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

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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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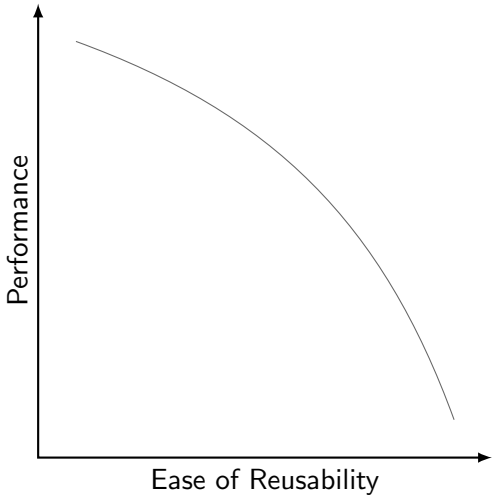

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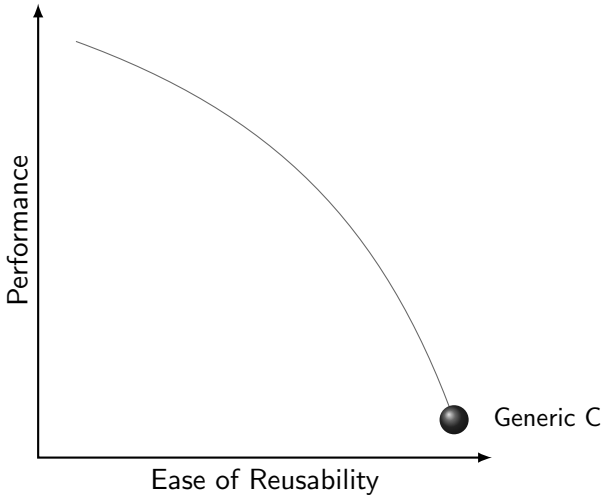

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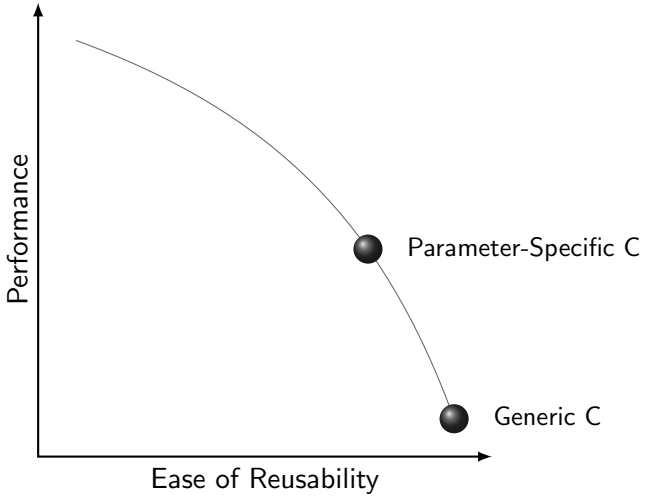

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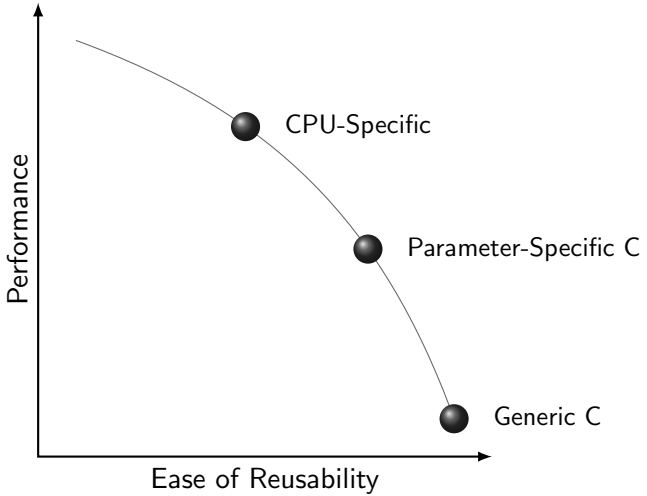

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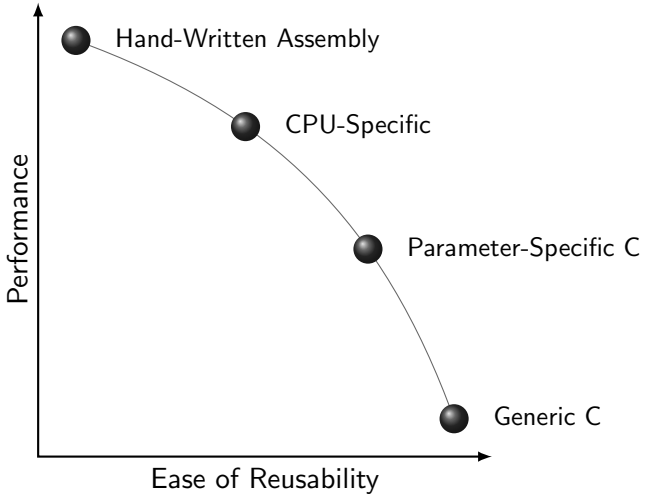

