
	y  = number;
	i  = * ( long * ) &y;                       // evil floating point bit level hacking
	i  = 0x5f3759df - ( i >> 1 );               // what the ?
	y  = * ( float * ) &i;
	y  = y * ( threehalfs - ( x2 * y * y ) );   // 1st iteration
//	y  = y * ( threehalfs - ( x2 * y * y ) );   // 2nd iteration, this can be removed

#ifndef Q3_VM
#ifdef __linux__
	assert( !isnan(y) ); // bk010122 - FPE?
#endif
#endif
	return y;
}
```

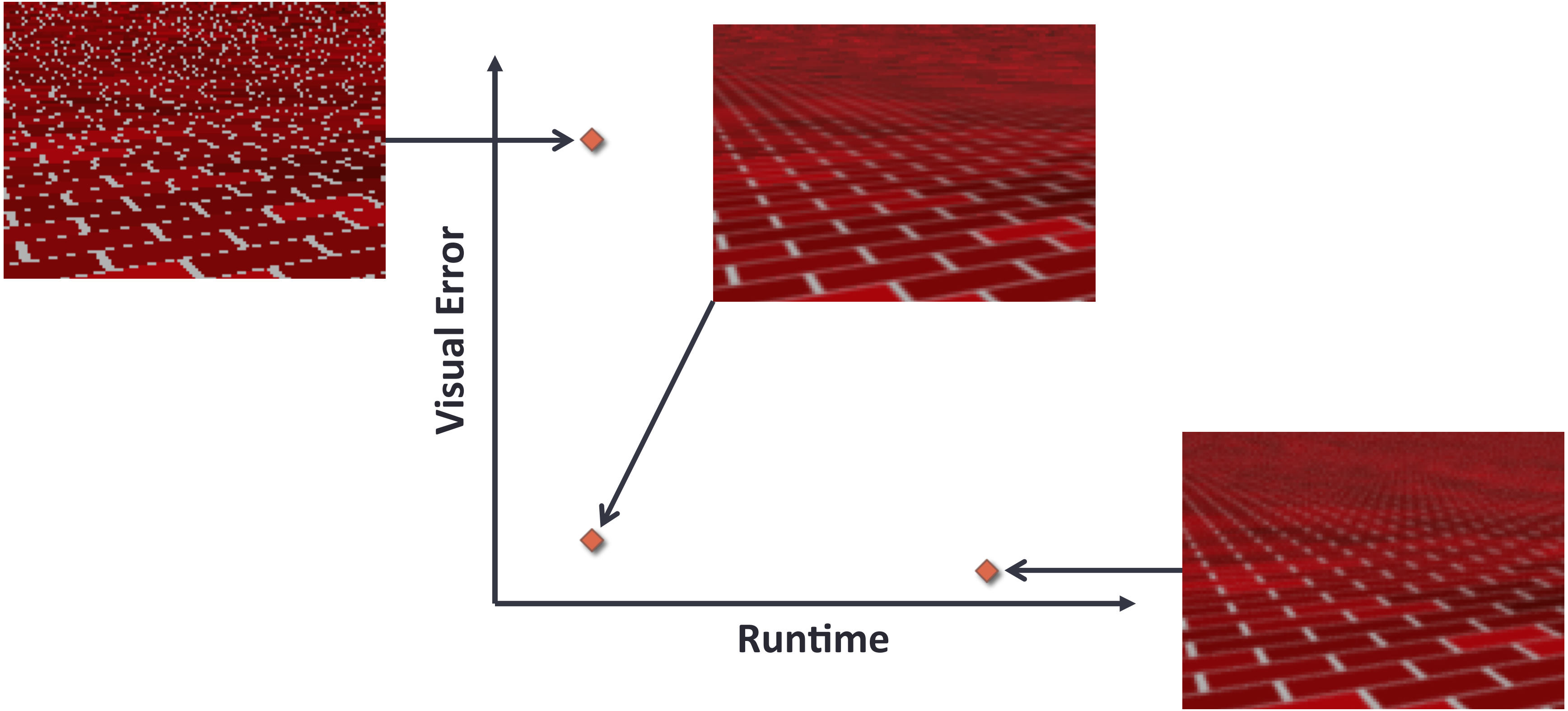
Non-Functional Properties

- “***How good***” instead of “***what***” [Paech 2004].
  - “More” or “less;” “higher” or “lower.”
- Difficult to reason about (e.g., security).
- Characterize implementations by how much of a property they possess.

Non-Functional Tradeoffs



Non-Functional Tradeoffs



Quantifying Non-Functionality

- Different metrics for different properties.
  - **Image quality**: RGB distance (e.g., L^2), SSIM, EMD.
