Is “Naturalness" a result of deliberate choice?

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Exploiting the Naturalness of Software

- Programs are written to be read

"Instead of imagining that our main task is to instruct a computer what to do, let us concentrate rather on ***explaining to human beings what we want a computer to do****."* [Don Knuth]

The Dual Channel Hypothesis (Barr/Sutton)

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public static void main (String[] args) {
     int val;
     System.out.println ("Inside main");
     funct1();
     System.out.println ("About to call funct2");
     val = funct2(8);
     System.out.println ("funct2 returned a value of " + val);
     System.out.println ("About to call funct2 again");
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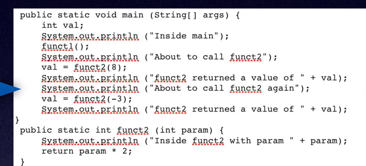

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Operational
Semantics
meaning=OS(code)

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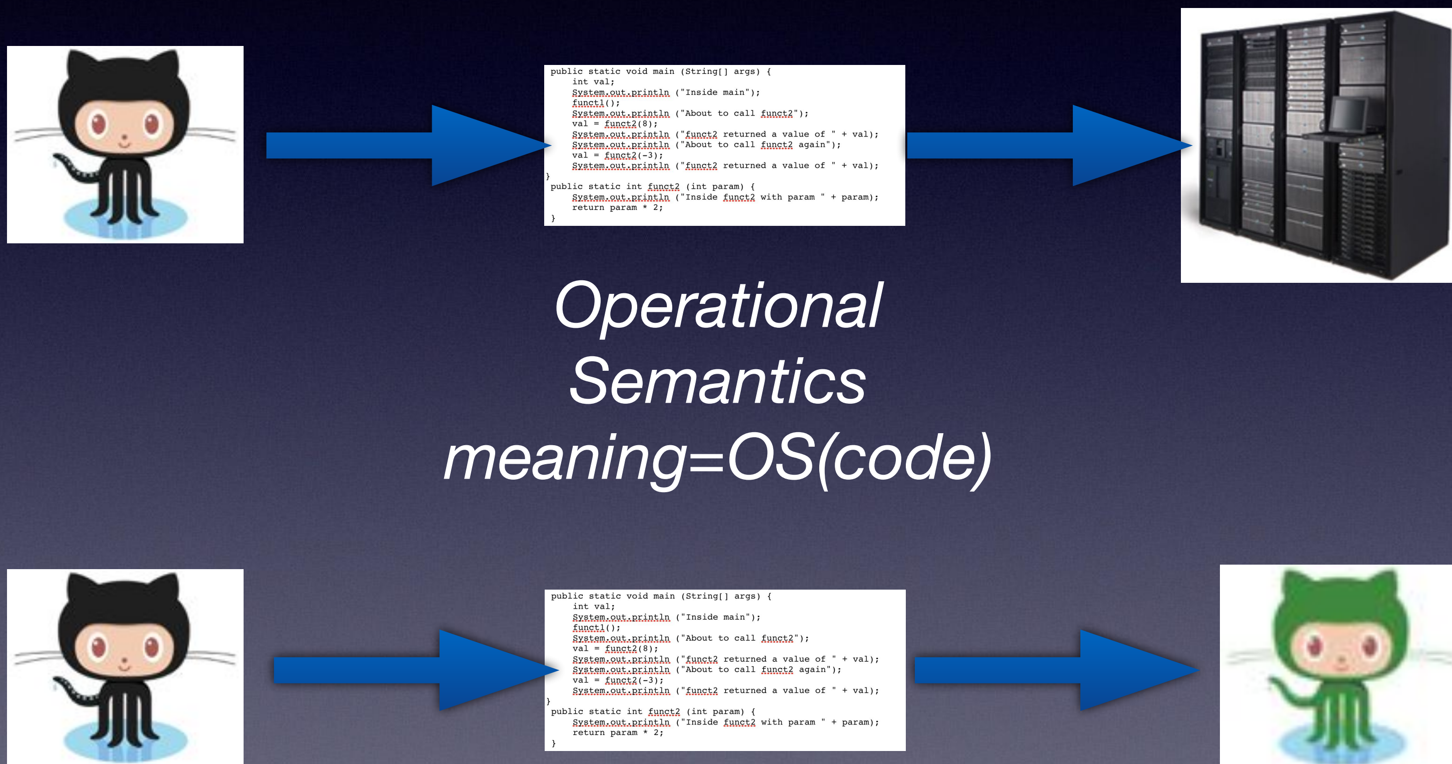

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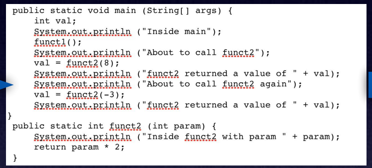

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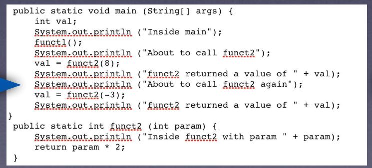


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Identifiers, structural patterns, program style….

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$$argmax_{meaning} P(meaning \mid code)$$

The "noisy" H-H channel

m = meaning
c = code

$$argmax_m P(m \mid c)$$

Bayes Rule

$$= argmax_m \frac{P(c \mid m)\ P(m)}{P(c)}$$

For a given c

$$\approx argmax_m P(c \mid m)\ P(m)$$

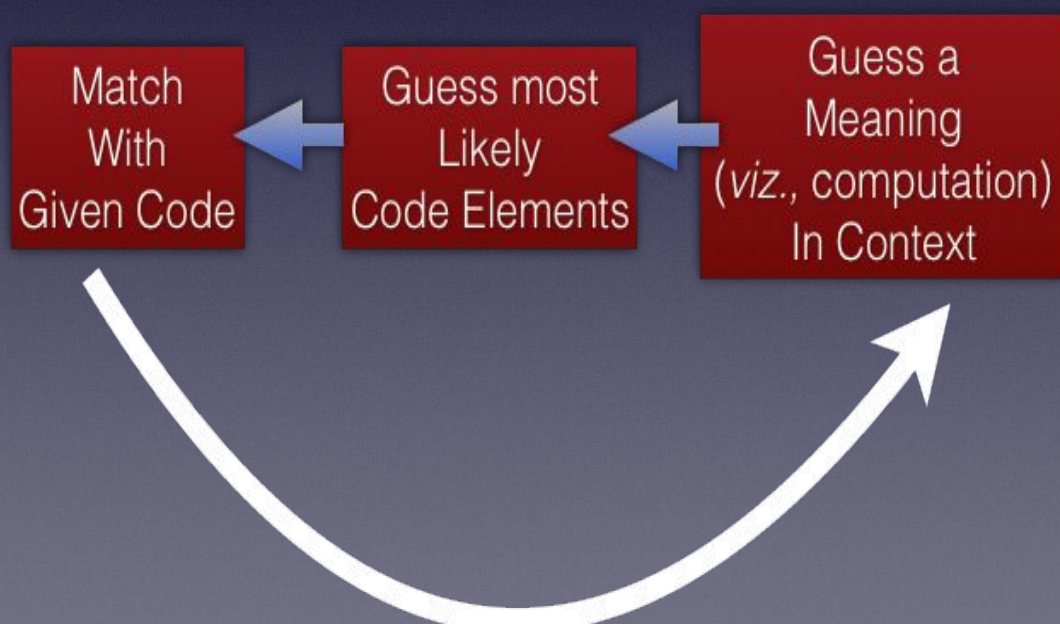
Informed by coding and domain knowledge

$$\approx argmax_m P(c \mid m)\ P(m \mid context)$$

The “noisy” H-H channel

$$argmax_{meaning} P(meaning \mid code)$$

$$\approx argmax_{meaning} P(code \mid meaning)\ P(meaning \mid context)$$



The “noisy” H-H channel

Guess a
Meaning
(*viz.*, computation)
In Context

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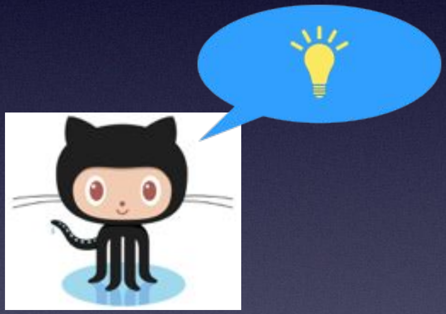

