CryptOpt

Verified Compilation with Randomized Program Search for Cryptographic Primitives

Joel Kuepper, Andres Erbsen, Jason Gross, Owen Conoly, Chuyue Sun, Samuel Tian, David Wu, Adam Chlipala, Chitchanok Chuengsatiansup, Daniel Genkin, Markus Wagner, Yuval Yarom

THE UNIVERSITY of ADELAIDE
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Georgia Tech
MONASH University
RUB

Challenges

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The fact that these bugs existed in the first place shows that the traditional development methodology (i.e. "being super careful") has failed.

- Thomas Pornin, Sep. 2019 (in PQC Mailing List on a Falcon implementation)

Cryptographic Code

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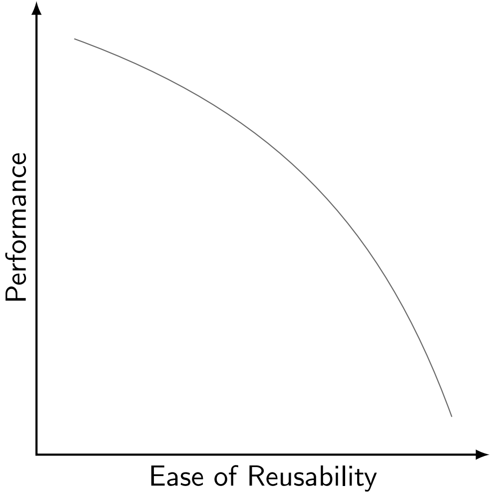

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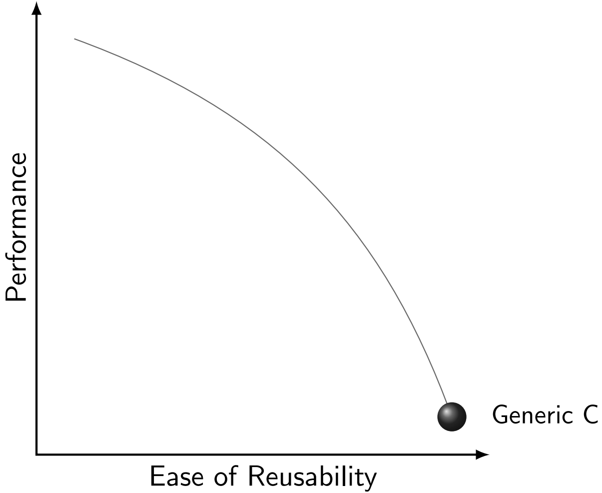

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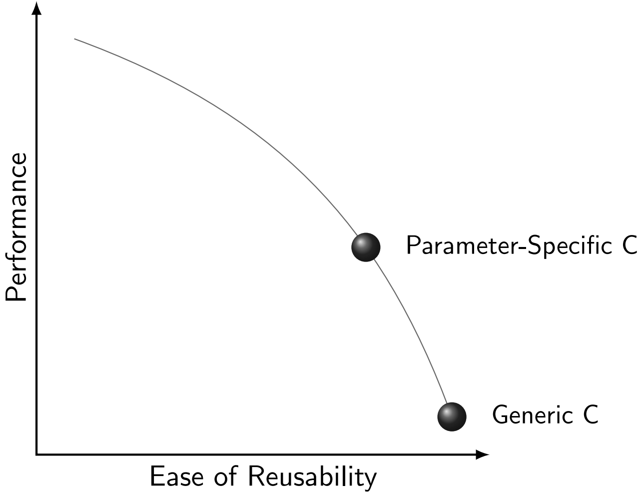

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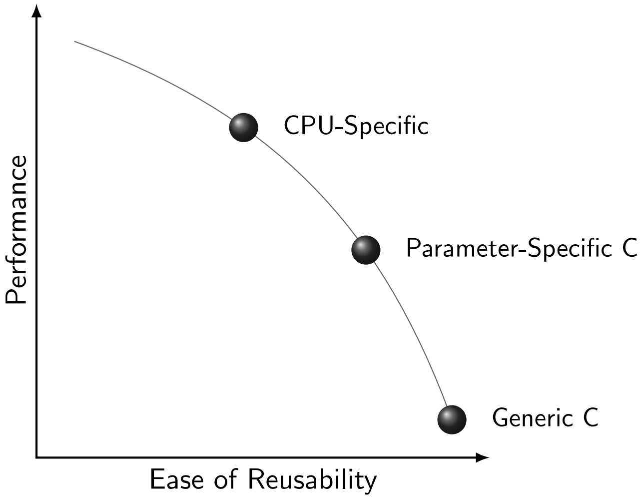

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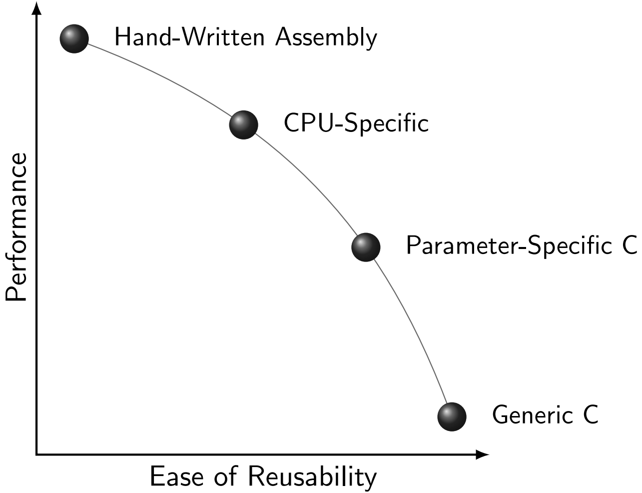