  - **Runtime**: seconds, speedup/slowdown.
  - **Energy efficiency**: joules, watts.
  - **Maintainability**: bug fix time, defect density.
  - **Correctness**: % error, accuracy, precision, PSNR.

Local Changes

- ***Small*** changes can have ***large*** effects.
  - E.g., `bubble_sort(a)` → `quick_sort(a)`.
- Option of ***fine-grained*** control.
- Program lines, statements, AST nodes.

Proposal Thesis

By applying ***local software transformations***, we can select better tradeoffs between ***non-functional properties*** of existing software artifacts.

The rest of this proposal

- Overview of the proposed research thrusts
  - Visual error and runtime performance
  - Energy usage
  - Coding style
- Proposed research timeline
- Conclusion

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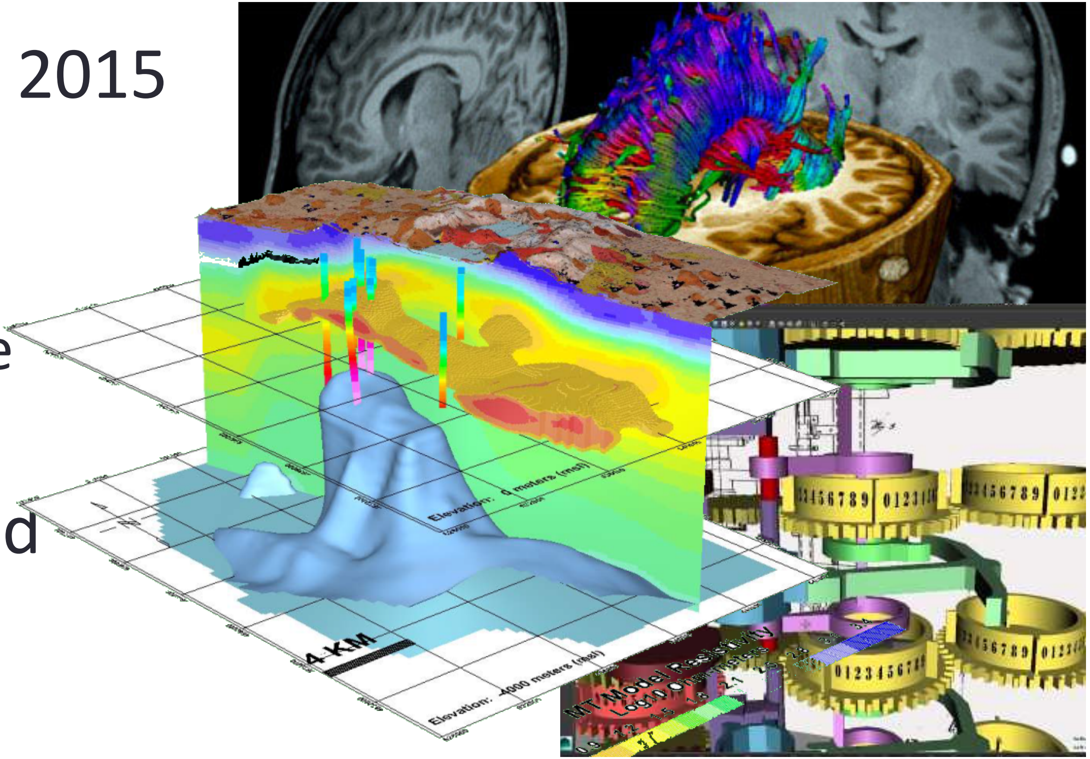
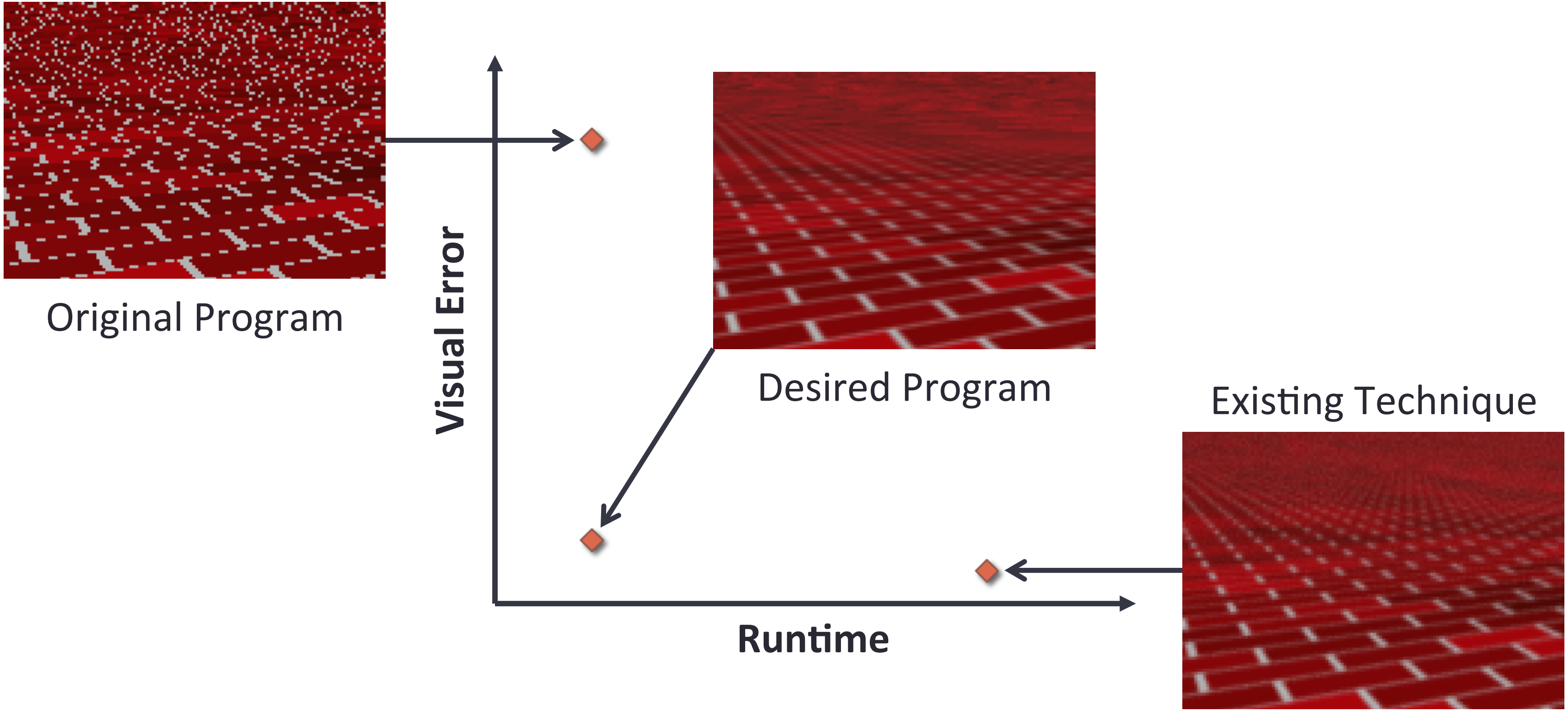
Computer Generated Imagery