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Guess most
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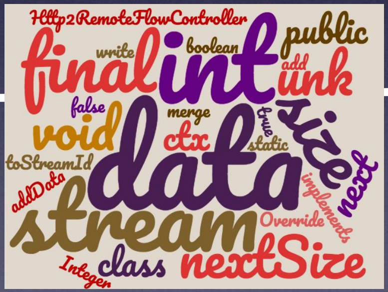

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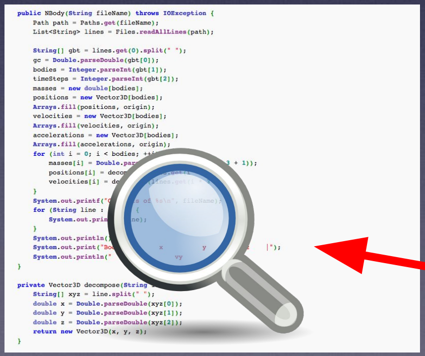

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Guess most
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Match
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Given Code

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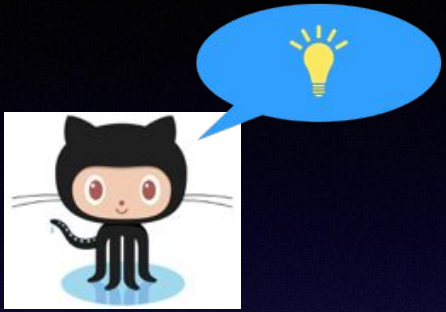

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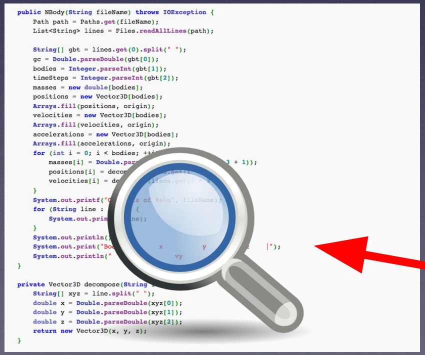

Guess a Meaning (*viz.*, computation) In Context

Guess most Likely Code Elements

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$$argmax_m P(m \mid c)$$

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m = meani
c = code

This ‘guessing’ will be more effective if p(c|m) is ‘skewed’.

So what?

Given a computation to implement:

Programmers tend to favor one implementation over others.

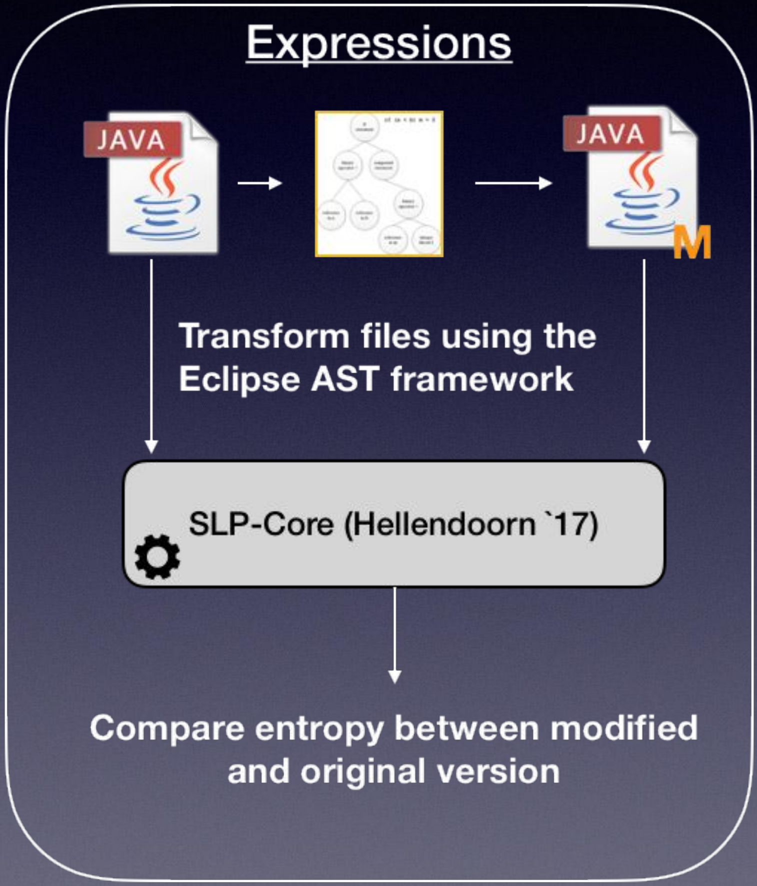
So if $C_1, C_2, \ldots C_n$ *are different, equivalent implementations of the same computation M, usually:*

$$\exists j : p(C_j \,|\, M) \gg p(C_i \,|\, M) \quad \forall i = 1 \ldots n, i \neq j$$

General Scheme

- Estimate a language model *LM* over a large corpus
- Using *LM*, Measure the entropy of “natural” program ***S*** (not in training set)
- Apply meaning preserving transform to ***S*** yielding
- Using *LM, measure entropy of S and*
- ***Null hypothesis:*** there is no difference.
  Alternative hypothesis: S is lower in entropy, than since programmers have a definite preference.

How to test?



Estimate language model *LM* over a corpus (12 Java projects/~16-17 million tokens)

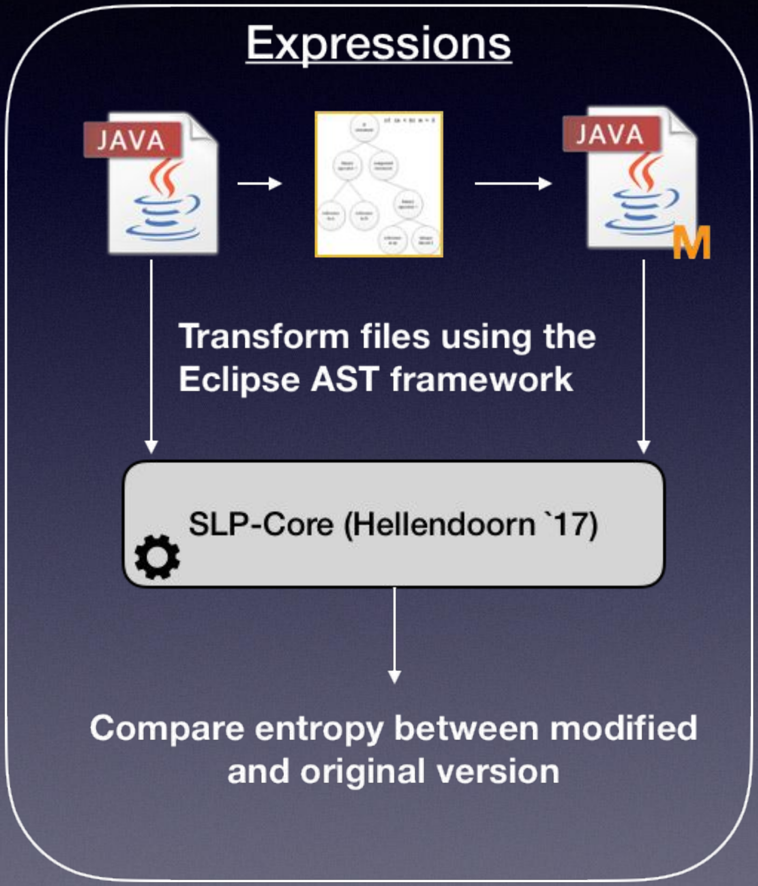
Using *LM*, Measure the entropy of "natural" program *S* (not in training set)

Apply **meaning preserving transforms** to *S* to create $\hat{S}_1, \hat{S}_2, \hat{S}_3 \ldots .$

Using *LM, measure entropy of S and*

$\hat{S}_1, \hat{S}_2, \hat{S}_3 \ldots .$

How to test?