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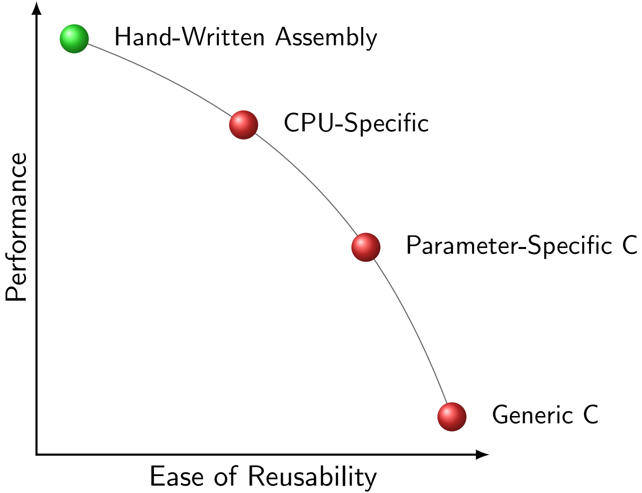

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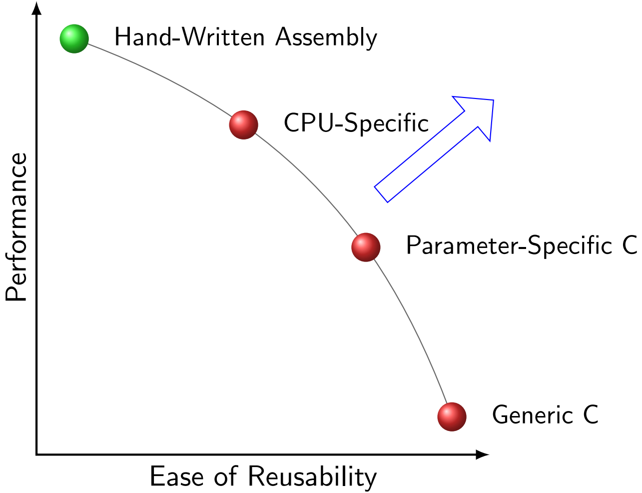

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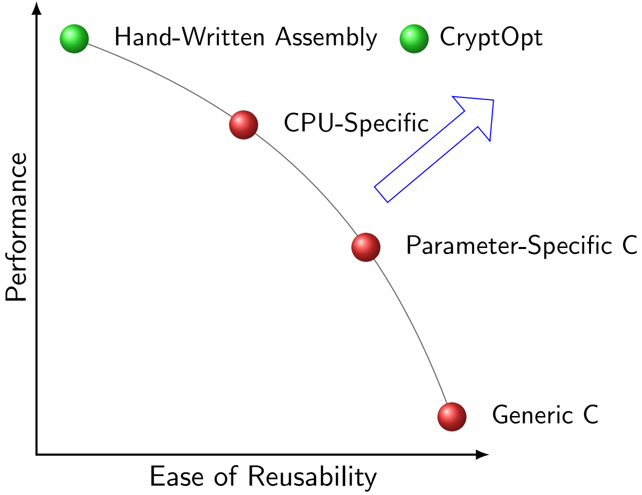

Idea

Observations:

1. Compilers are general-purpose.

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Idea:

1. ~~Compiling to~~ → search for a fast implementation.
2. Prove it correct.

Search for Fast Implementation

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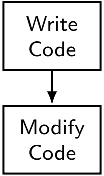
Write Code

Search for Fast Implementation



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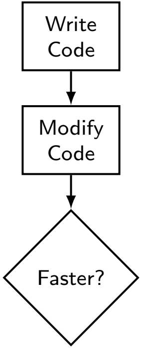

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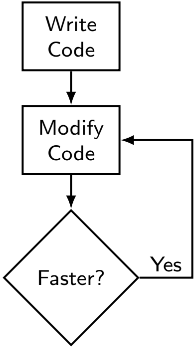

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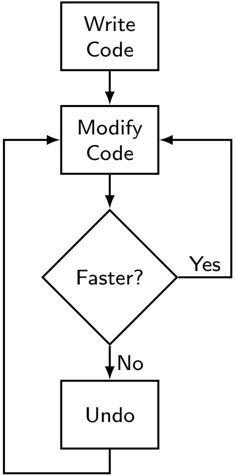

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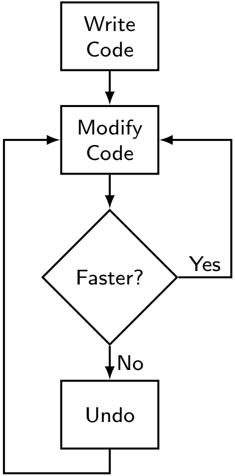

"Random Local Search"

Example: $(X + Y) \cdot Z + Z^2$

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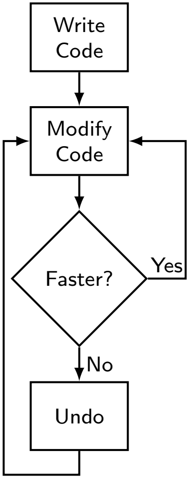

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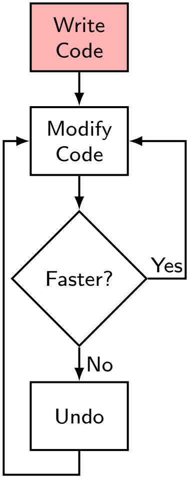

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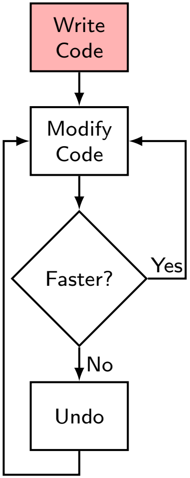

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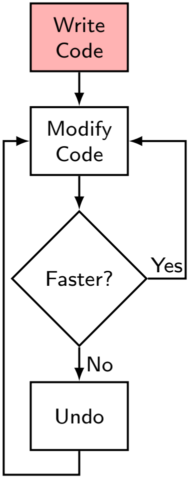