- 11% of all tickets in 2015 went to computer animated movies.*
  - Does not include live movies with CGI.
- Video games topped $90B in 2015.**



* http://www.boxofficemojo.com/
** http://www.gamesindustry.biz/articles/2015-04-22-gaming-will-hit-usd91-5-billion-this-year-newzoo

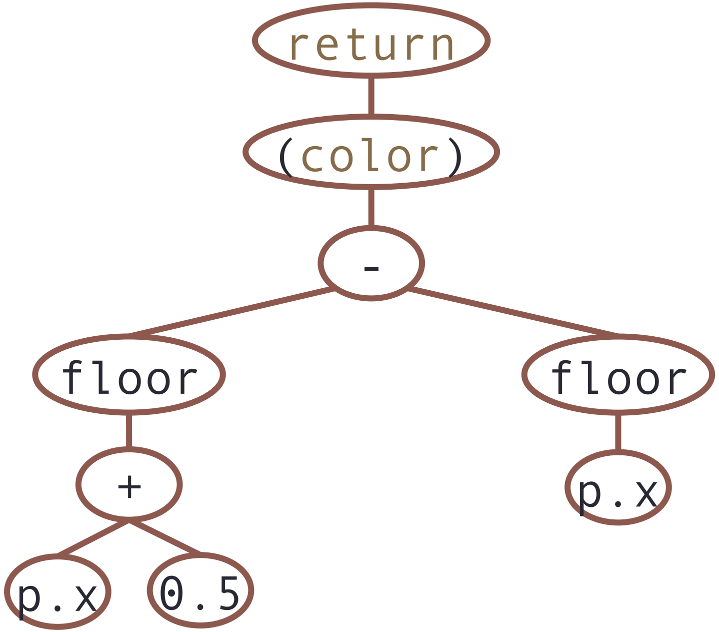
Visual Error and Runtime Performance

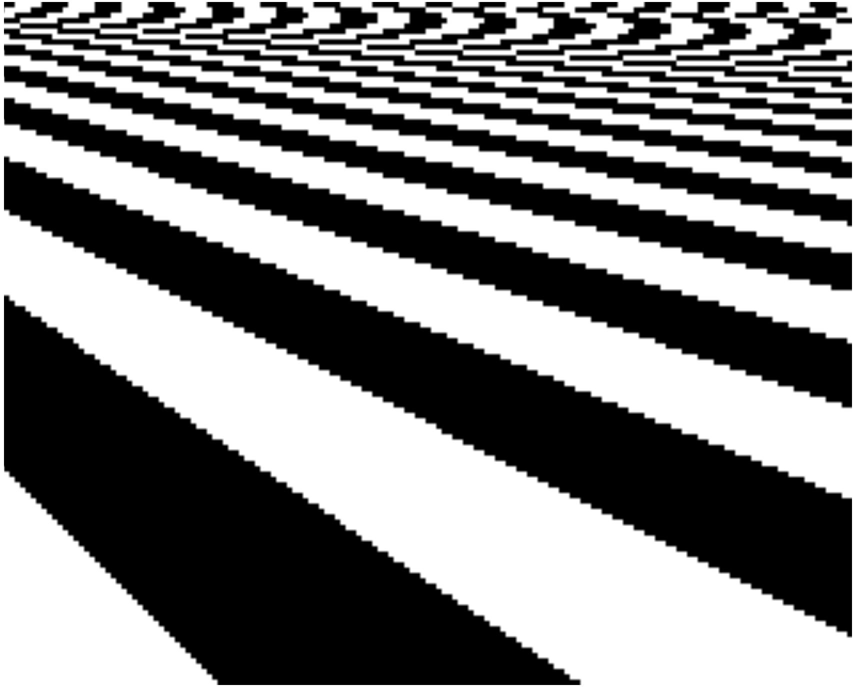


Hypothesis

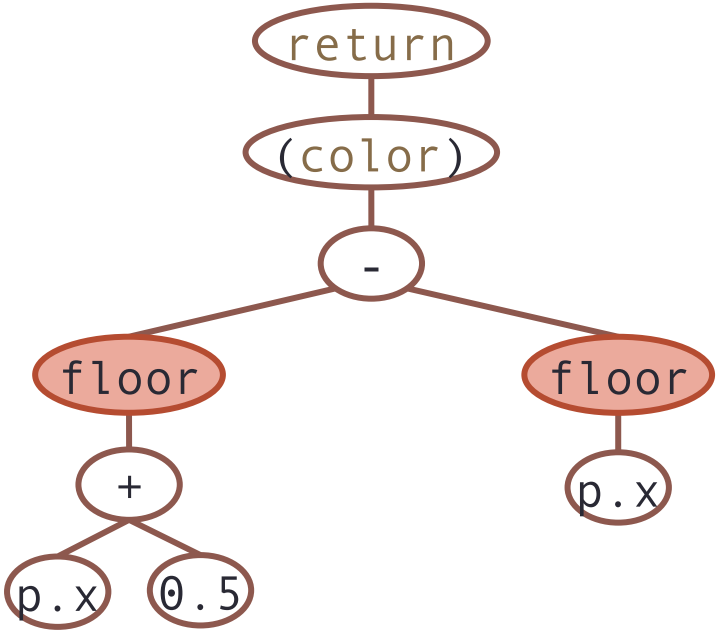
- We can apply local changes to the abstract syntax tree of a graphics program to produce an approximation that is:
  - ***Visually faithful*** to the original and
  - ***Efficient*** to compute.
- Evaluate both image quality and runtime.

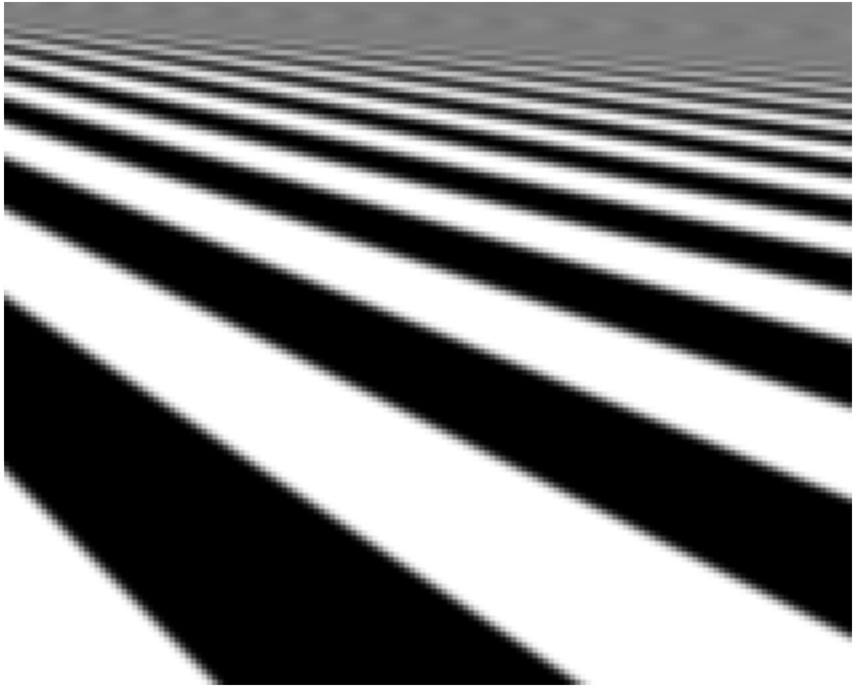
Simple Example





Simple Example





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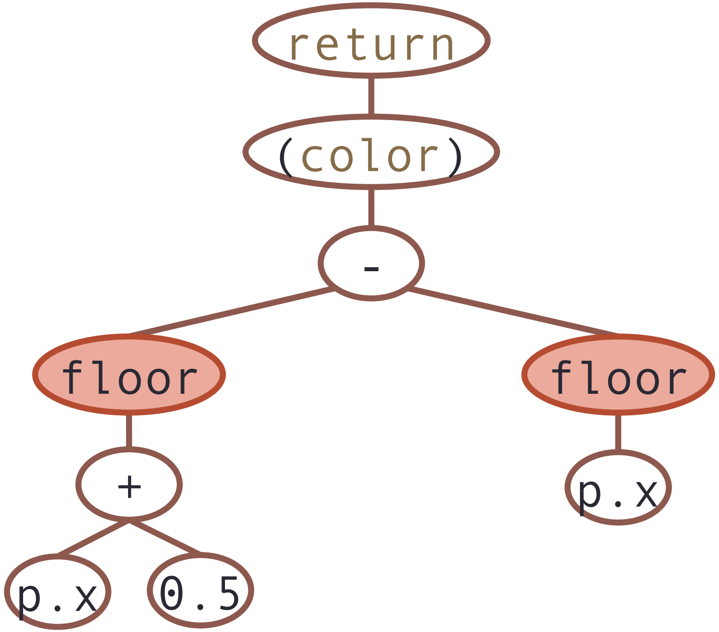
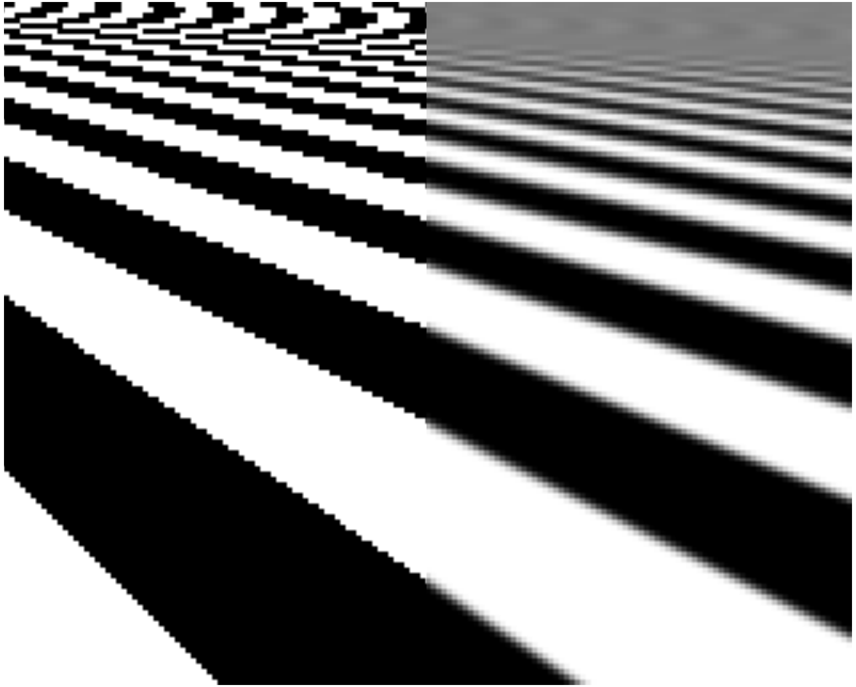


Before After



Approach