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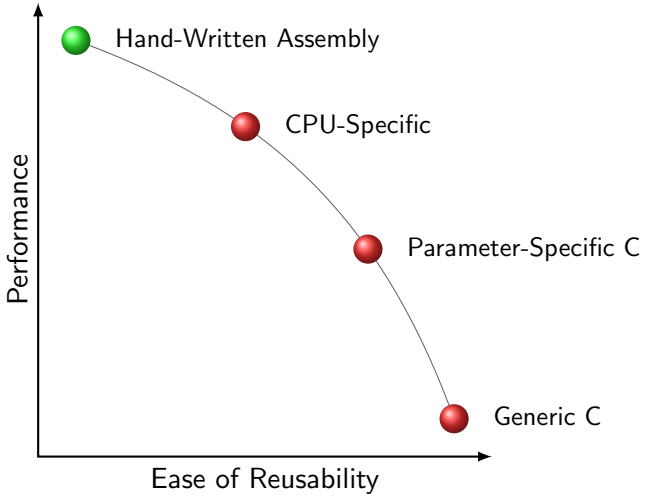

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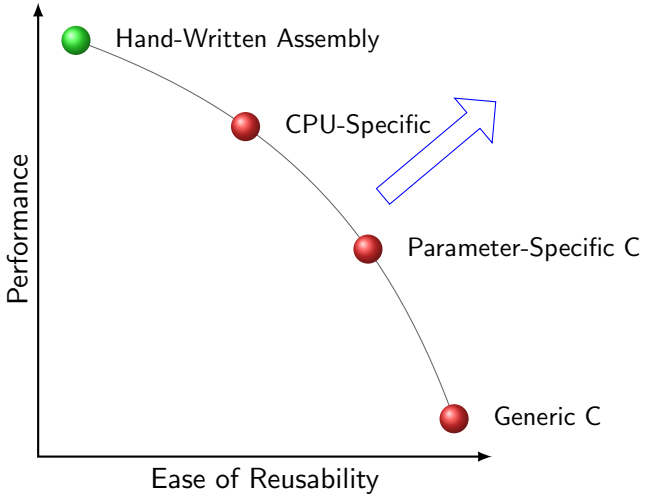

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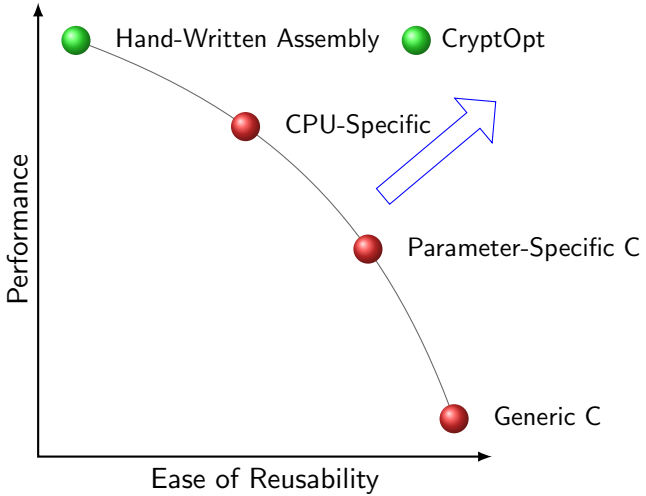

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2. Prove it correct.

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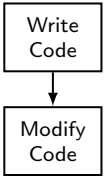

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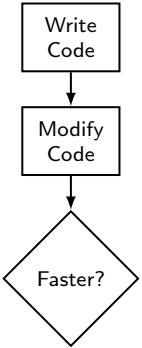

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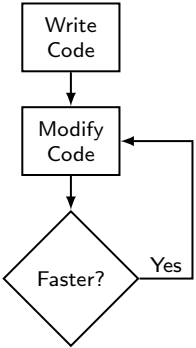

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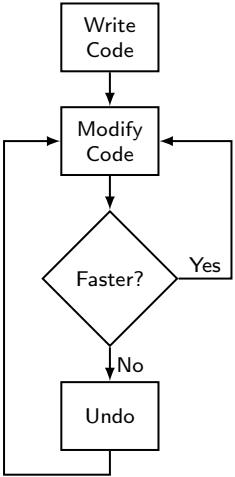

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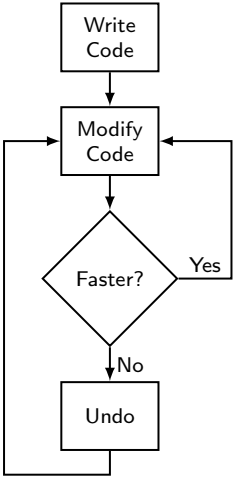

"Random Local Search"

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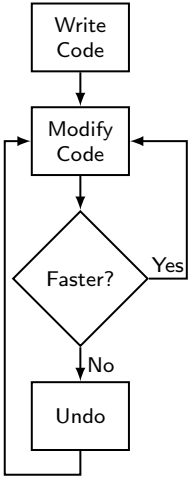

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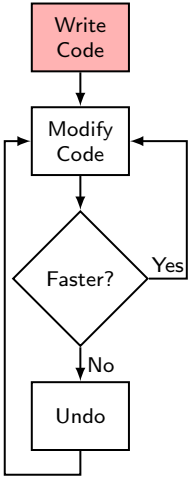

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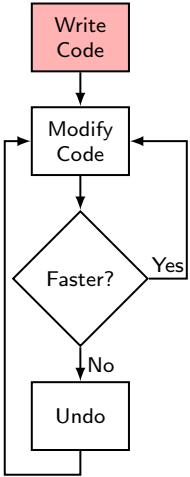

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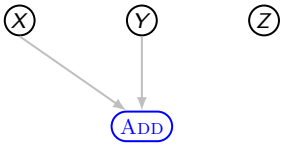