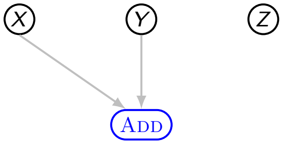

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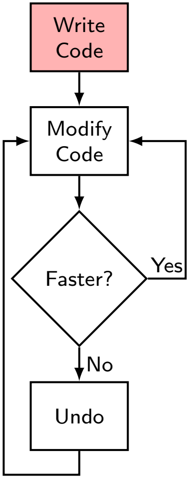

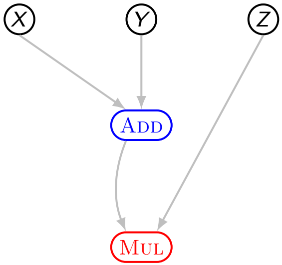

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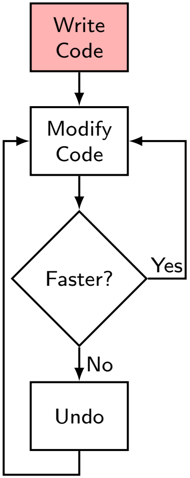

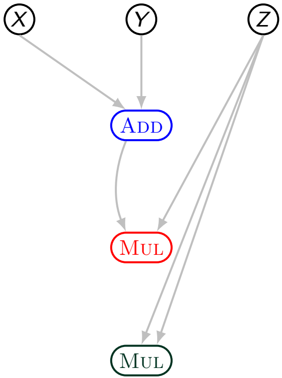

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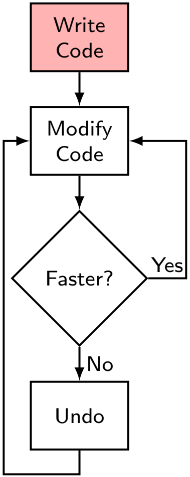

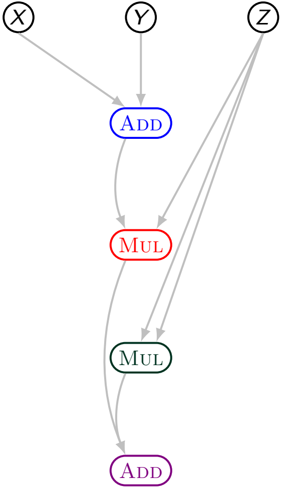

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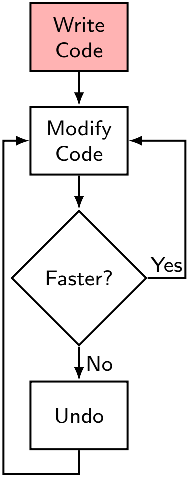

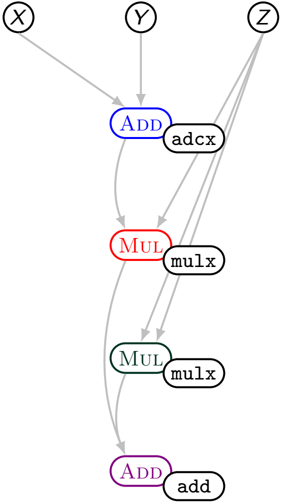

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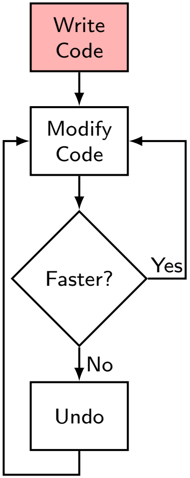

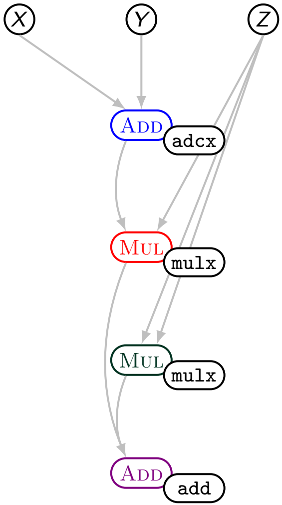


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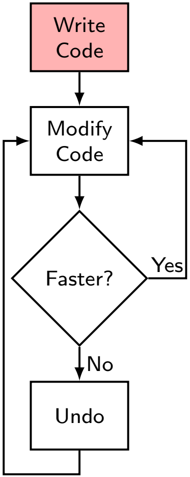

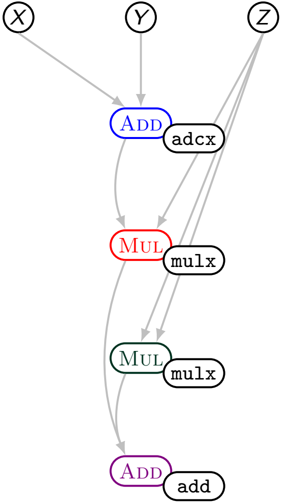


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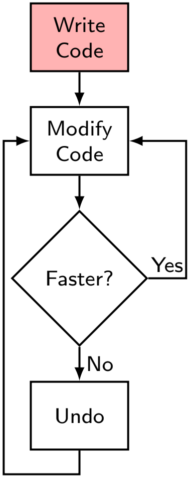

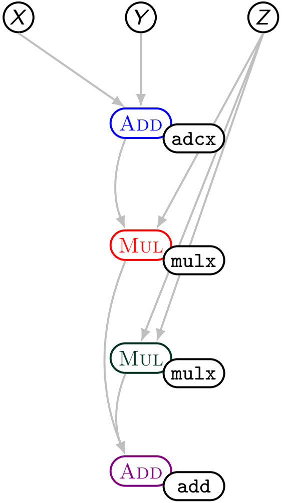


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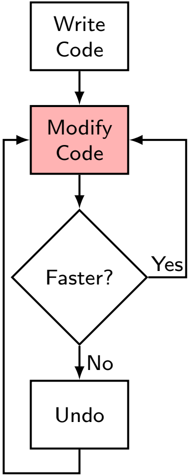