- Transformation: Replace node N with N’.
- Determine replacements offline (manual).
- Genetic search to select nodes to replace.
  - Use image quality as fitness function.

Experimental Setup

- Benchmarks chosen from previous work.
- Record ***runtime*** and ***image quality***.
- Three data points for each benchmark:
  1. Original program.
  2. Baseline "slower but less error" approach.
  3. Best transformed variant from our search.

Runtime Results

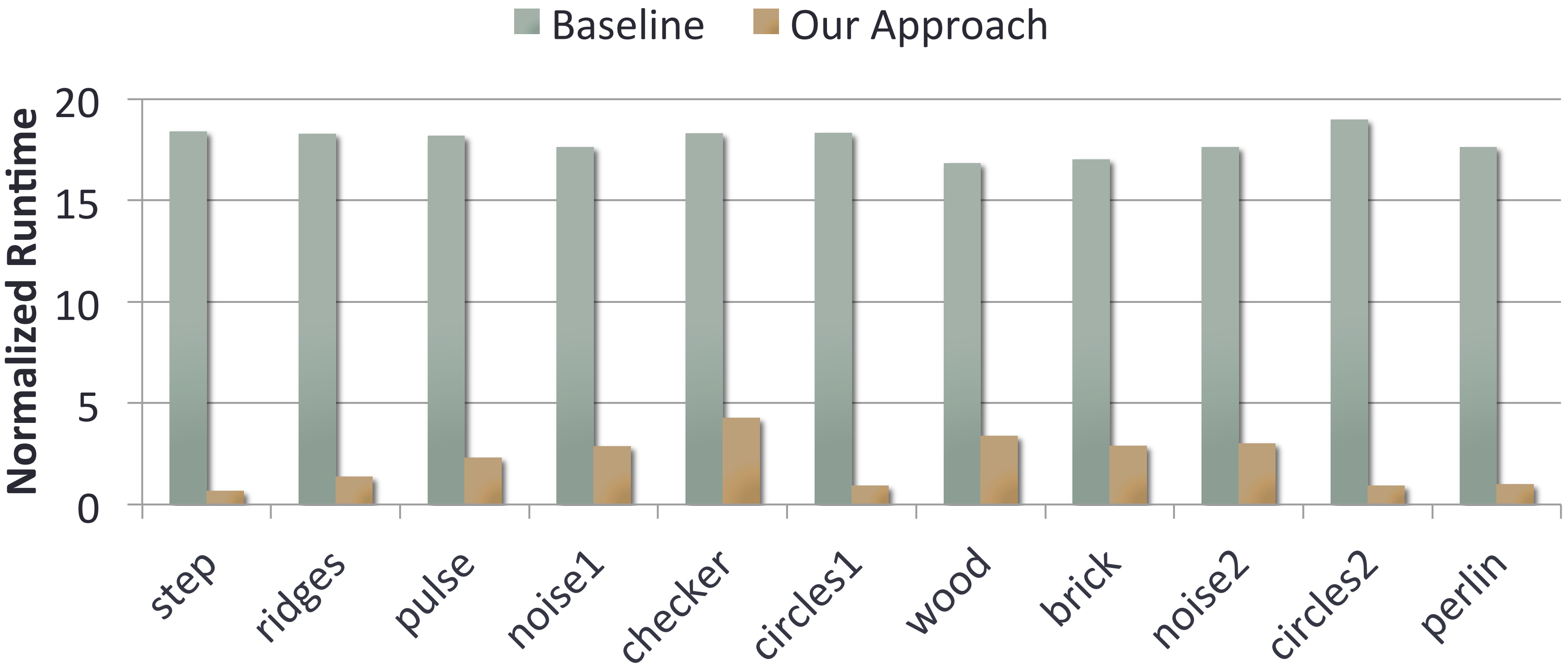
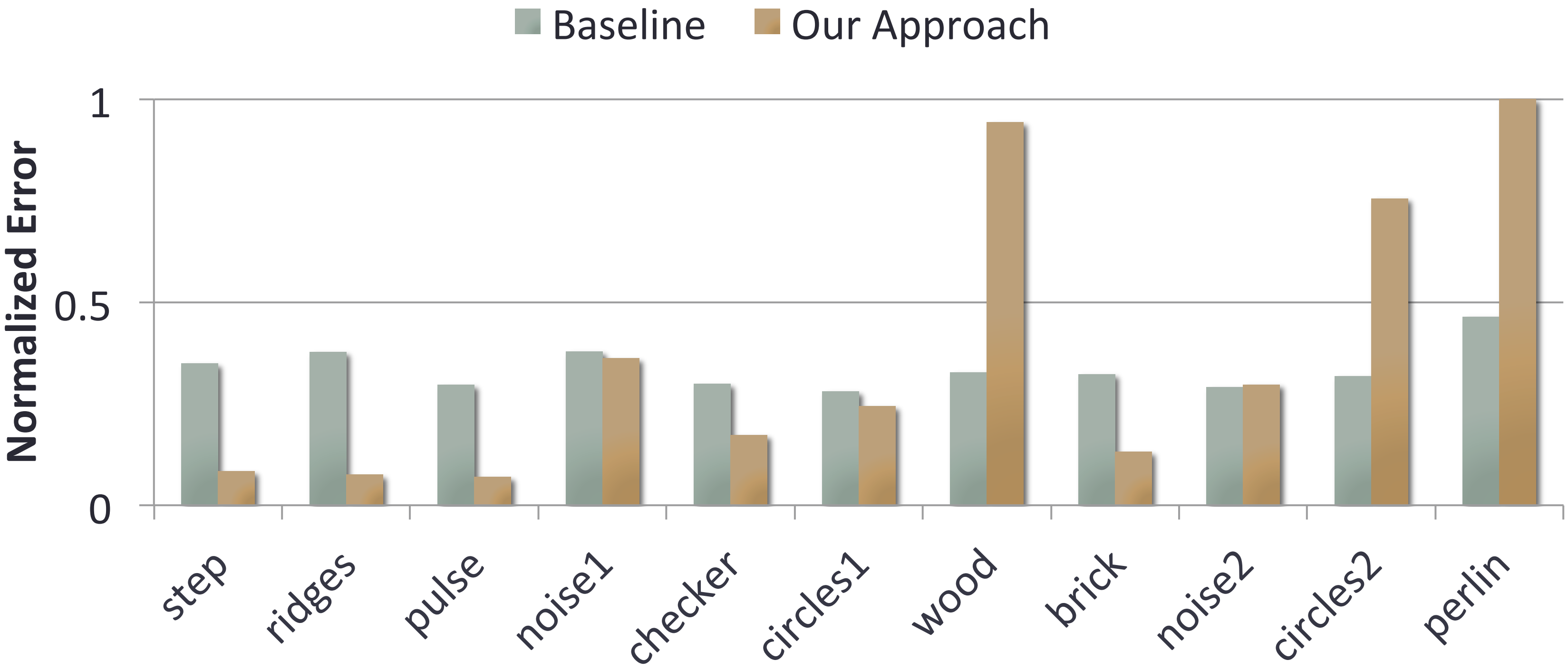


Image Quality Results



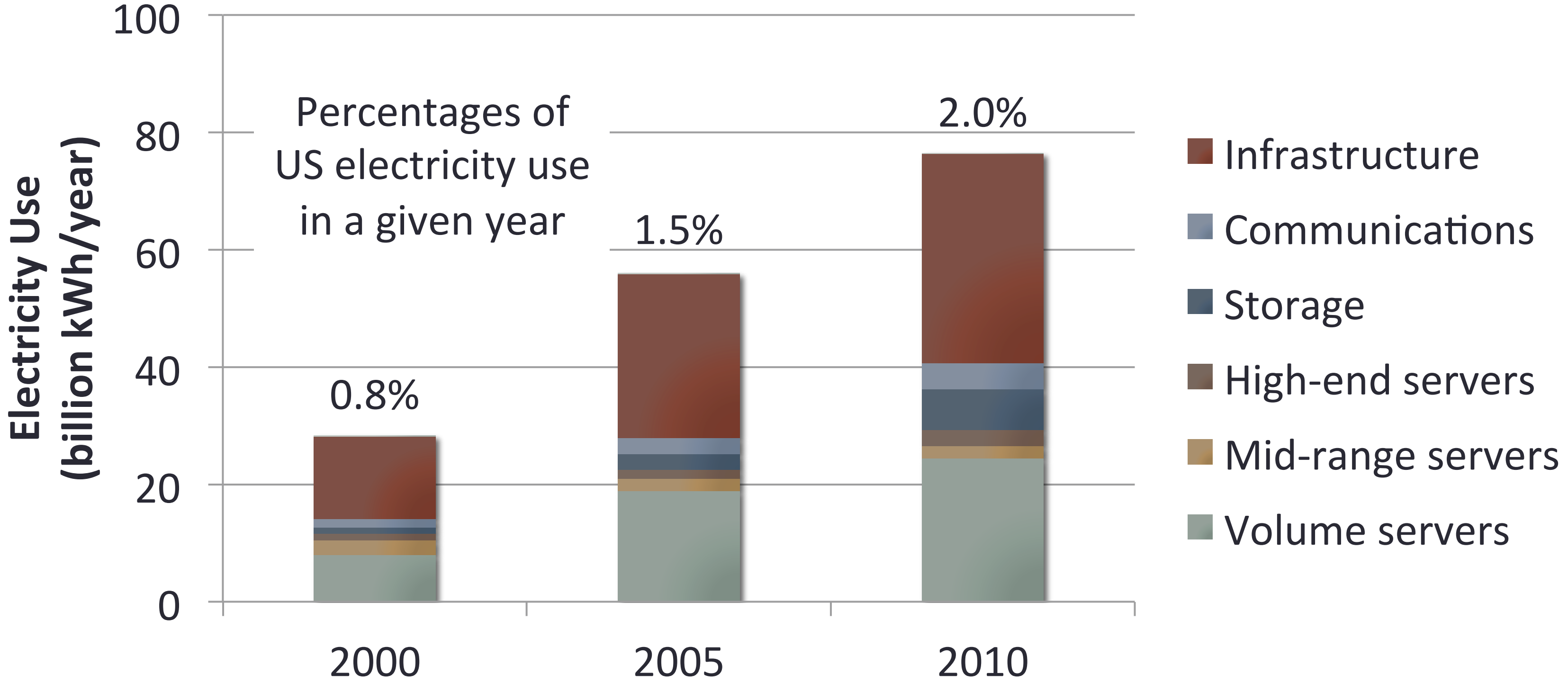
Summary

- We can apply local changes to produce programs that:
  - Are significantly ***faster*** than the baseline approach,
  - Have ***less error*** than the original program, and
  - Often have ***less error*** than the baseline.

Outline

- Overview of the proposed research thrusts
  - Visual error and runtime performance