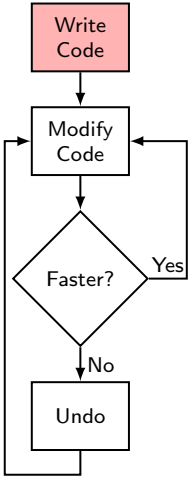

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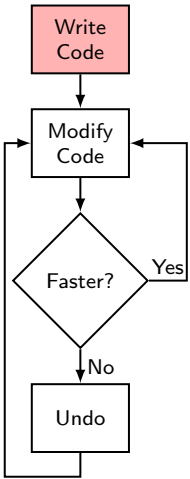

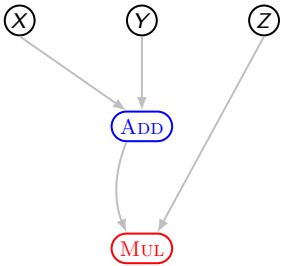

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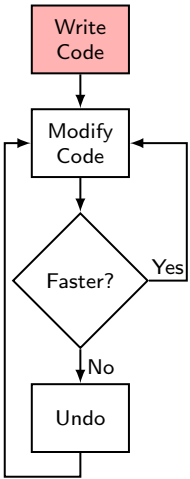

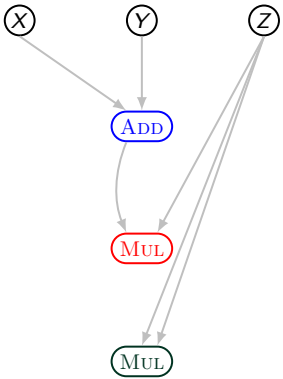

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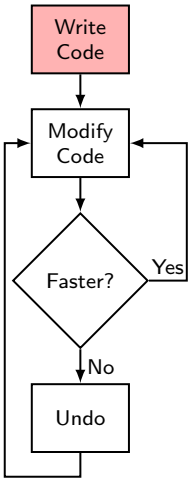

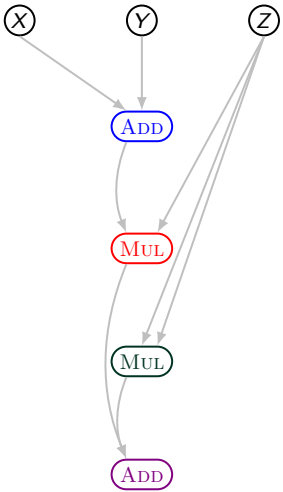

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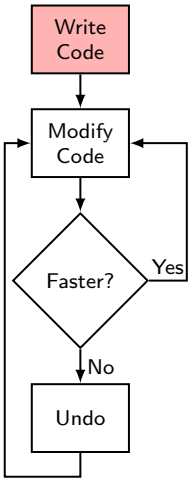

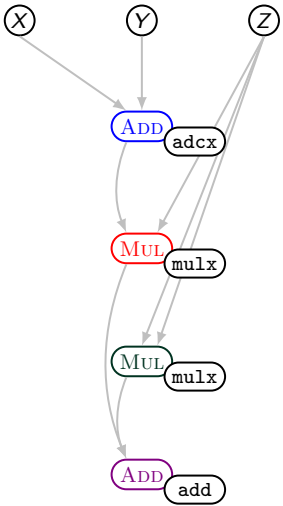

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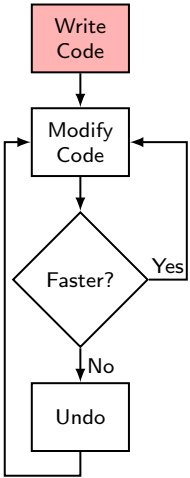

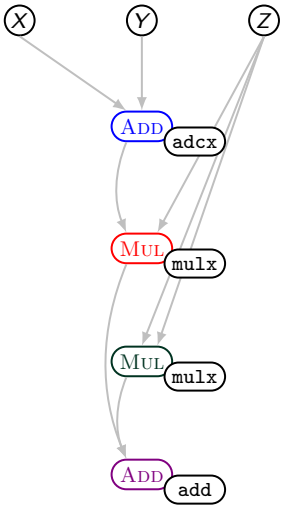


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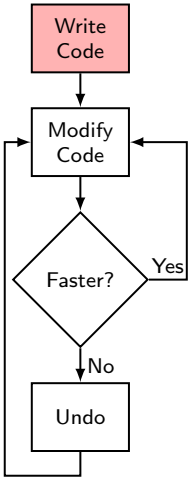

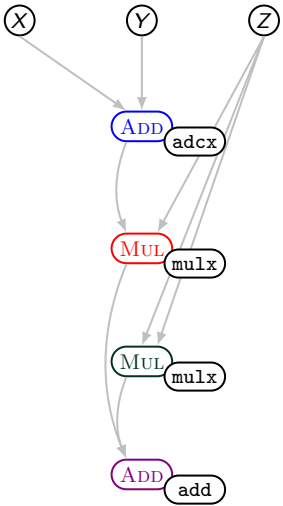


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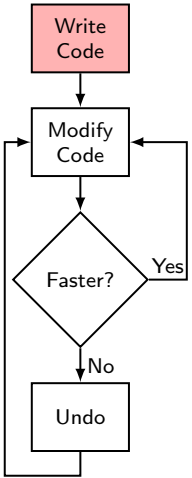

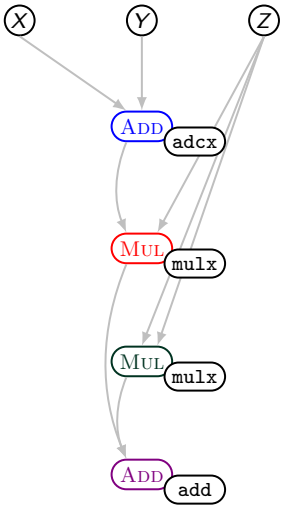


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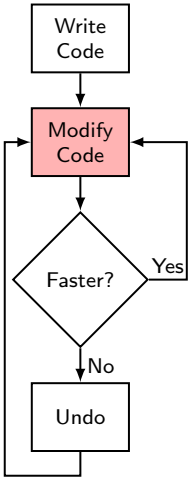