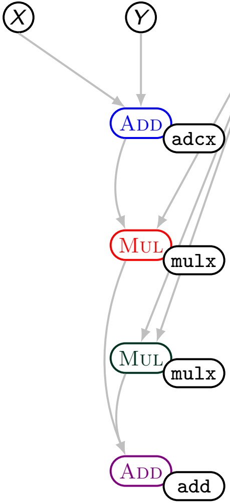


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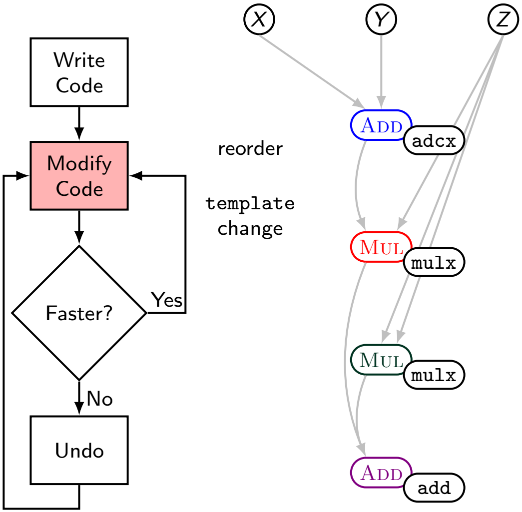


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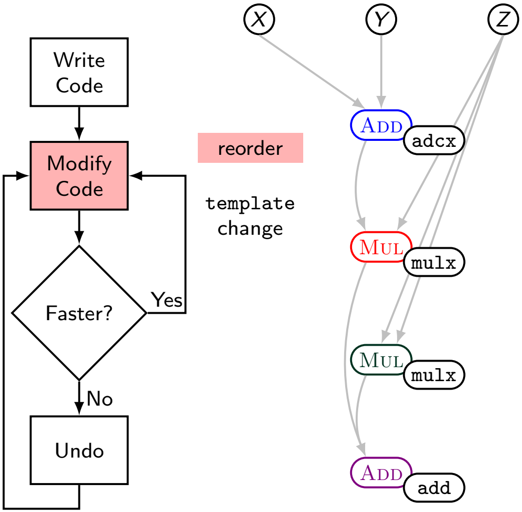


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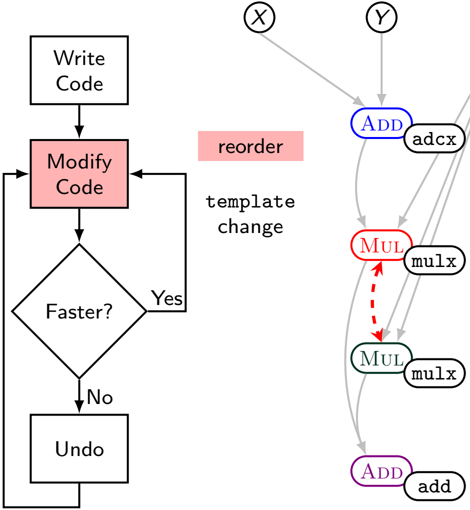


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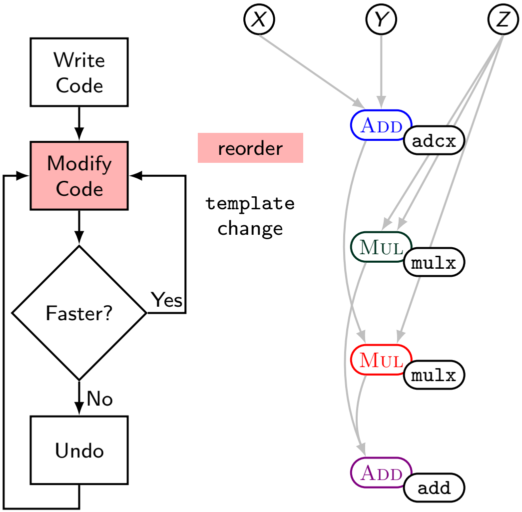


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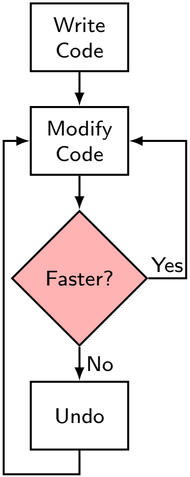

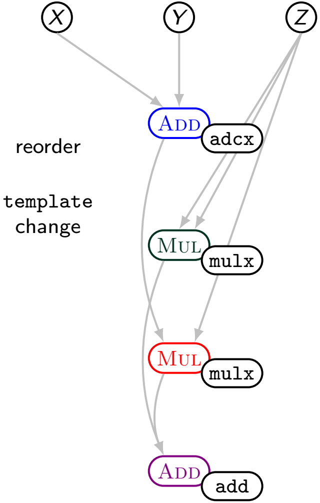


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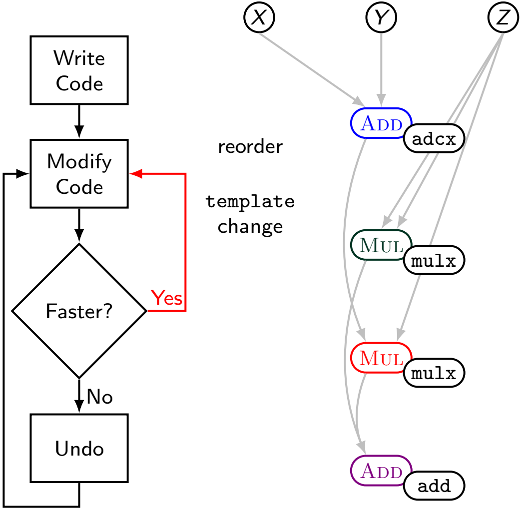