  - Energy usage
  - Coding style
- Proposed research timeline
- Conclusion

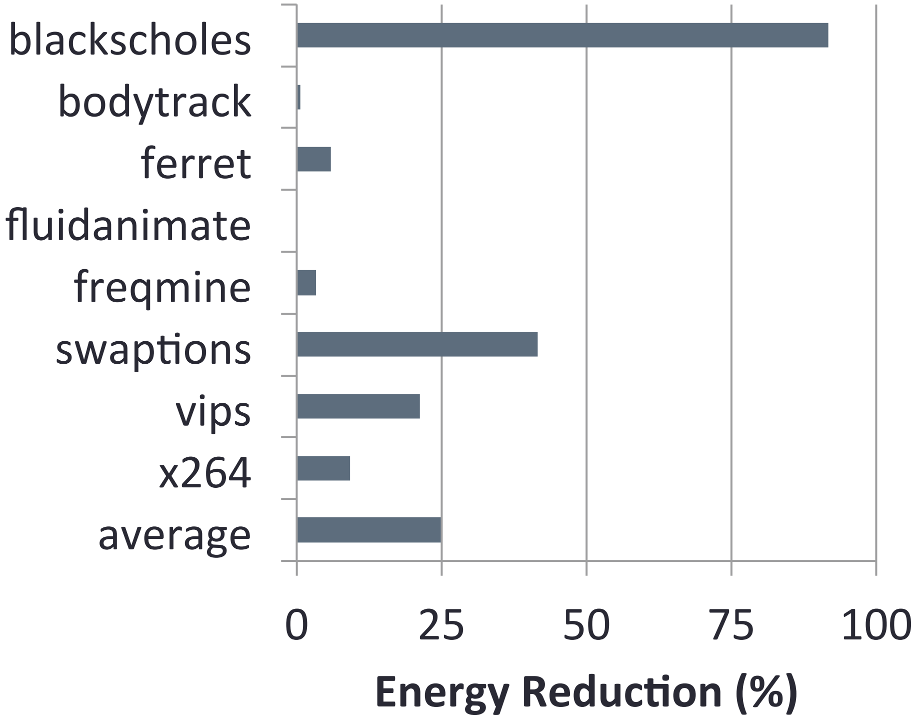
Data Center Energy Use



Reproduced from J. Koomey. *Growth in data center electricity use 2005 to 2010*. Analytics Press, Oakland, CA, 2011.

Genetic Optimization Algorithm

- Local changes to assembly code.
- Tradeoff between ***reduced energy*** and ***relaxed semantics***.
  - Validated with test suite.



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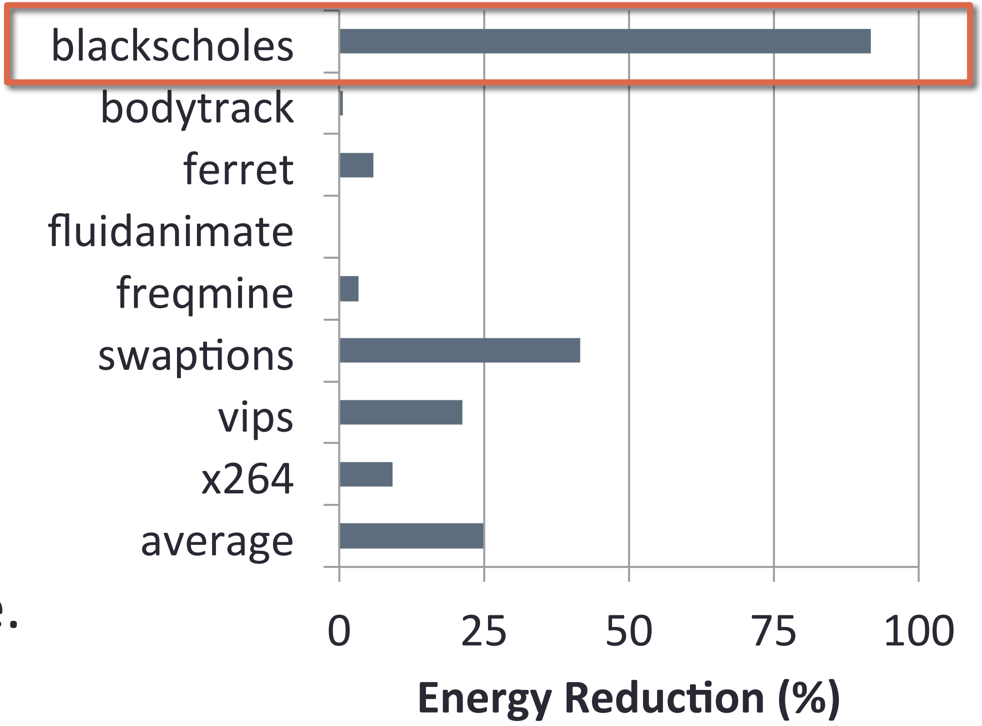
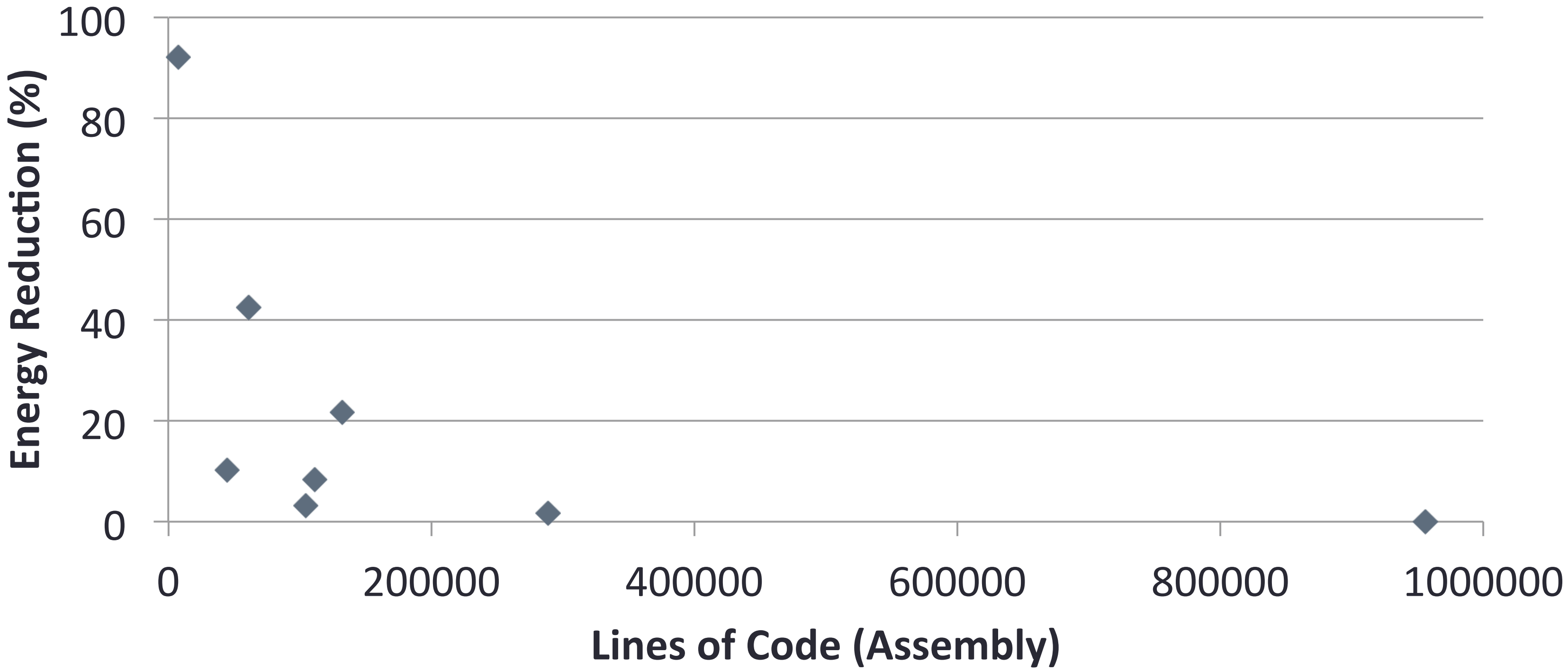


Scaling to Larger Programs



Hypothesis

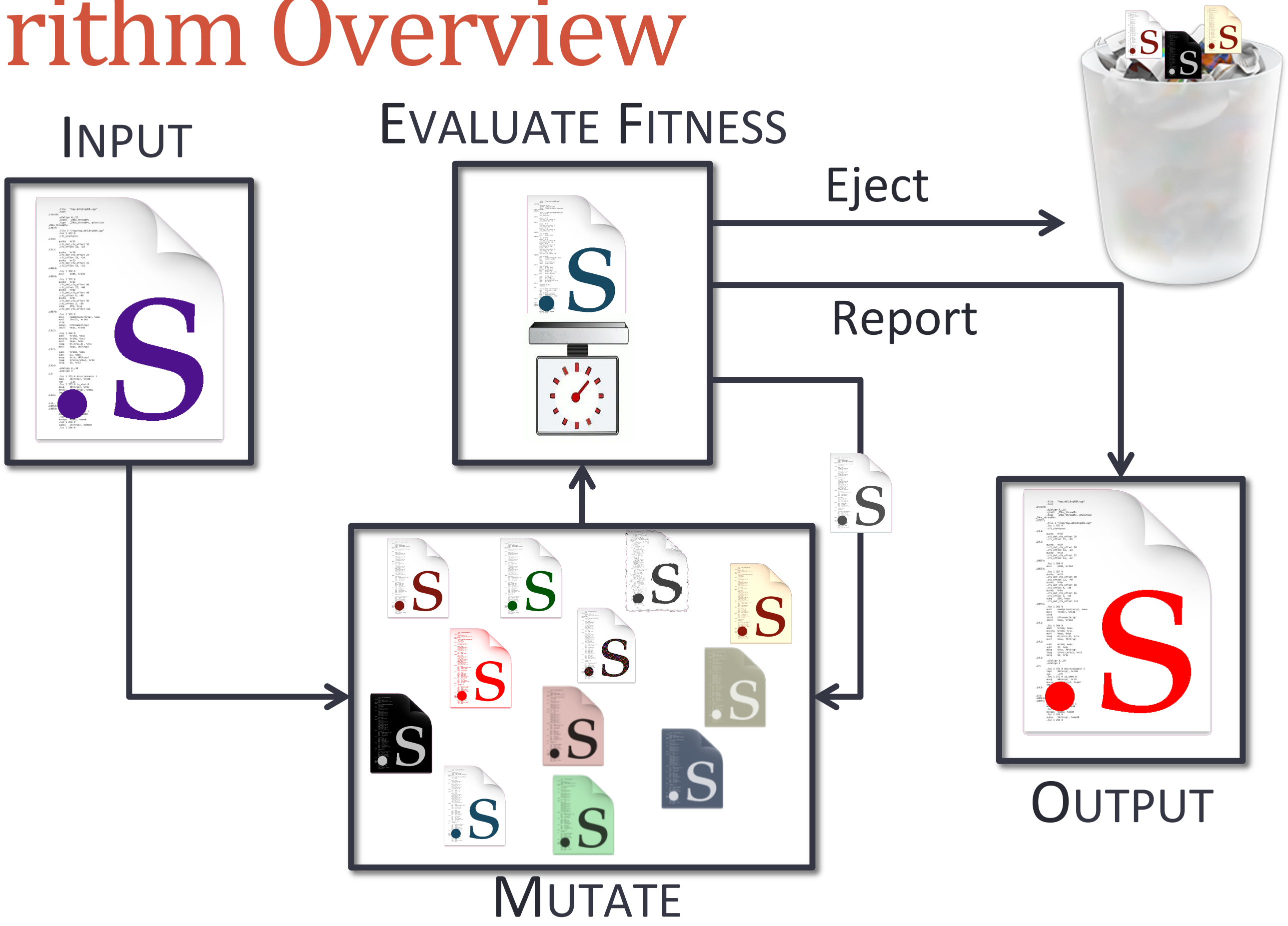
By directing the genetic search more effectively and ***reducing*** the search space, we can achieve ***larger*** energy optimizations ***faster***.

Evaluate both magnitude of optimization and search time.

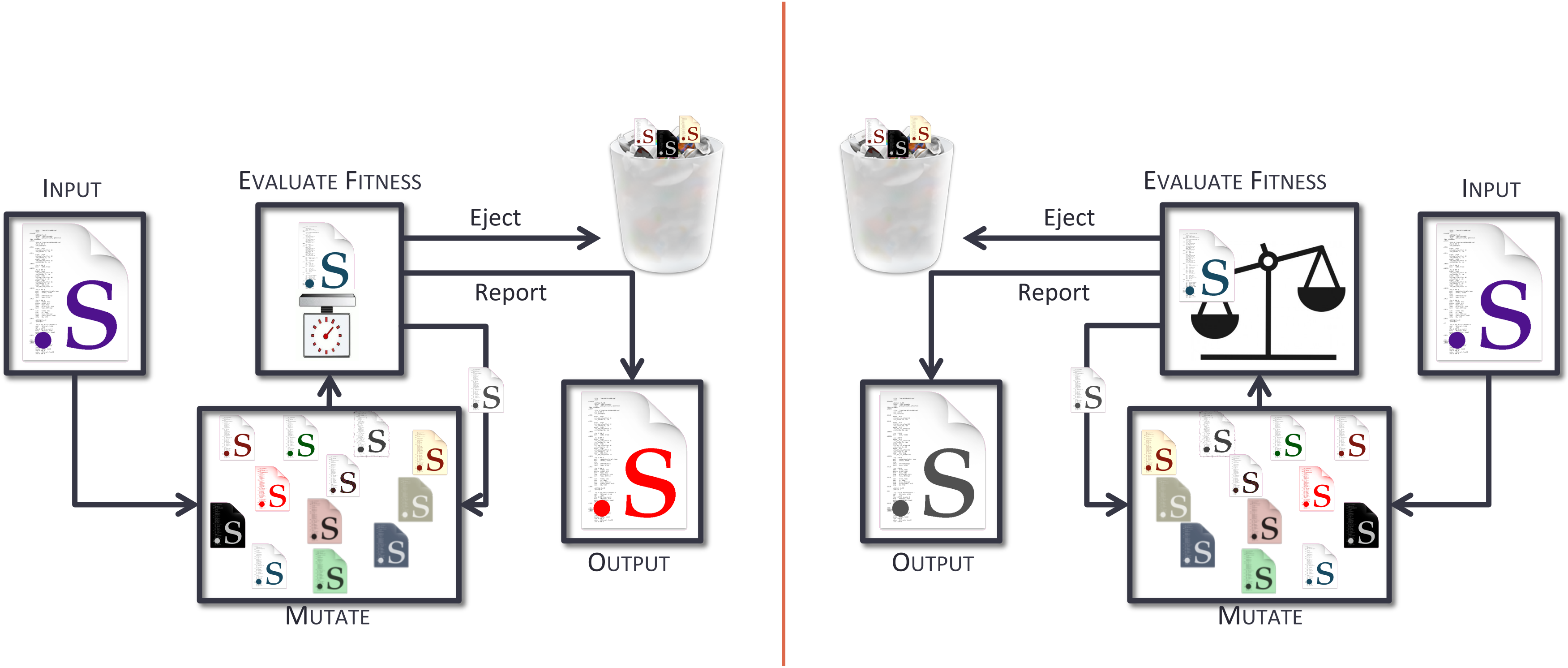
Intuition