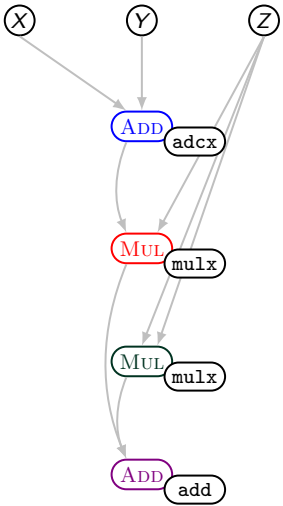


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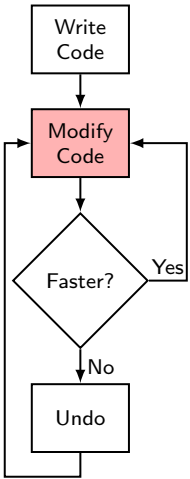
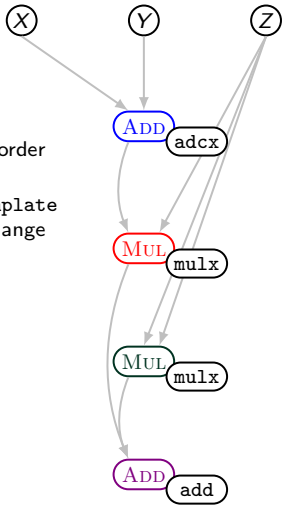


reorder

template change

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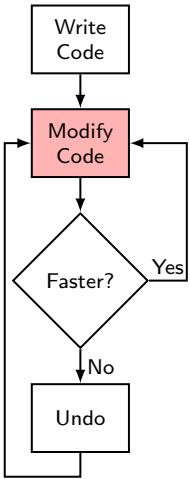

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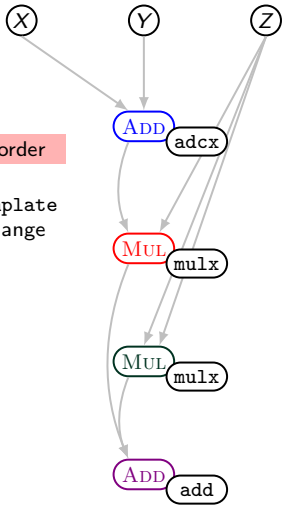


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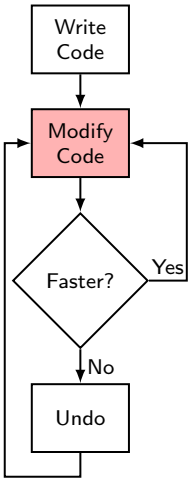

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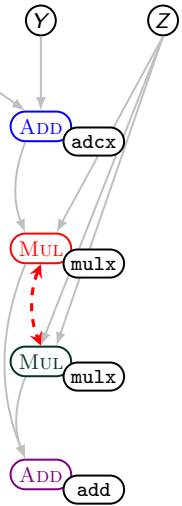


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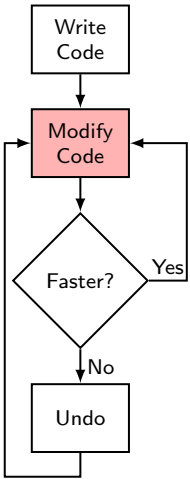

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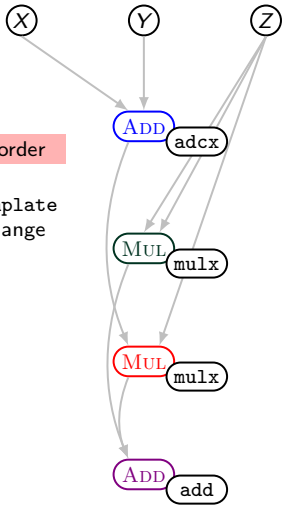


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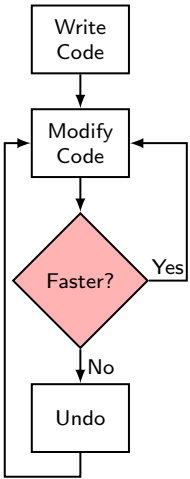

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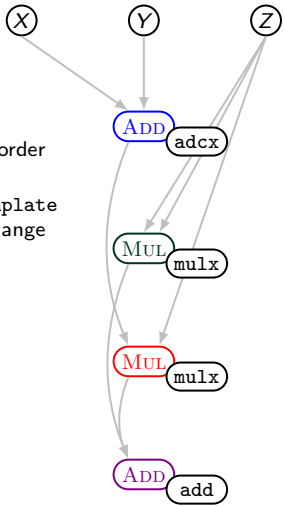


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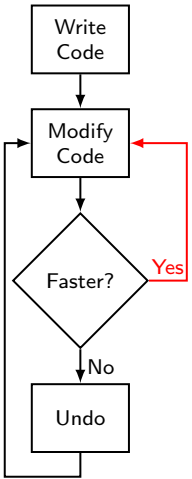

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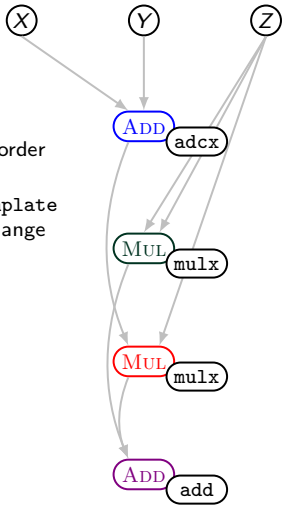