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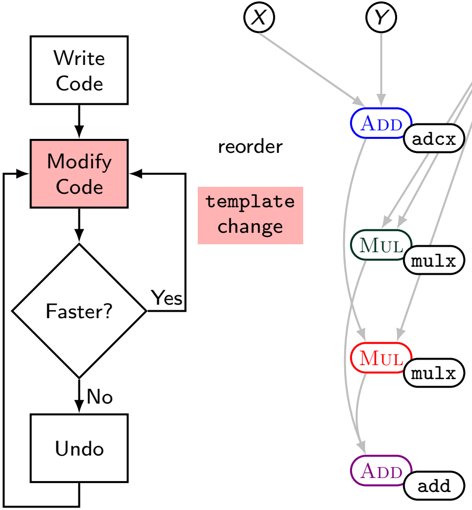


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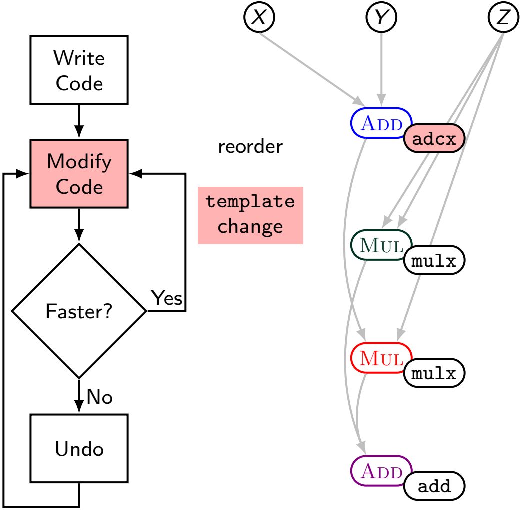


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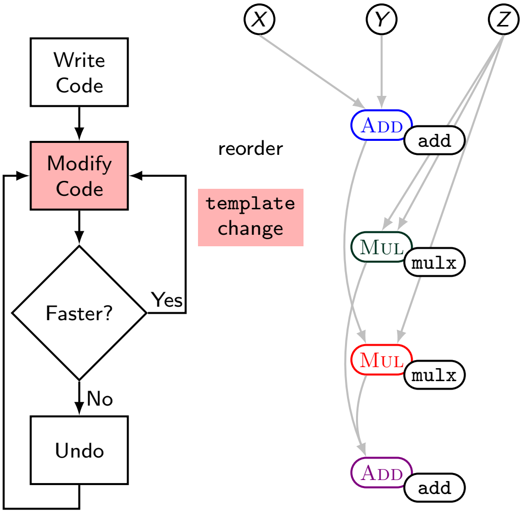


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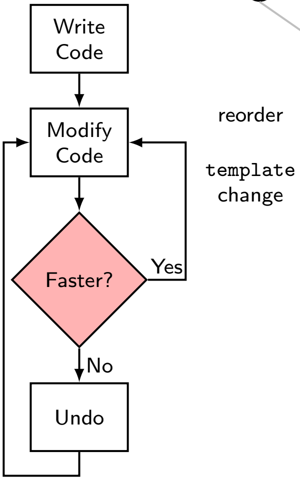

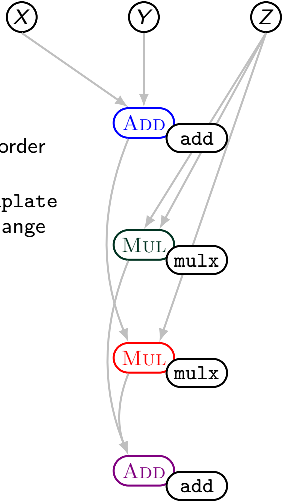

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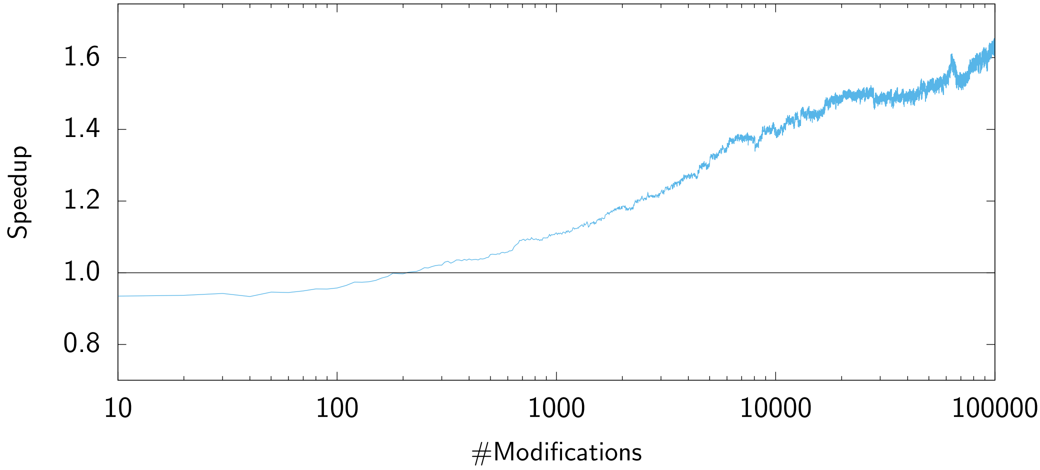
Performance



Fiat Cryptography

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[Erbsen et al. 2019, IEEE S&P]

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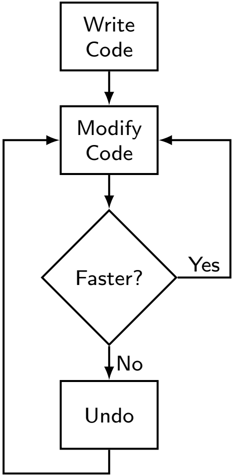