- Optimizations on different paths through the program are likely to be independent.
  - ***Combine*** optimizations from separate searches.
- Optimizations on frequently executed paths are likely to have larger impact.
  - ***Profile*** the program to target hot paths.

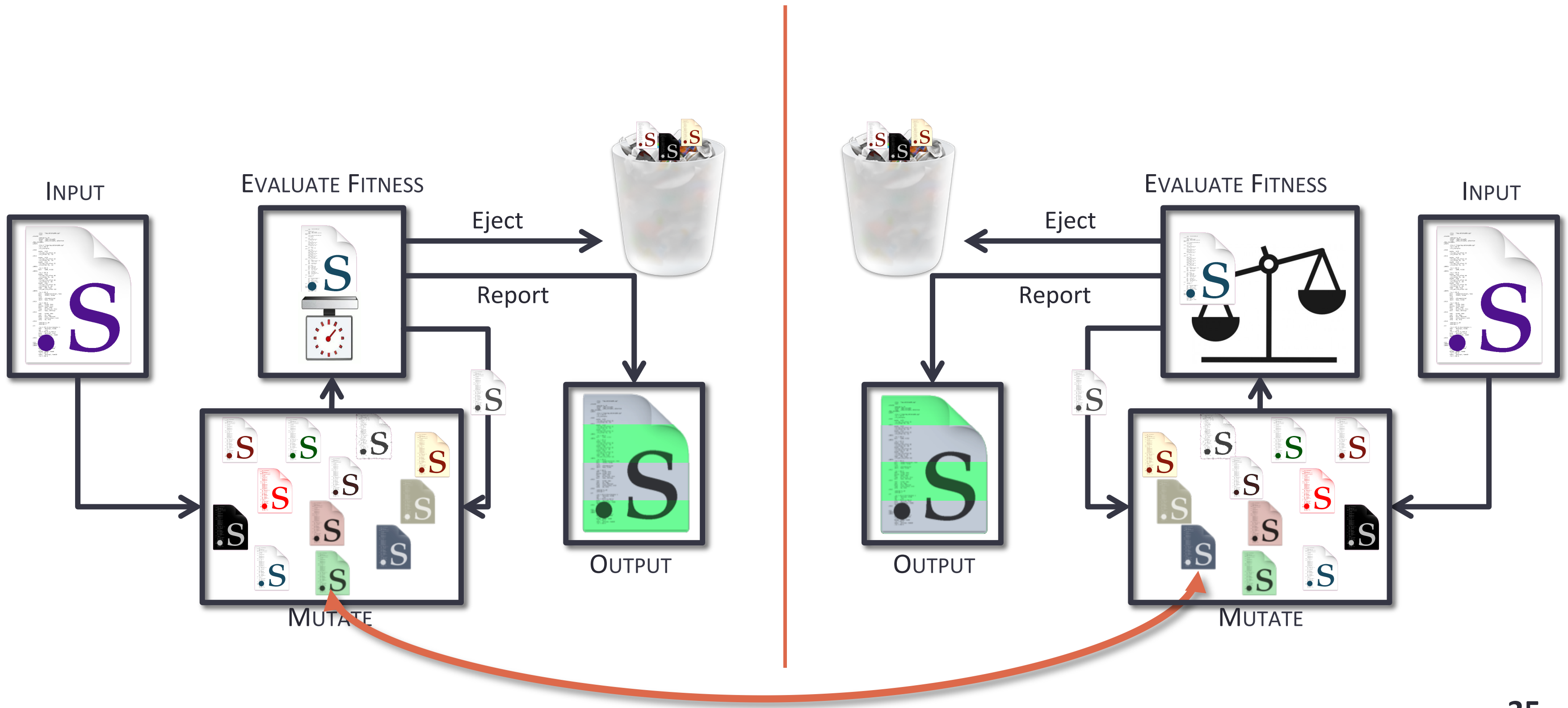
Algorithm Overview



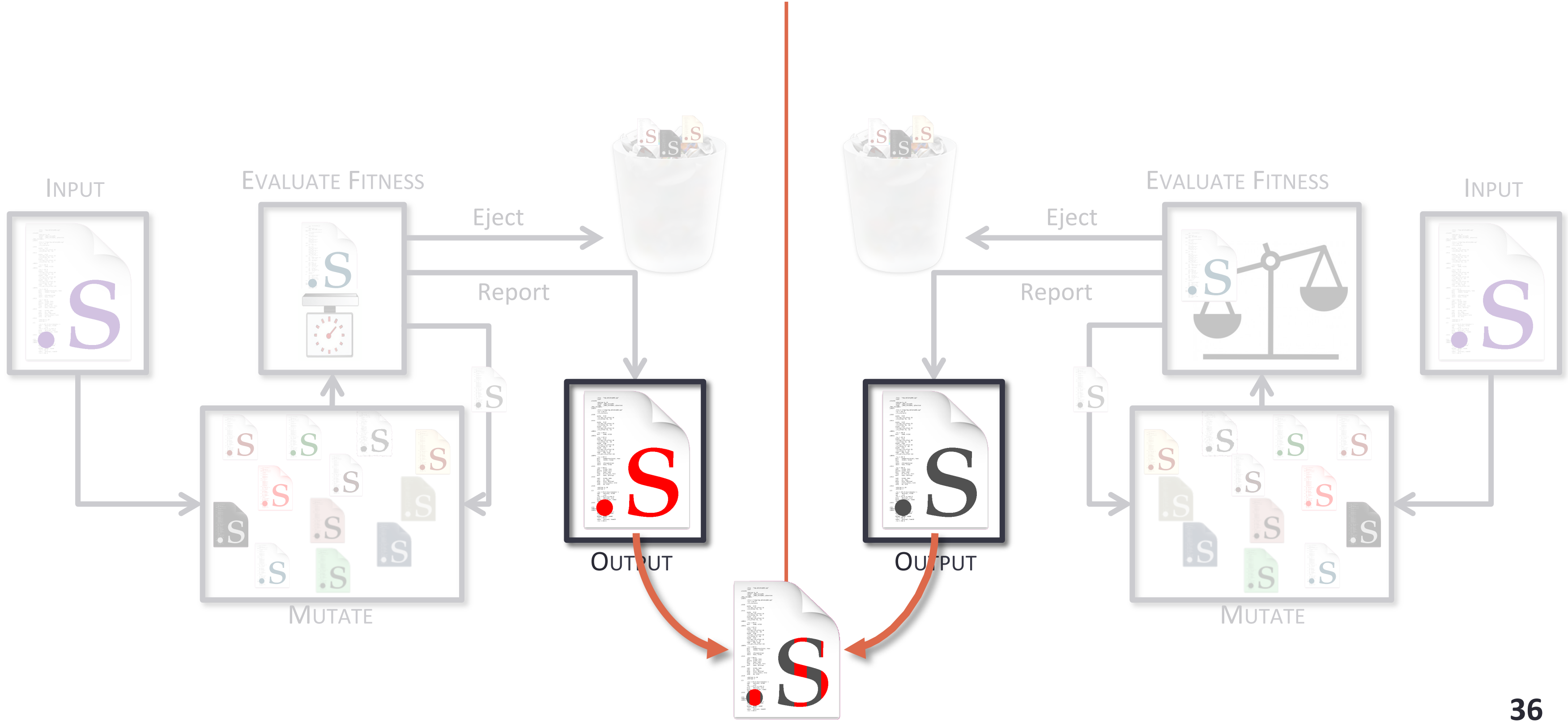
Optimizing Two Workloads



Option 1: Share Variants During Search



Option 2: Combine Best After Search



Experimental Setup

Benchmarks

- Collect HPC and data center benchmarks.
- Collect multiple workloads for each benchmark.

Baseline: GOA search

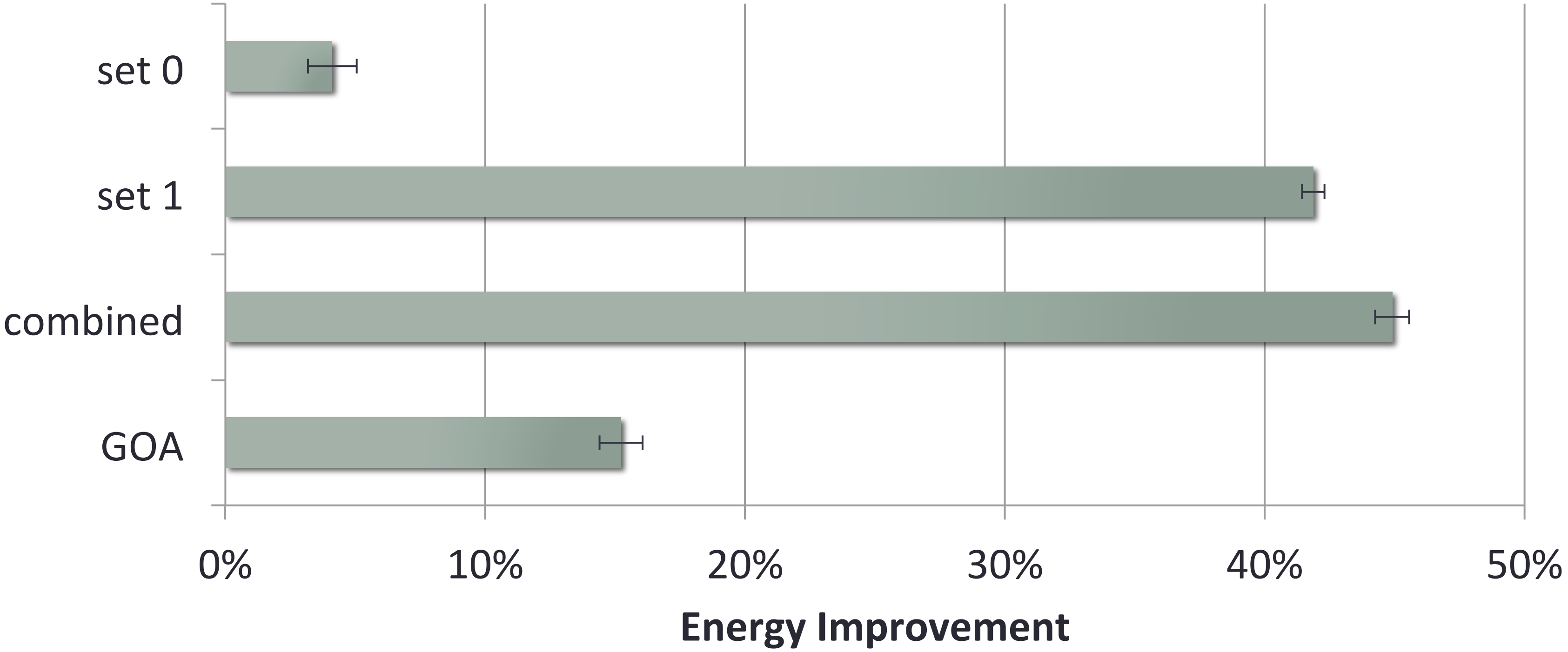
1. Only one workload.
2. All workloads in single fitness function.

Metrics for Energy Optimization

- ***Energy*** measured at the wall.
- ***Wall time*** before best variant.
  - Latest best variant if combining after search.
- ***Fitness evaluations*** before best variant.