Null hypothesis: There is no difference in entropy between S and $\hat{S}_1, \hat{S}_2, \hat{S}_3 \ldots.$

Alternative hypothesis: S is lower in entropy, than $\hat{S}_1, \hat{S}_2, \hat{S}_3 \ldots.$ since programmers have a definite preference.

Meaning Preserving Transform?

Focus on Expressions

Operator Commutation

A + B → B + A

A * B → B * A

Variable Name Swap

Int a
Int b

→

Int b
Int a

Adding Parenthesis

A + B * C

↓

A + (B * C)

Removing Parentheses

A + (B * C)

↓

A + B * C

Limit to operations without side effects to avoid changing meaning.

Future direction: *statement level transformations* (line, if block shuffling, etc)

Meaning Preserving Transform?

- Operator Commutation
- Superfluous parentheses removal
- Superfluous parentheses insertion
- Operator associativity (Pending)
- Renaming Variables within and across types
- Independent statement reordering (Pending)

Training/Testing

- Training:
  - 12 popular (Most Starred) Github projects
  - Manually selected to cover a diverse set of domains

- Testing (Projects with large number of numeric expressions)
  - Apache Commons Math Library, Biojava, Spring Framework by Pivotal

Language Models

- 6-gram with Jelinek-Mercer smoothing (‘global’)
- 6-gram-cache
- Above models with types from Pygments syntax highlighter
- Implemented using SLP-Core framework

Language Models

<u>Ordinary Ngram Models</u>

**return this . objectDepth = = 0 & &
((token = = JsonToken . START_ARRAY ...)) ;**

<u>Identifiers Replaced with Types</u>

**return this . Token_Name_Attribute = = 0 & & ((
Token_Name = = Token_Name .
Token_Name_Attribute ...)) ;**

Implemented in SLP-Core (Hellendoorn)

- Fast and easy to quickly update

Used Pygments to generate types for variables.

- Uncover structural patterns separate from identifiers.

Language Models

Ordinary Ngram Models

6-gram model

6-gram model
+ cache

Identifiers Replaced with Types

6-gram model

6-gram model
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Implemented in SLP-Core (Hellendoorn)

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Used Pygments to generate types for variables.

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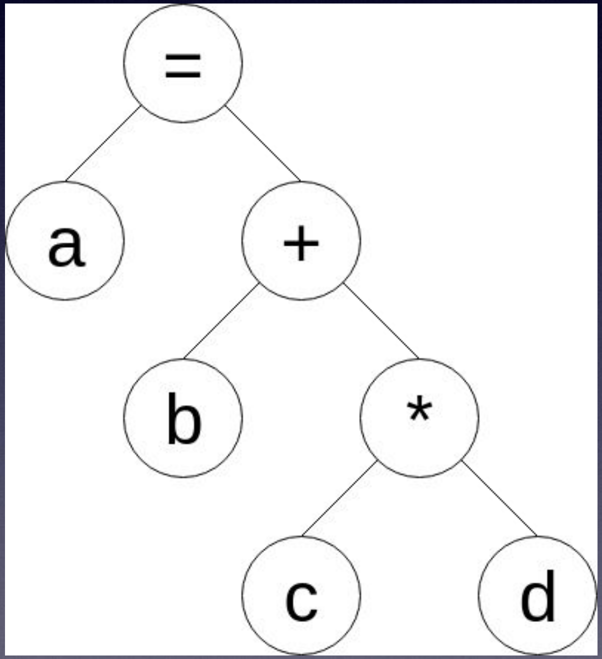
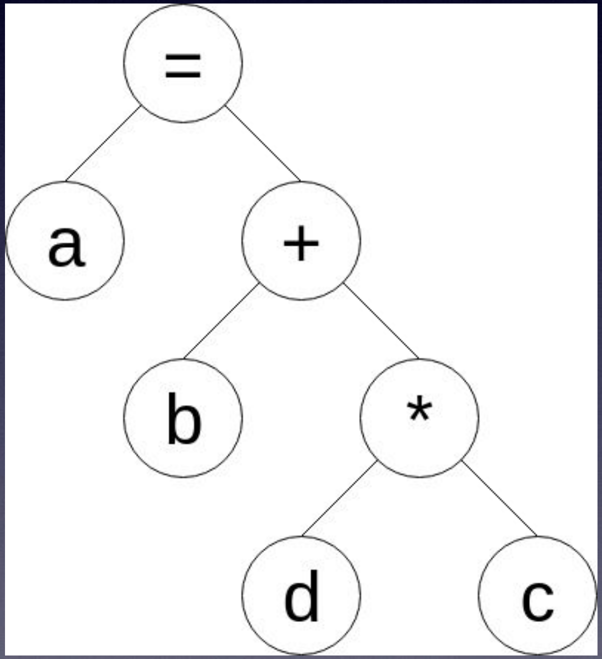
AST Transformations

- Abstract Syntax Tree
- Parser from Eclipse Foundation’s Java Development Tools (JDT) API