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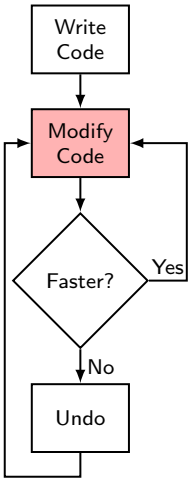
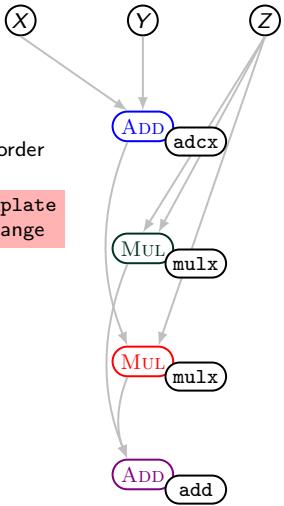


reorder

template change

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mov rax, [X]
clc
adcx rax, [Y]

mov rdx, [Z]
mulx r10, r11, [Z]

mulx r8, r9, rax

add r11, r9
mov [out], r11
```

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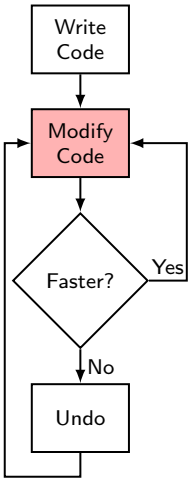

reorder

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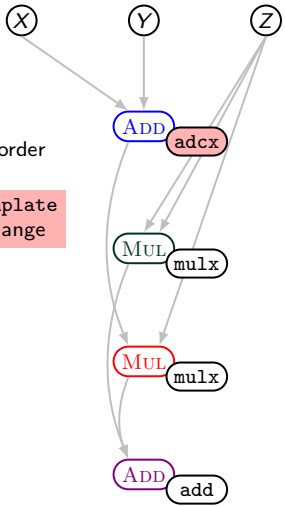


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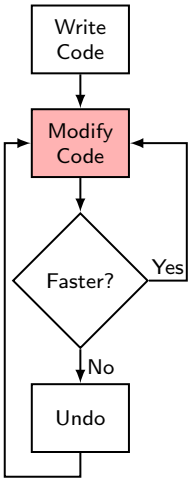

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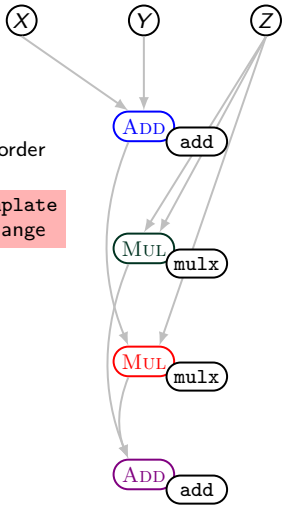