- Success if searching separately produces larger energy reduction across all workloads.

Preliminary Results



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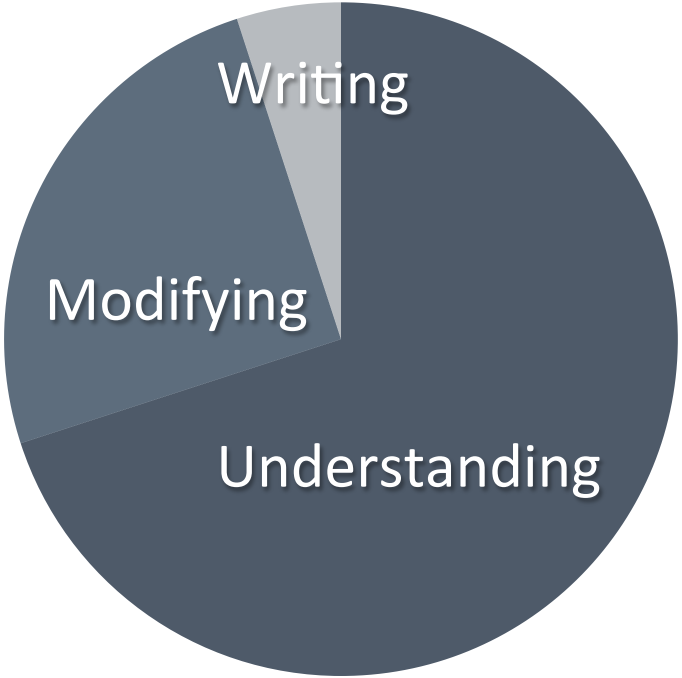
Programmer Time

- Programmer salaries in the U.S. exceed $100B.
- Programmers spend ***much more*** time reading code than writing it.



Reproduced from P. Hallam. What do programmers really do anyway? (aka part 2 of the yardstick saga). http: //blogs.msdn.com/b/peterhal/archive/2006/01/04/509302.aspx. Accessed: 2016-02-01.

Stylish Code

- ***Broad consensus*** for standardized coding style.
- ***Persistent disagreement*** on specifics.
  - E.g., tabs vs. spaces.
- “Every major open source project has its own style guide.” – Google’s style guide.

Beacons

- Indicate likely structure or functionality.
- Semantic or syntactic.
- May vary
  - Between programmers,
  - And over time.