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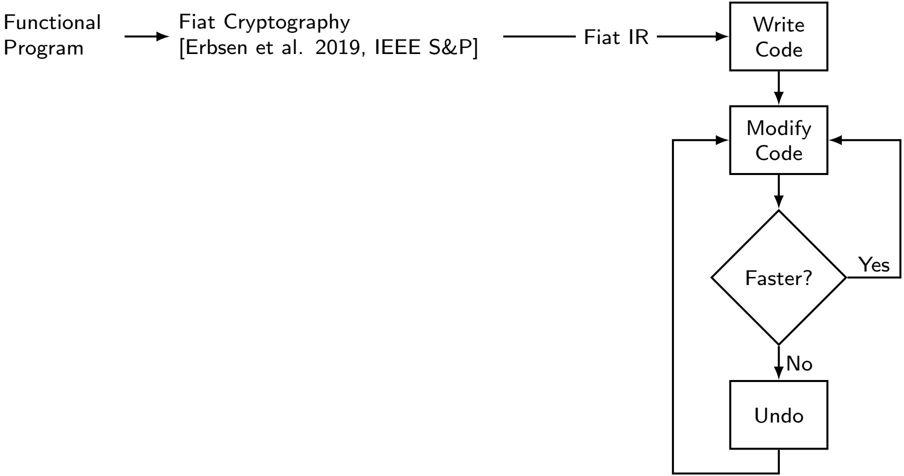

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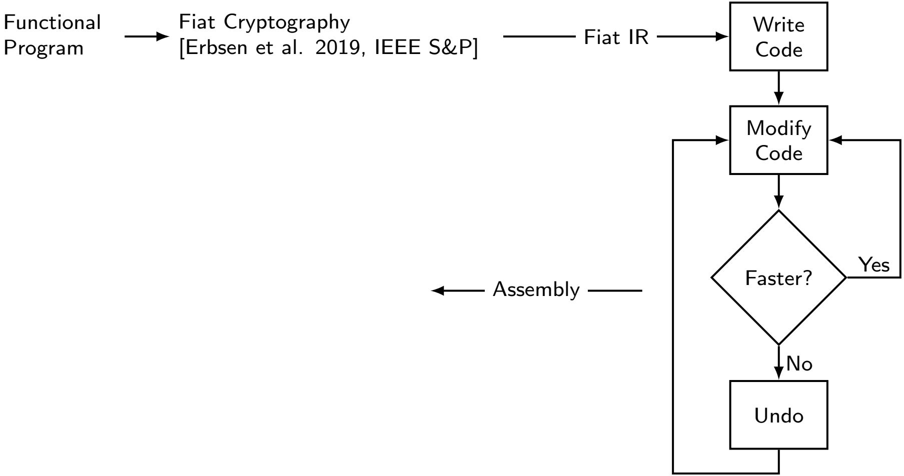

Performance: Field Arithmetic

Geometric Mean (4x AMD, 6x Intel)

	Multiply		Square	
Curve	Clang	GCC	Clang	GCC
Curve25519				
P-224				
P-256				
P-384				
SIKEp434				
Curve448				
P-521				
Poly1305				
secp256k1				

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	Multiply		Square	
Curve	Clang	GCC	Clang	GCC
Curve25519	1.19	1.14	1.14	1.18
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Curve25519	1.19	1.14	1.14	1.18
P-224	1.31	1.87	1.24	1.84
P-256	1.27	1.79	1.30	1.85
P-384	1.12	1.66	1.08	1.60
SIKEp434	1.30	1.70	1.29	1.83
Curve448	1.02	0.95	1.00	0.99
P-521	1.20	1.06	1.25	1.11
Poly1305	1.10	1.15	1.09	1.16
secp256k1	1.34	1.73	1.32	1.74

Performance: Scalar Multiplication

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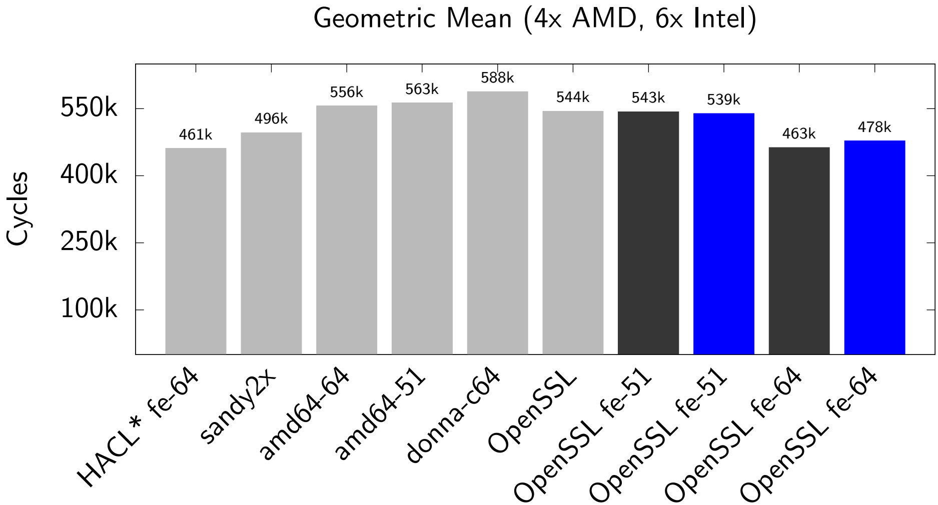