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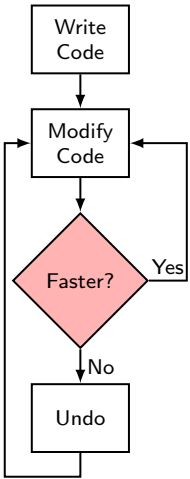
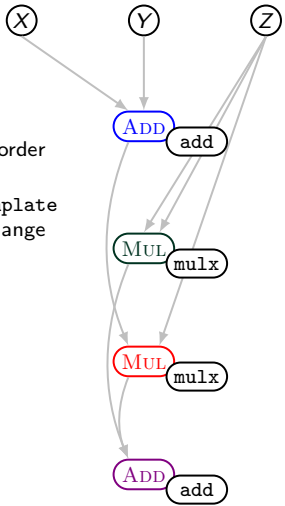


reorder

template change

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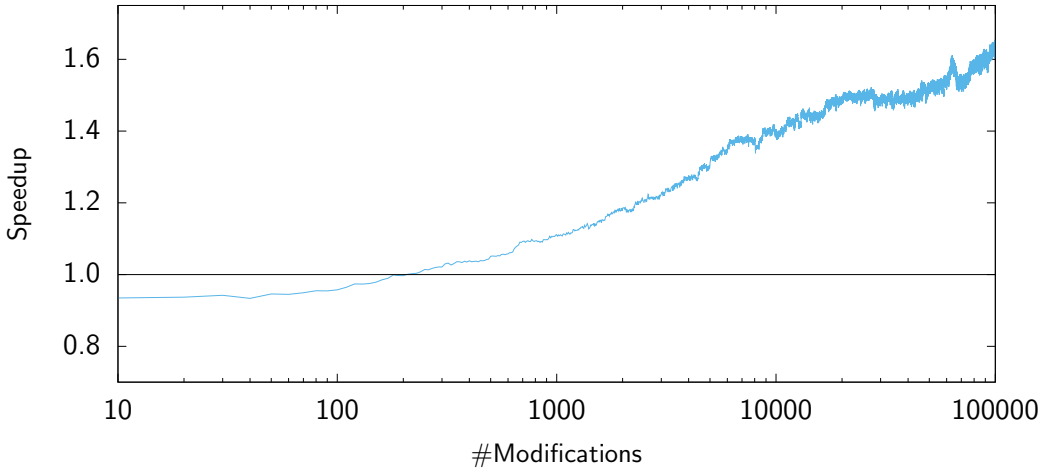
Performance



Fiat Cryptography

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

Fiat Cryptography

Functional Program → Fiat Cryptography [Erbsen et al. 2019, IEEE S&P]

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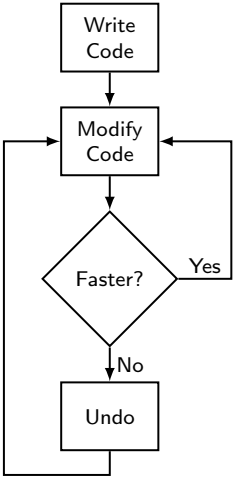
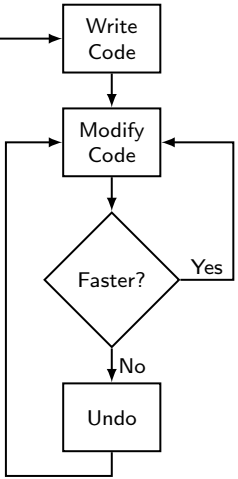
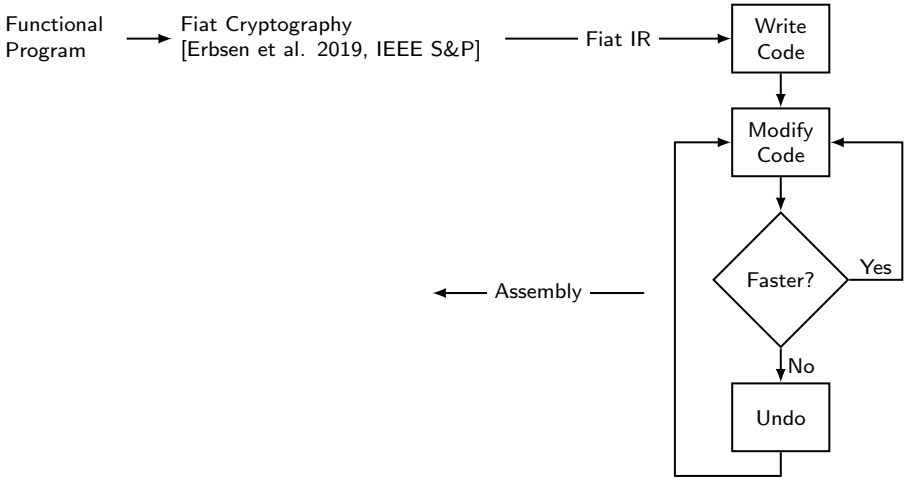


Fiat Cryptography