```
for (i=0; i<n; i++) {
  for (j=0; j<n; j++) {
    …
    temp = a[i];
    a[i] = a[j];
    a[j] = temp;
    …
  }
}
```

Beacons

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```

Possible sort Implementation?

Beacons

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for (i=0; i<n; i++) {
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    …
    temp = a[i];
    a[i] = a[j];
    a[j] = temp;
    …
  }
}
```

End of scope.

Classification of Coding Style

- Typographic and Structural [Oman 1988].
  - Typographic: whitespace, line length, identifier length, layout.
  - Structural: modularity, level of nesting, control and information flow.

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Hypothesis

- We can apply local changes to the typographic elements of source code to
  - Match a programmer's expected style and
  - ***Improve*** their understanding of the code.
- Evaluate time and accuracy on tests of understanding.

Modeling Typographic Style

- *N*-gram language model.
  - Uses previous *n*-1 tokens to predict next token.
  - Learn probabilities from existing code.
  - NATURALIZE framework [Allamanis 2014].
  - Can predict or suggest whitespace.

Similarity of Typographic Style

- Measure similarity of *N*-gram models.
  - *N*-gram models are probability distributions.
- Measure similarity of style-checker rules.
  - Allamanis et al. generate rules from *n*-gram models.

Experimental Setup

Benchmarks

1. Reformat the same code in different ways.
2. Collect similar code from different authors (e.g., textbook examples).

Participants

- Undergraduate student volunteers from upper level electives.
- Amazon Mechanical Turk workers who pass a screening test.

Human Study

1. Identify written style.
    - Participants write code to accomplish simple tasks.
    - E.g., check that a list is sorted.

2. Perform maintenance tasks.
    - Participants answer questions about code examples.
    - E.g., what is the value of x on line 5?

Metrics for Program Understanding

- Collect ***similarity*** between code participants wrote and the code samples.
- Collect ***time*** and ***accuracy*** in answering questions.
- Measure correlation between similarity and time and between similarity and accuracy.

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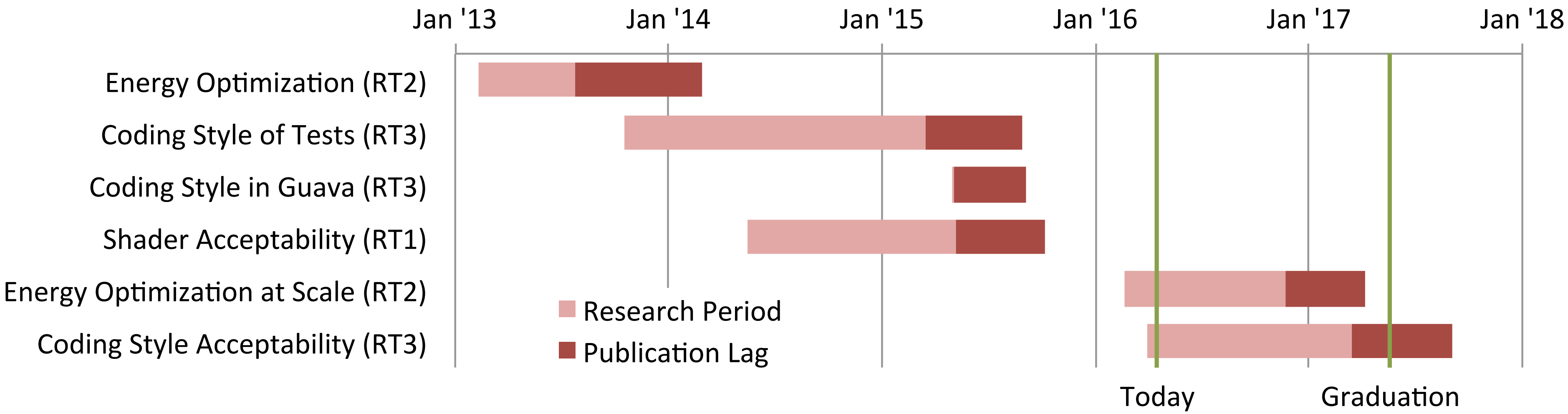
Research Timeline



Conclusion

Enable better tradeoffs between non-functional properties through local software transformations.

1. Visual error and runtime performance.
2. Energy usage.
3. Coding style.

BACKUP

Does Coding Style Matter?

```
IF         A>B            THEN S := 1;
IF (A=B) AND (C>D)   THEN S := 2;
IF (A=B) AND (C<=D) THEN S := 3;
IF (A<B) AND (C>D)   THEN S := 4;
IF (A<B) AND (C=D)   THEN S := 5;
IF (A<B) AND (C<D)   THEN S := 6;
```

```
IF A > B THEN
 S := 1
ELSE IF A = B THEN
 IF C > D THEN
  S := 2
 ELSE
  S := 3
ELSE IF C > D THEN
 S := 4
ELSE IF C = D THEN
 S := 5
ELSE
 S := 6;
```

Reproduced from P. W. Oman and C. R. Cook.
A paradigm for programming style research. *ACM Sigplan Notices*, 23(12):69–78, 1988.

Does Coding Style Matter?

```
IF          A>B          THEN S := 1;
IF (A=B) AND (C>D)   THEN S := 2;
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IF (A<B                  := 4;
IF (A<B) AND (C=D)   THEN S := 5;
IF (A<B) AND (C<D)   THEN S := 6;
```

Avg. Score: 4.90
Avg. Time: 1.93

```
IF A > B THEN
 S := 1
ELSE IF A = B THEN
 IF C > D THEN
  S := 2
E
 S := 4
ELSE IF C = D THEN
 S := 5
ELSE
 S := 6;
```

Avg. Score: 3.36
Avg. Time: 2.87

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A paradigm for programming style research. *ACM Sigplan Notices*, 23(12):69–78, 1988.