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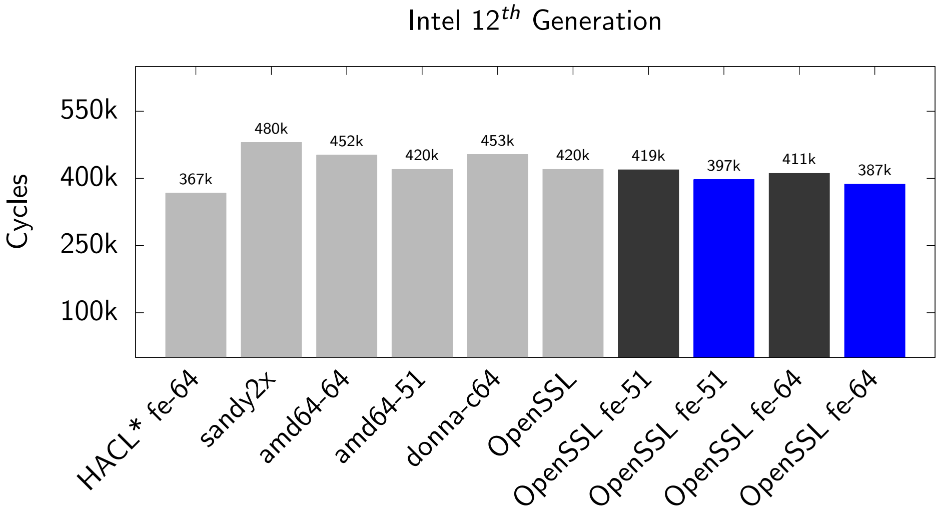
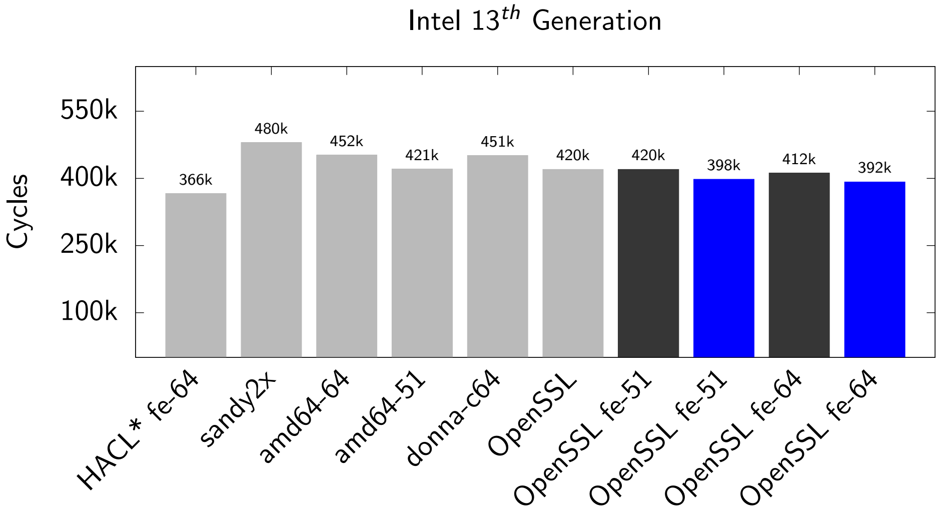
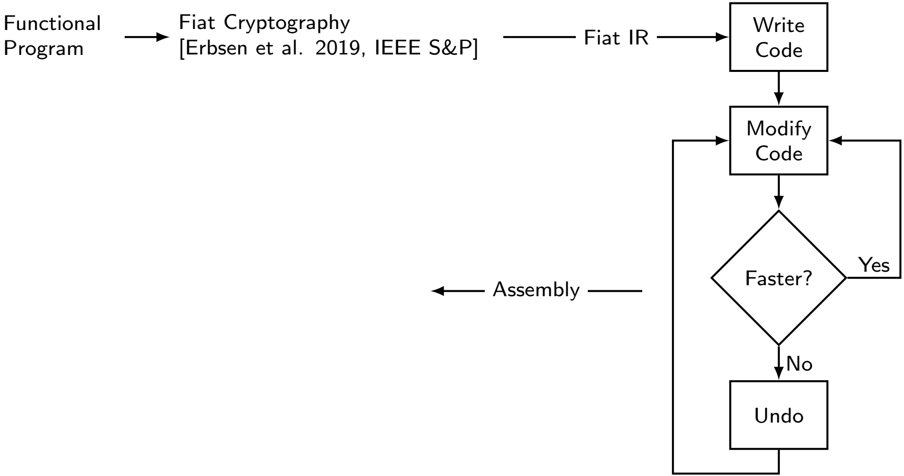