Functional Program → Fiat Cryptography [Erbsen et al. 2019, IEEE S&P] — Fiat IR →



Fiat Cryptography



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
P-224				
P-256				
P-384				
SIKEp434				
Curve448				
P-521				
Poly1305				
secp256k1				

Performance: Field Arithmetic

Geometric Mean (4x AMD, 6x Intel)

	Multiply		Square	
Curve	Clang	GCC	Clang	GCC
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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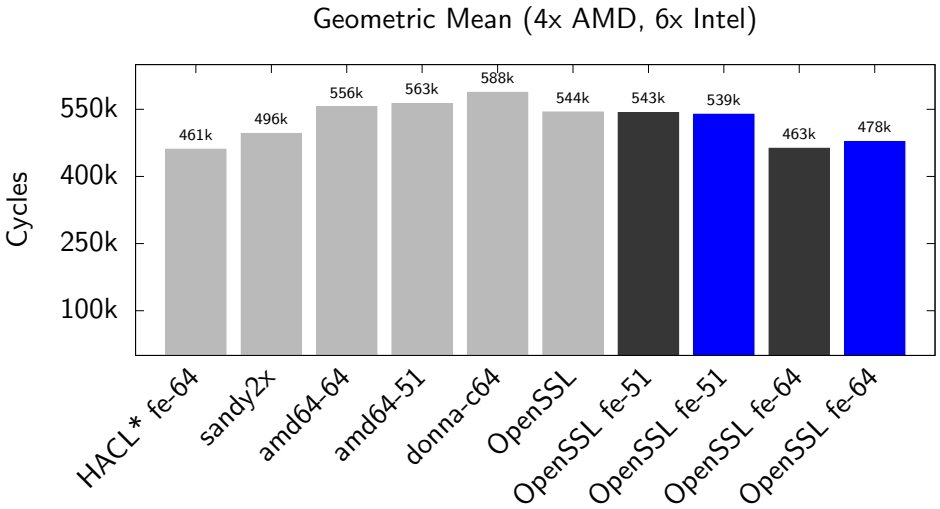

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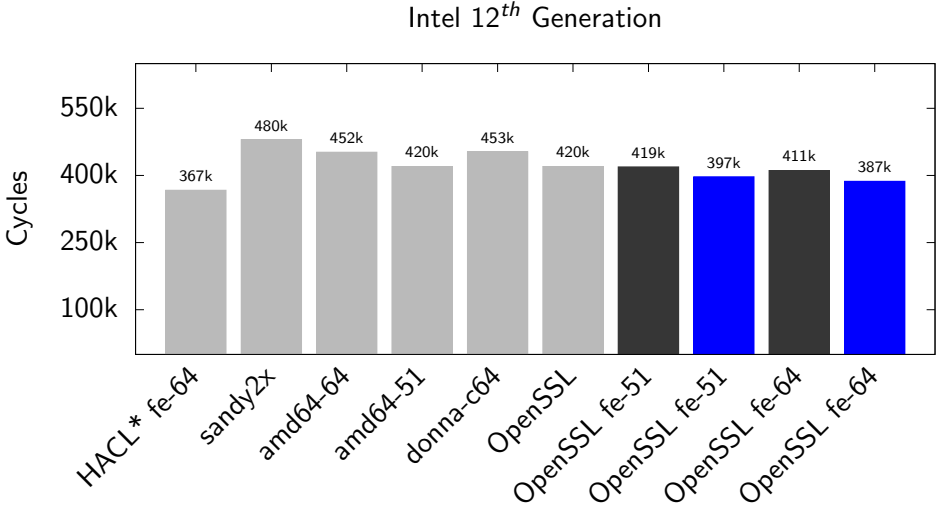

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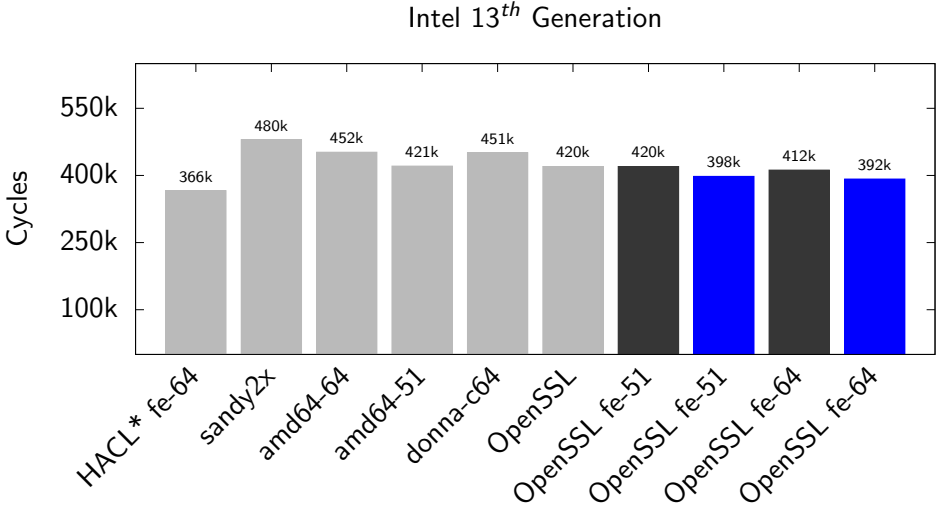