Commutation

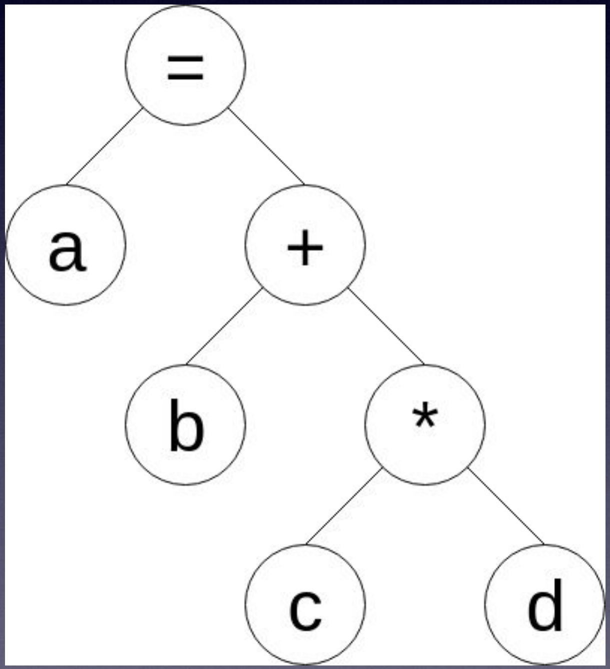
a = b + c * d -> a = b + d * c

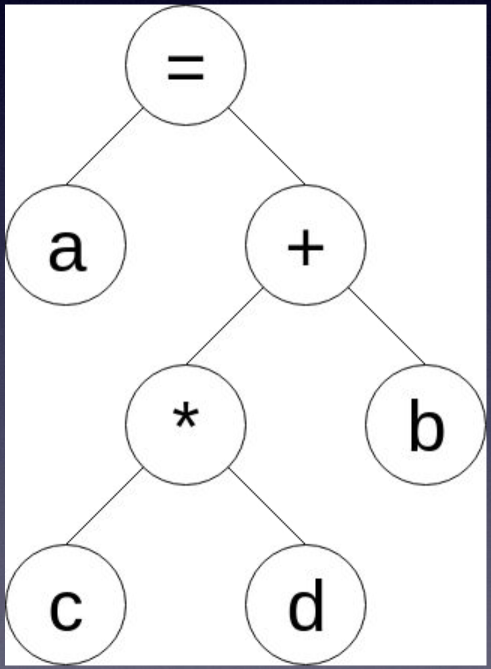




Commutation

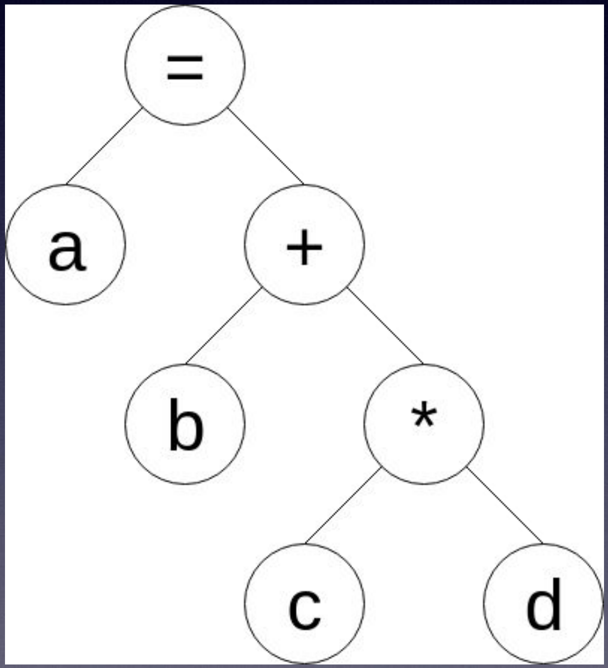
a = b + c * d -> a = d * c + b

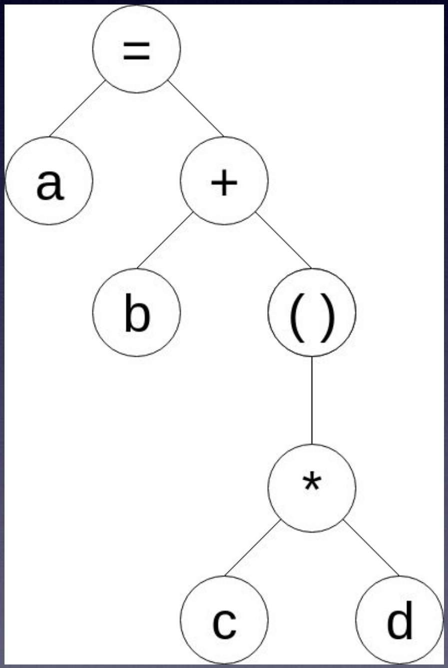




Parentheses Addition

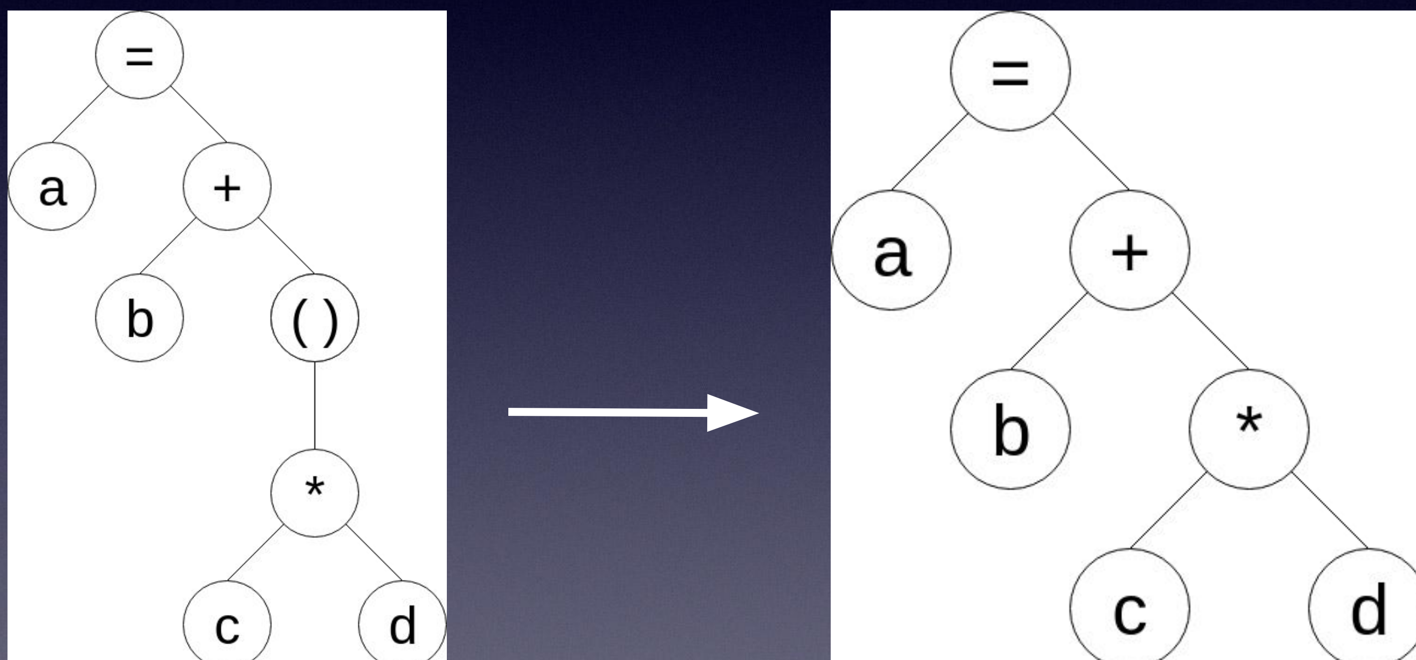
a = b + c * d -> a = b + (c * d)





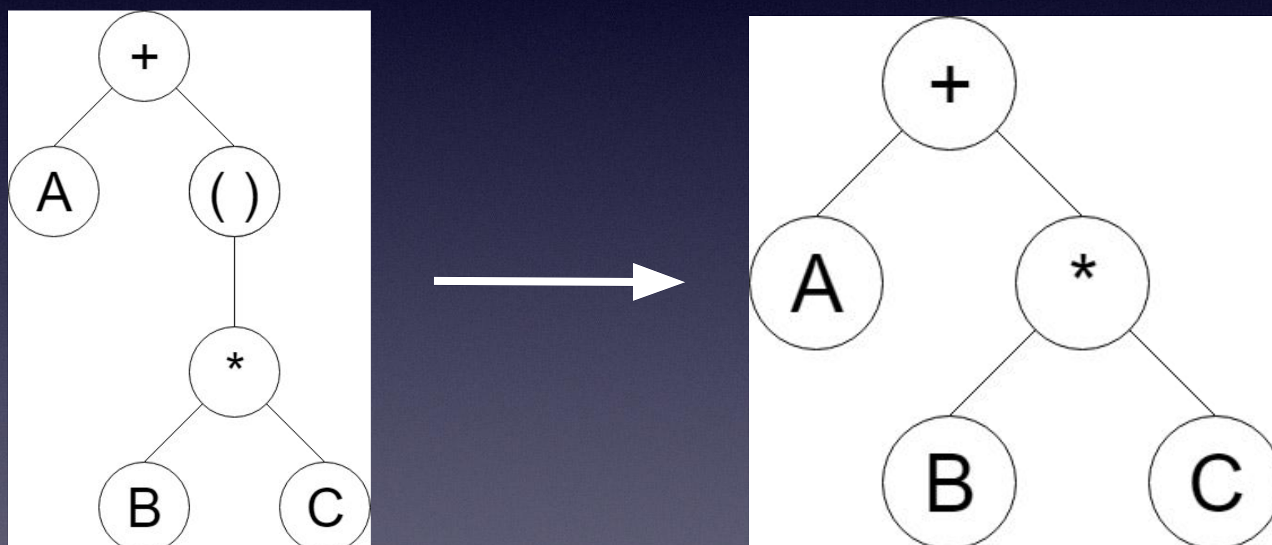
Parentheses Removal

a = b + (c * d) -> a = b + (c * d)



Parentheses Removal

A + (B * C) → A + B * C



Data Collected

- File Path
- Line Number
- Number of Tokens (Java and Pygments Type)
- Number of Transformations
- Average depth of transformed AST nodes
- Entropies
- Common Parent of Transformed Nodes
- Most and Least common operator involved

Number of Data Points

- 8,611 commutations
- 20,844 parentheses additions
- 2,670 parentheses removals

Results

What do we want to convey?

These transformations generally make code harder to predict (matching our theory) (Show Cohens D table?

Transformations relationship to the original entropy of the expression.