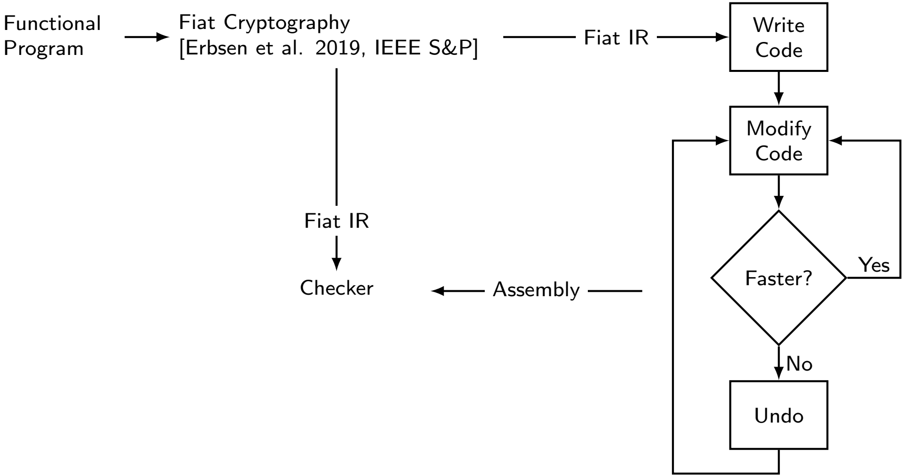
Performance: Scalar Multiplication



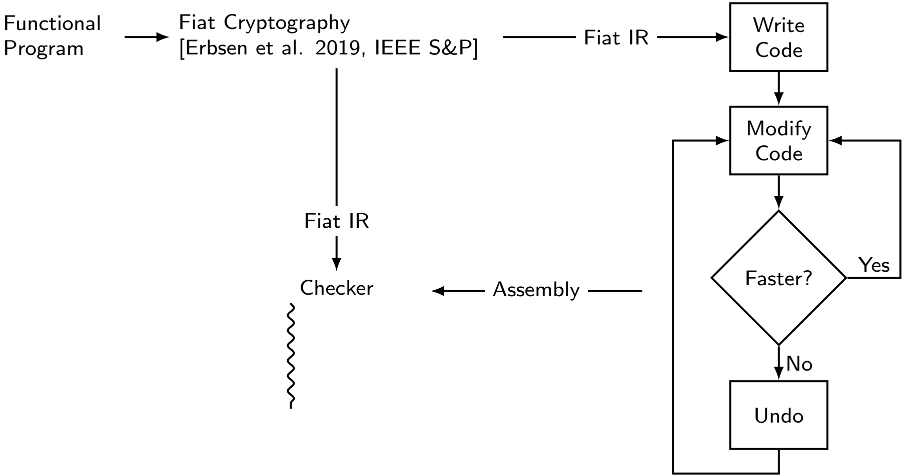
Correctness



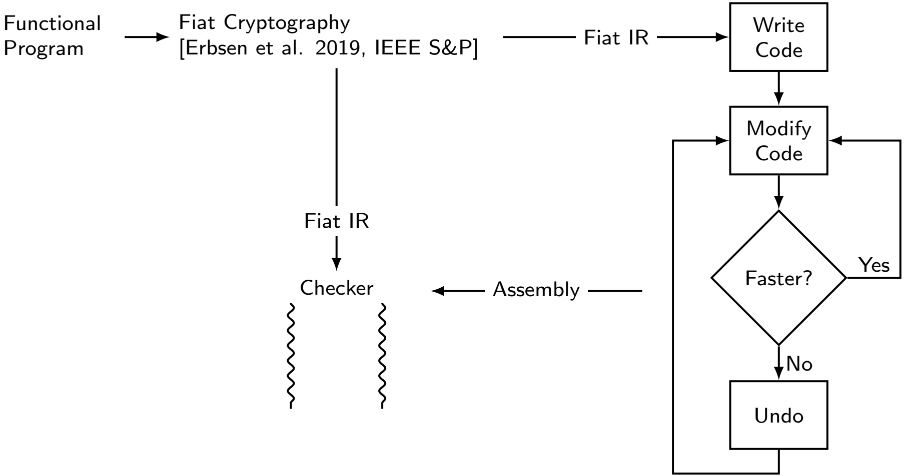
Correctness



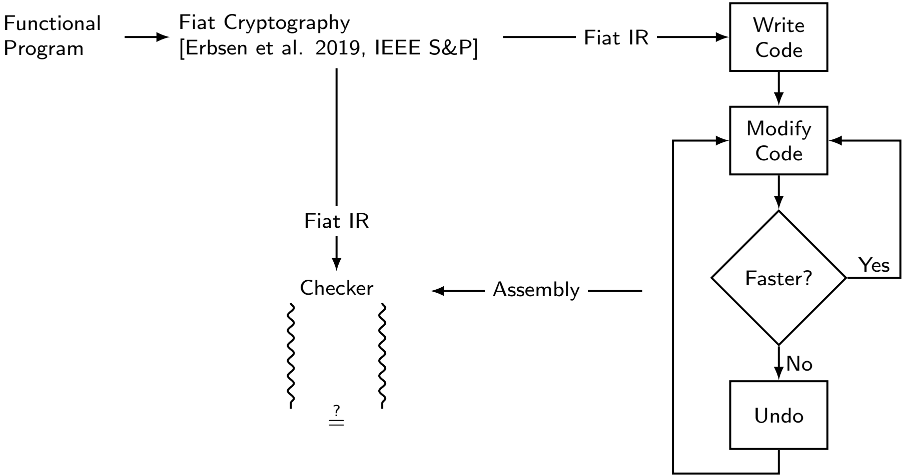
Correctness



Correctness



Correctness



Summary

Summary

Compilation of cryptographic code
$\implies$ Search

Summary

Compilation of cryptographic code
$\implies$ Search

Random Local Search + Runtime

Summary

Compilation of cryptographic code
$\implies$ Search

Random Local Search + Runtime

Proven-correct assembly for field arithmetic by Fiat Cryptography now with on-par performance to hand-optimized assembly.

Summary

Compilation of cryptographic code
$\Longrightarrow$ Search

Random Local Search + Runtime

Proven-correct assembly for field arithmetic by Fiat Cryptography now with on-par performance to hand-optimized assembly.

Summary

GitHub Project

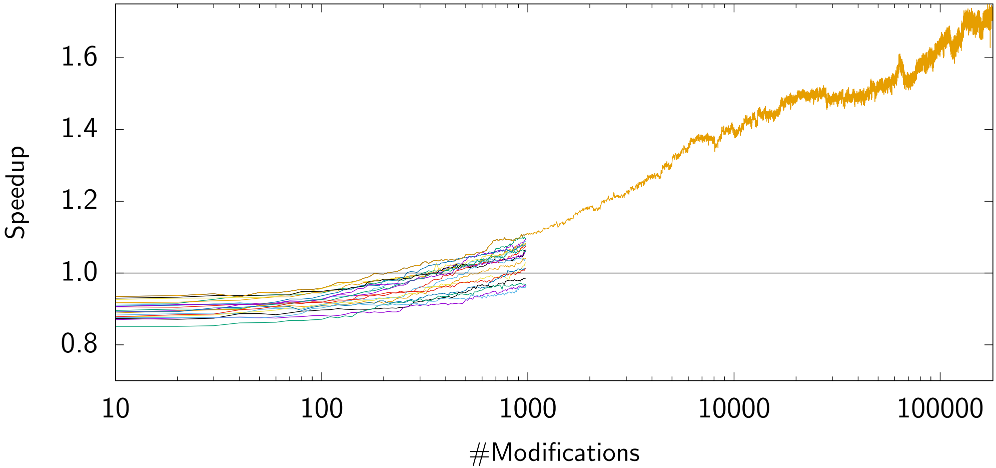
Compilation of cryptographic code
$\implies$ Search

Random Local Search + Runtime

Proven-correct assembly for field arithmetic by Fiat Cryptography now with on-par performance to hand-optimized assembly.

`https://0xade1a1de.github.io/CryptOpt`

Bet and Run


Speedup
1.6
1.4
1.2
1.0
0.8
10
100
1000
10000
100000
#Modifications