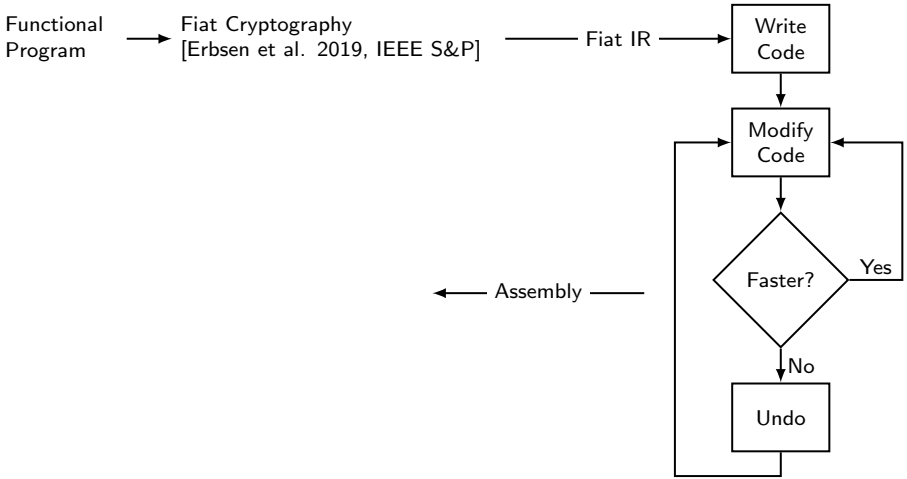
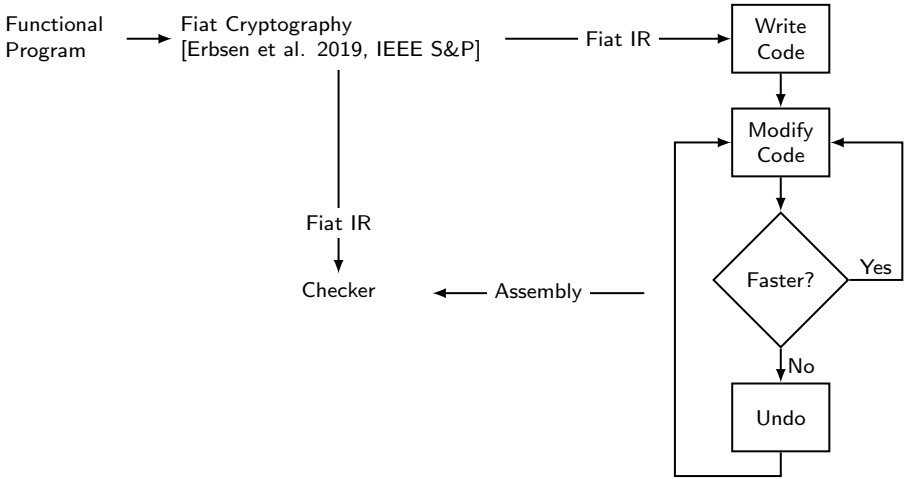


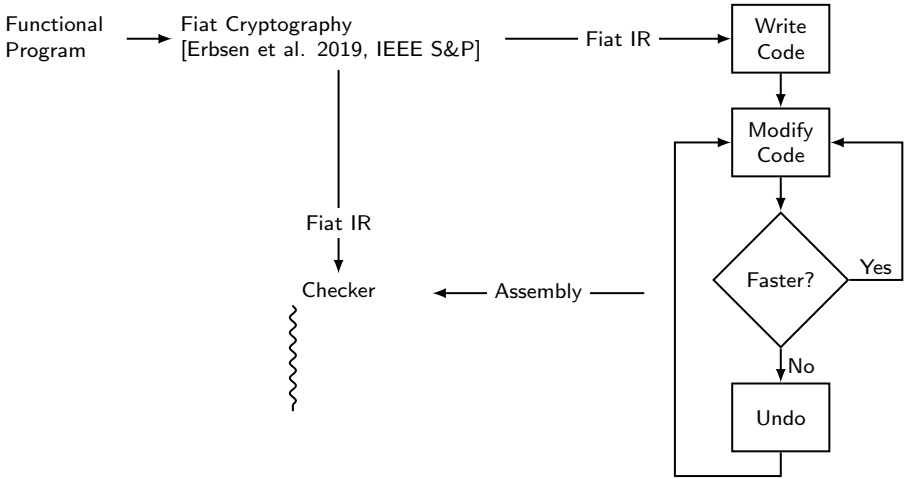
Correctness



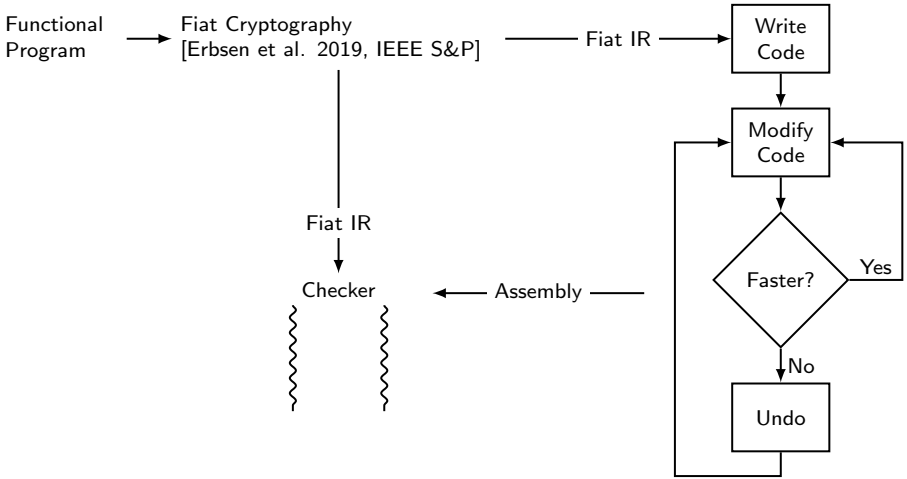
Correctness



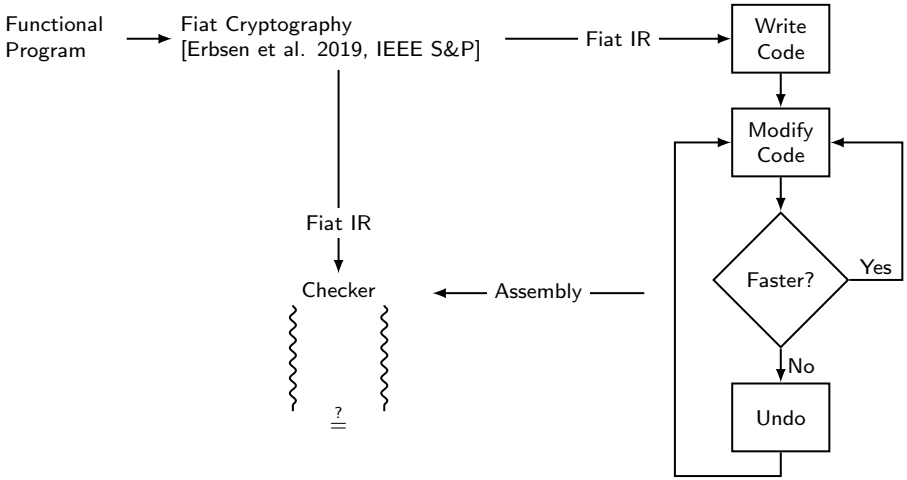
Correctness



Correctness



Correctness



Summary

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Compilation of cryptographic code
$\Longrightarrow$ Search

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Random Local Search + Runtime

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

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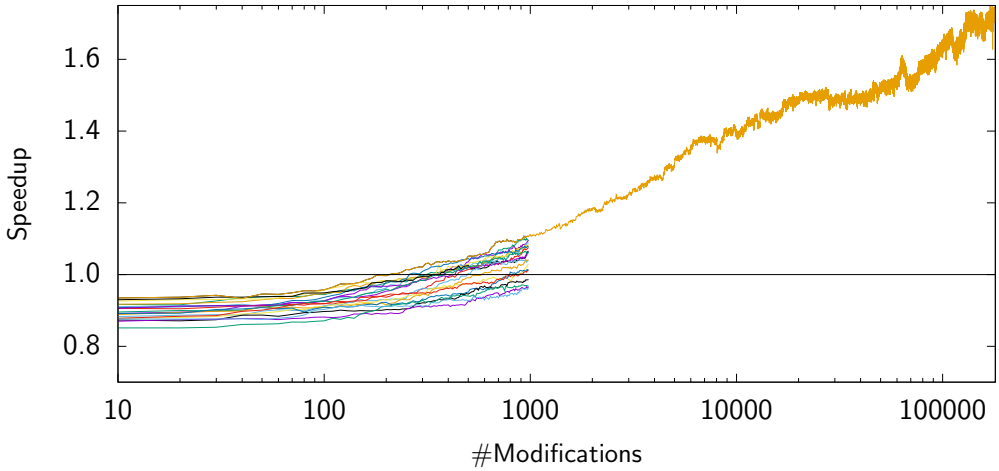
GitHub Project

`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