Certain ‘odd’ data out (add global model) + interesting interpretations of combined models.

Some ideas for future directions/gather feedback/ideas from audience.

A Note on Results

- Present results focusing on the change in average expression entropy.
  - Looked at line entropy as well (similar)

`X = A + ( B * C ) / D ;` → `H(B * C)`

- Include tokens that only appear in both the original and the changed lines (e.g. parenthesis) in average.

Do the models prefer the original?

- Paired T-tests comparing line before and after the change (all significant $p<.001$)

- Directed paired Cohen's D effect size.

	Global	Cache	Global Type	Cache Type
Operator Swap	0.313	0.859	0.360	0.706
Addition	-0.858	0.142	0.366	0.869
Removal	1.034	0.940	0.087	0.361

Summary

- When employing cache models, the negative impact on entropy is usually stronger...
- Interpretation: Local style tends to add additional restrictions?

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Local Style Stronger

- When employing cache models, the negative impact on entropy is usually stronger...
- => Local style tends to be even more consistent.

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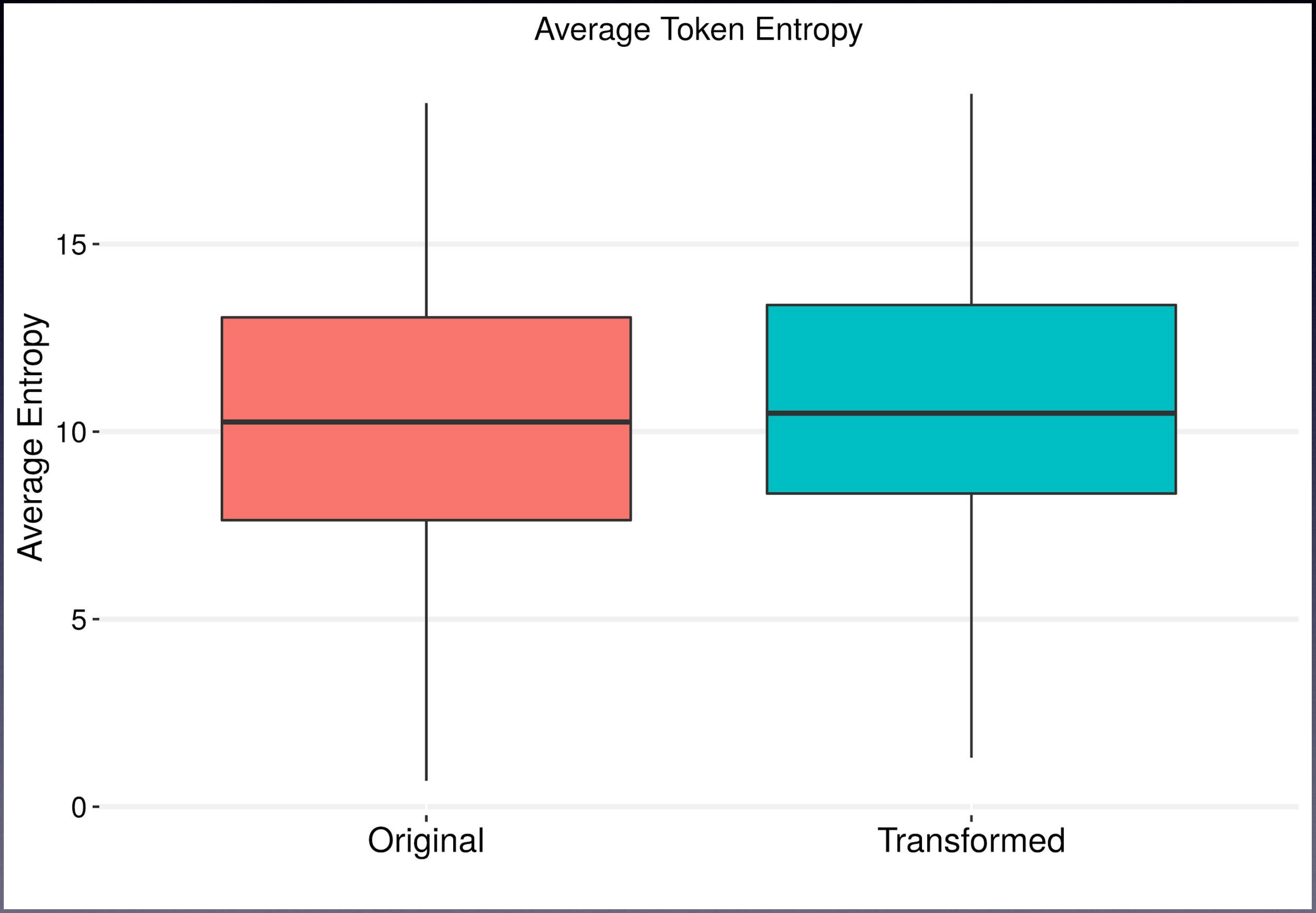

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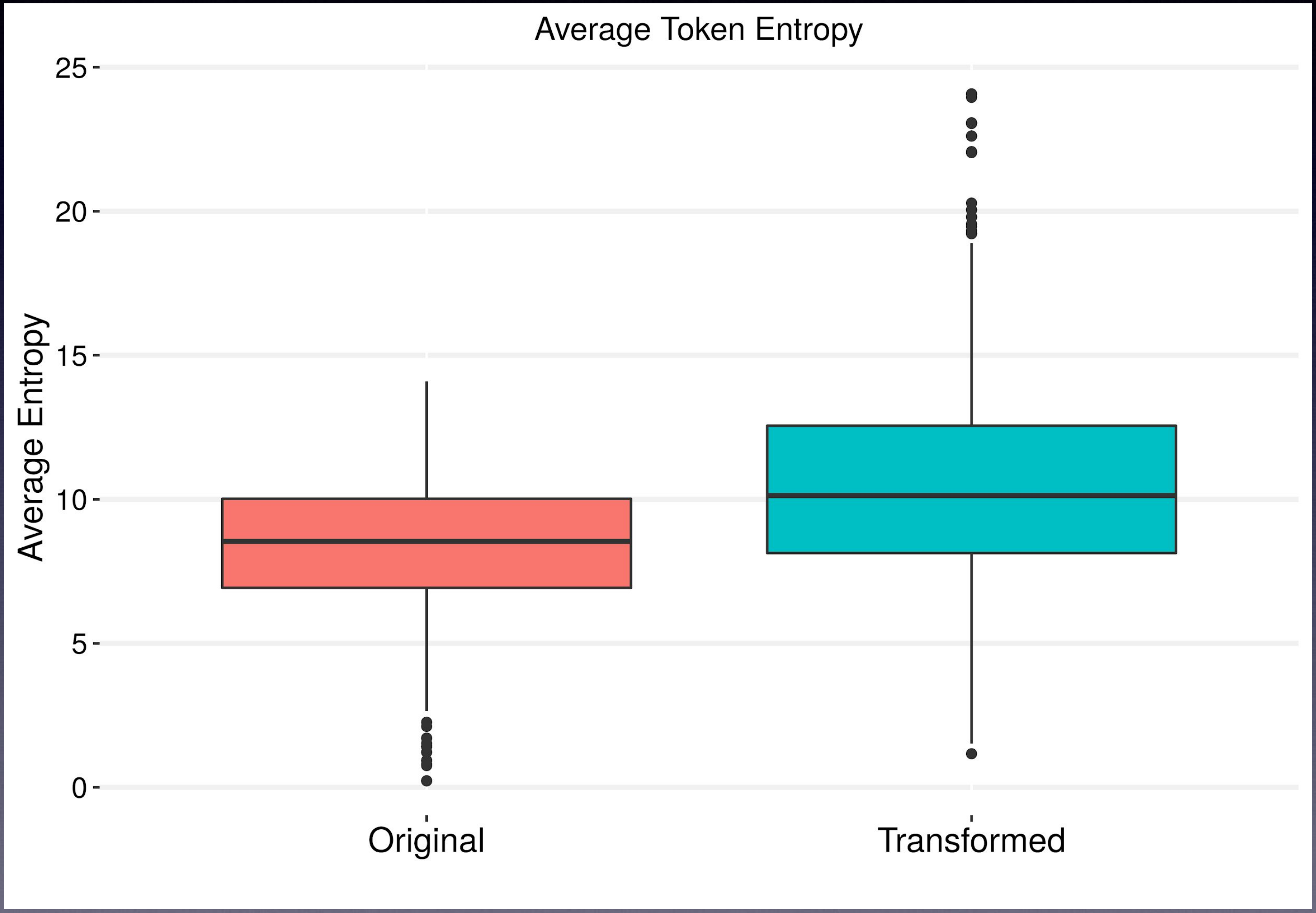

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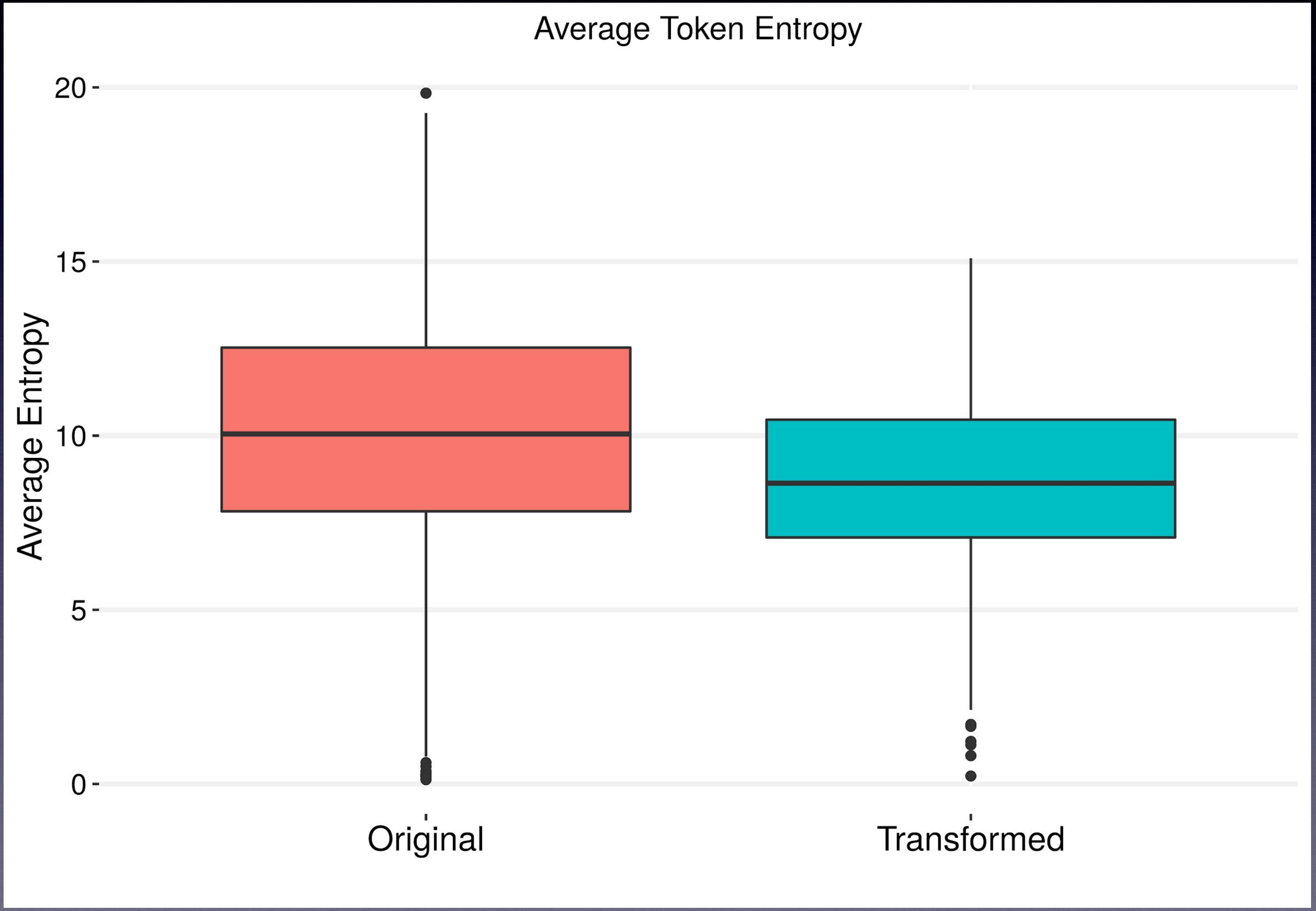
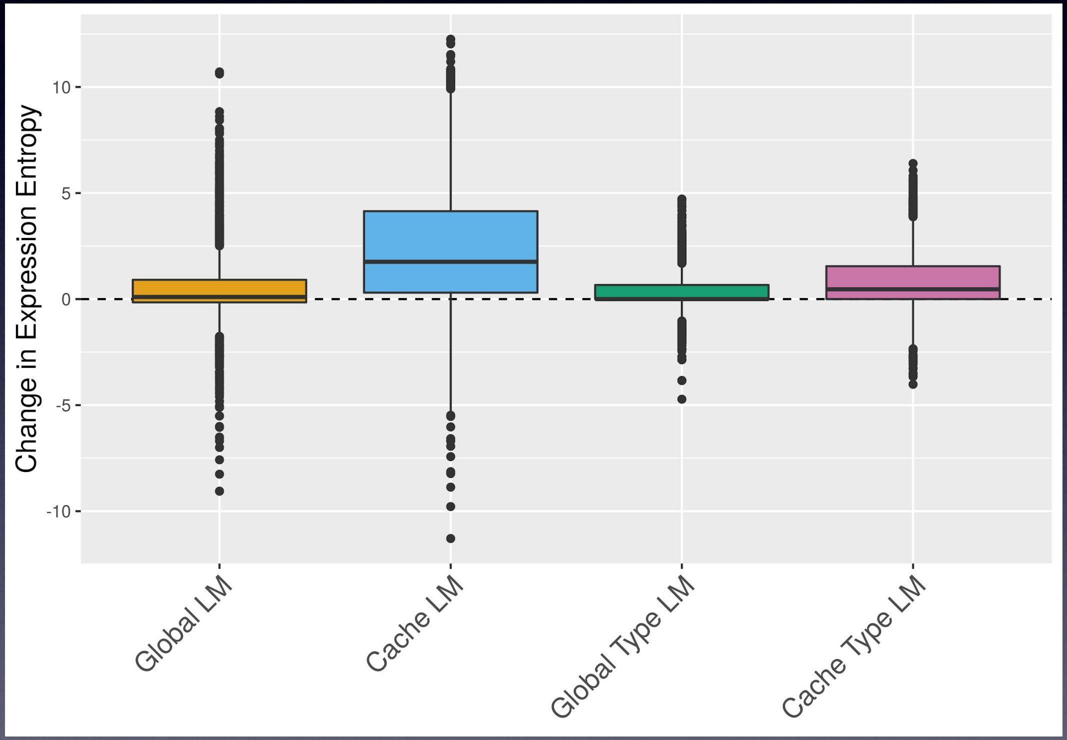
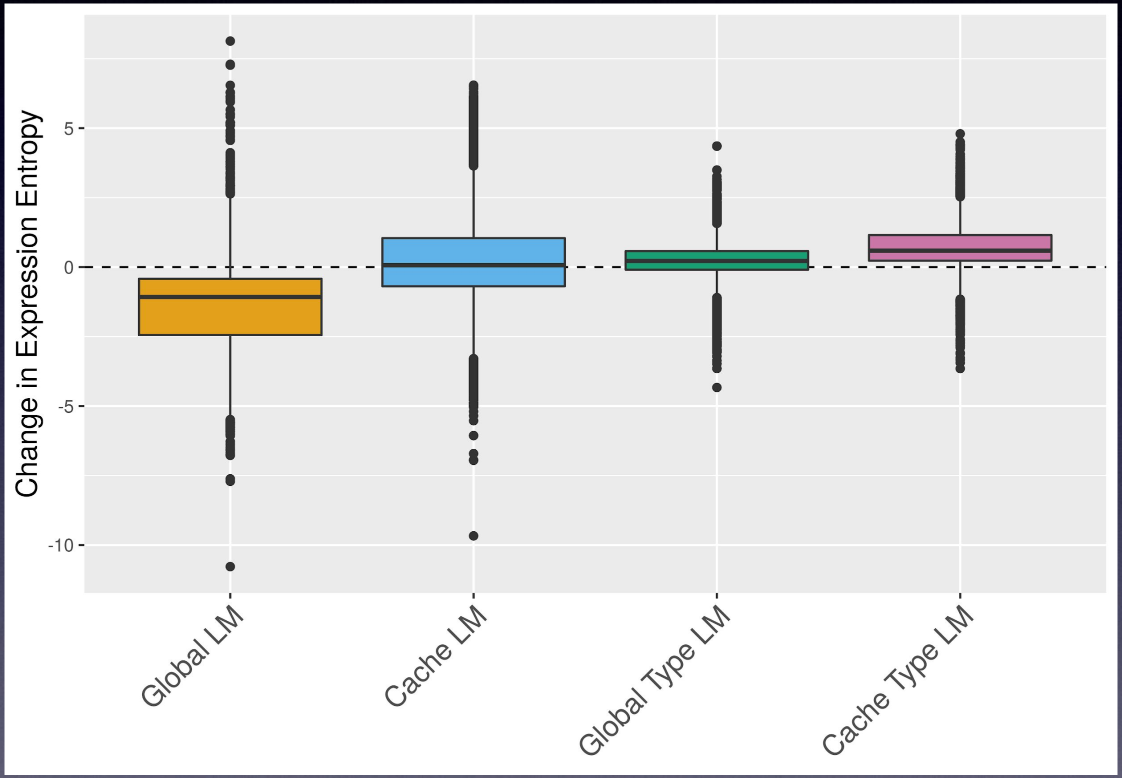


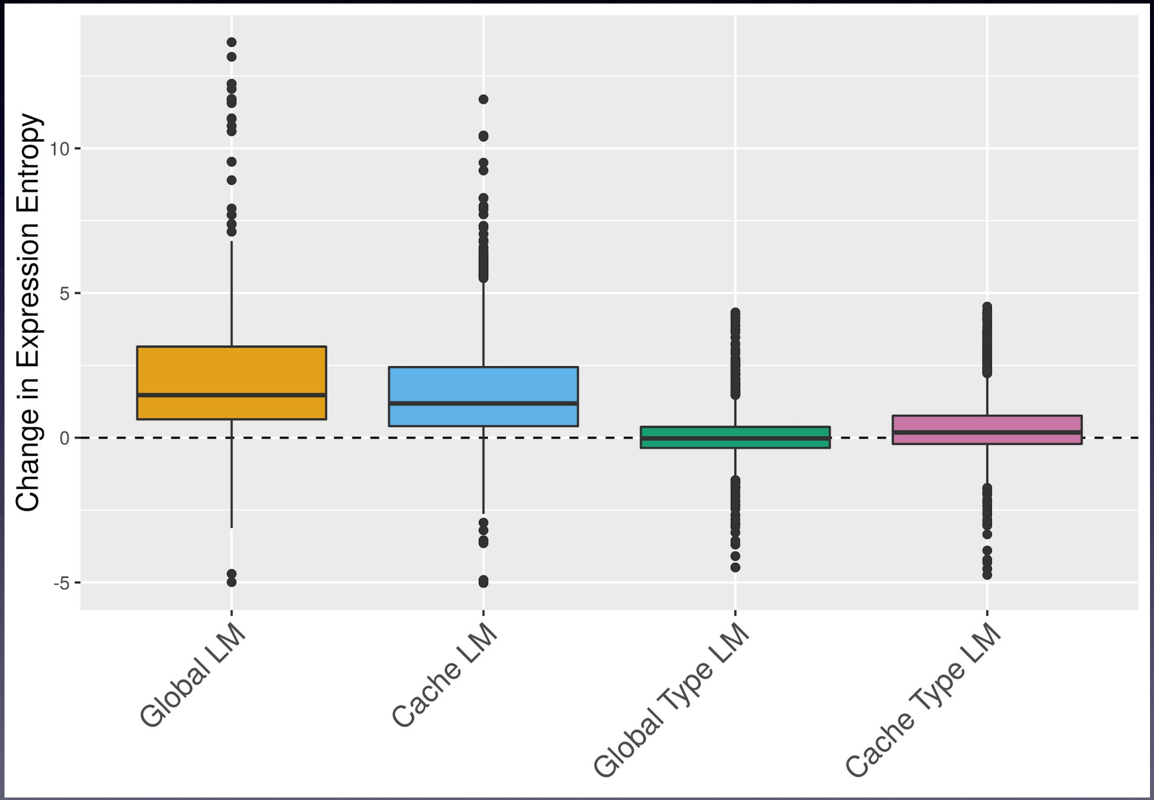
Operator Swapping



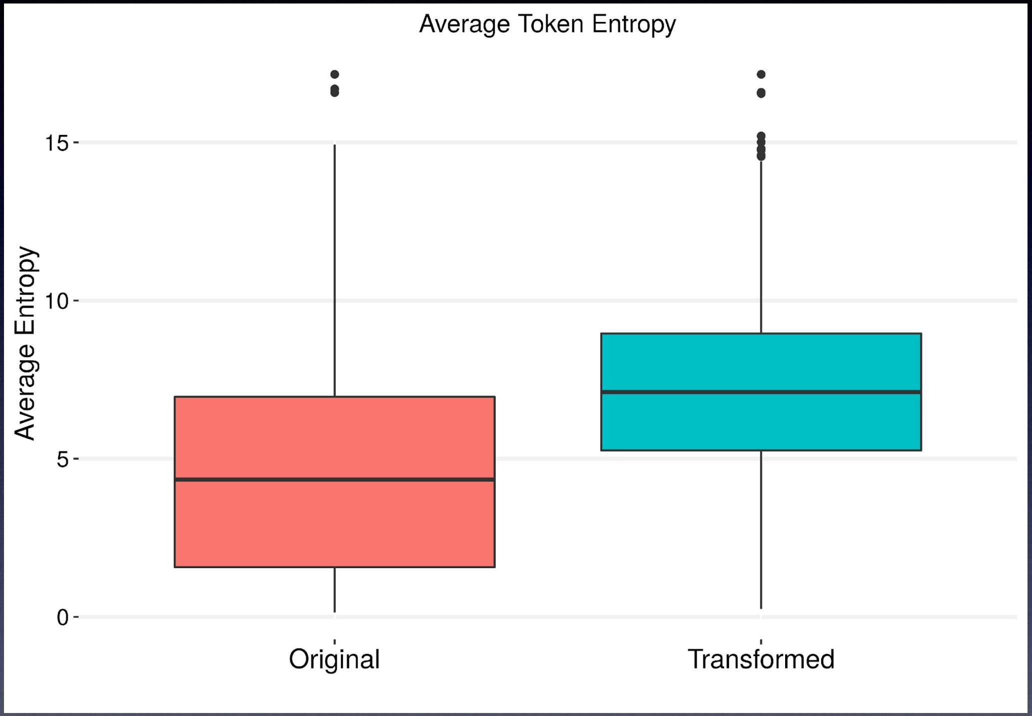
Adding Parenthesis



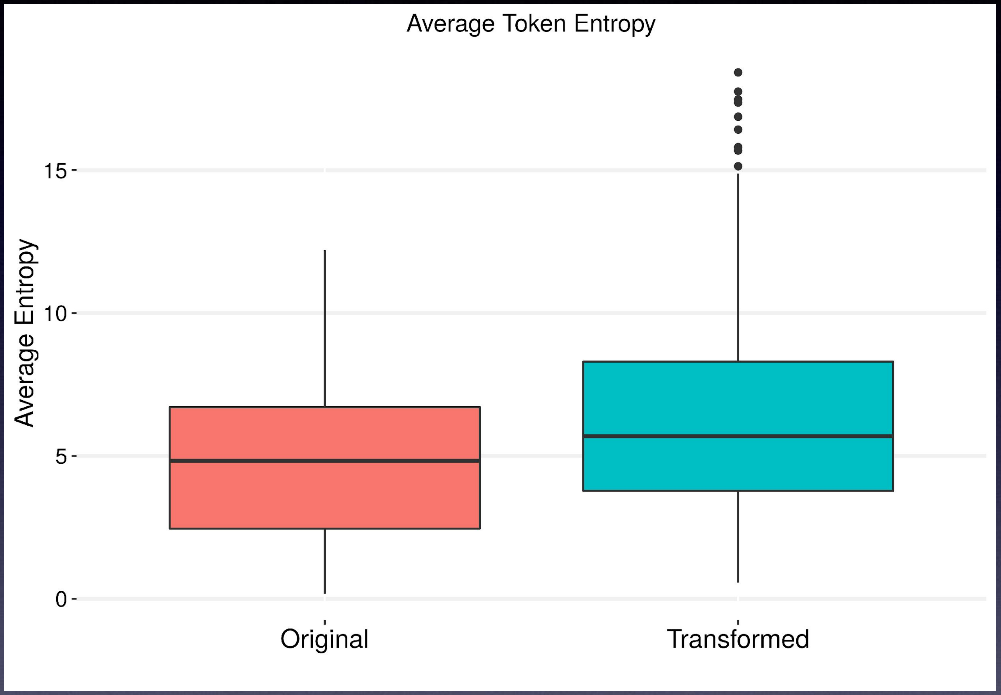
Removing Parenthesis



Commutation (Line)



Parentheses Removal (Line)



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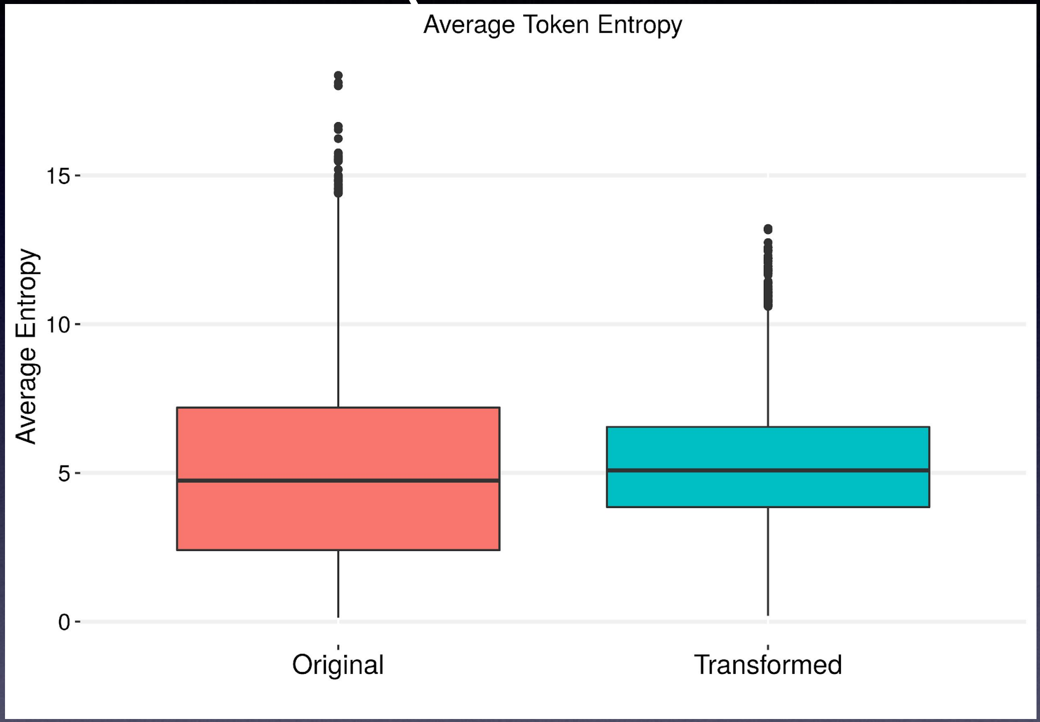
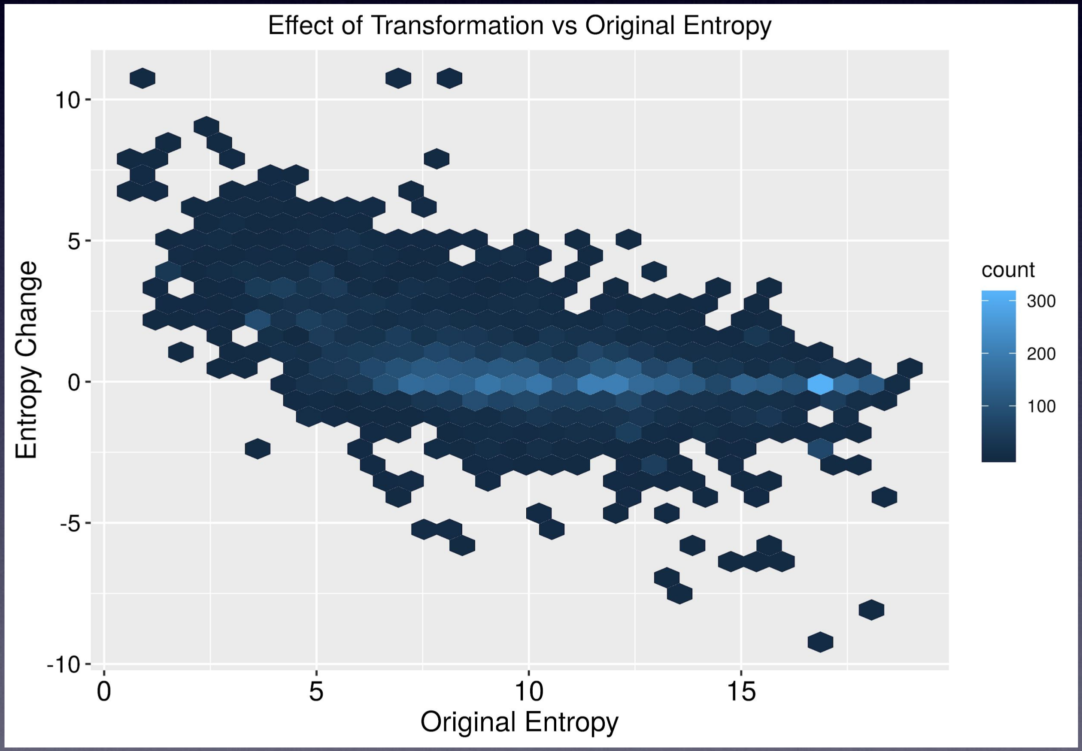


What's up with adding ()?

Code Examples	(Global) Ent Change
result = 31 * result + (int)(temp ^ (temp >>> 32));	-10.78
if (strict && (lowerBound == upperBound)) {	-7.62
Num = (floor*den) + num;	-6.78
final int minIndex = (binIndex * numRows) / numComponents;	-6.59
if (k > (n / 2)) {	-6.58

Effects Vs Original Entropy

Operand Swap (Global Model)



Higher Original Entropy = Greater Potential to reduce entropy

True for most, but not all of the transformations.

<u>Exception</u>: **Global models on () remove transformation**.

- Models capturing preference for including () in complex expressions?

Summary

- Programmers ***do*** generally show preference in choice of computations over the same meaning.
- But, not always true...
  - Opportunity for transforming code?
  - How well can LMs (and entropy measures) correspond with human understanding of code?

Future Directions

- Larger transformations (line swapping)
  - May move to C#/Roslyn
- Human evaluation of entropy score vs understanding/readability metrics
- Variation in human written programs (student code/multiple solutions to Rosetta Code)