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

Motivation

LLVM

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OpenSSL
Cryptography and SSL/TLS Toolkit
$\longrightarrow$

LLVM

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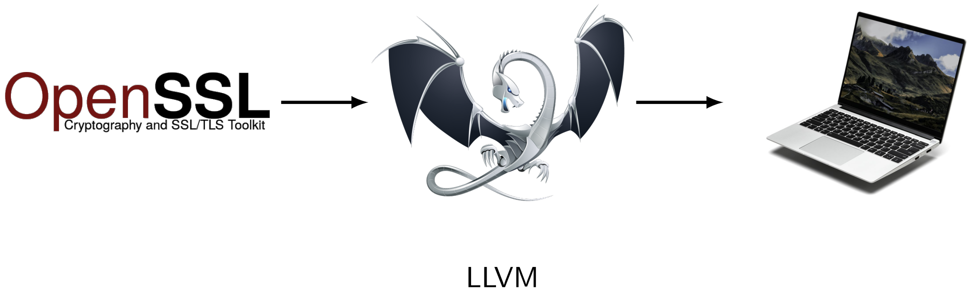

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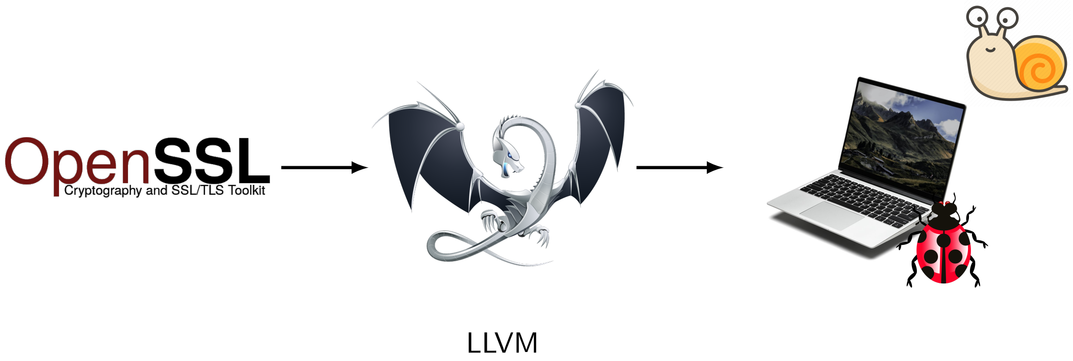

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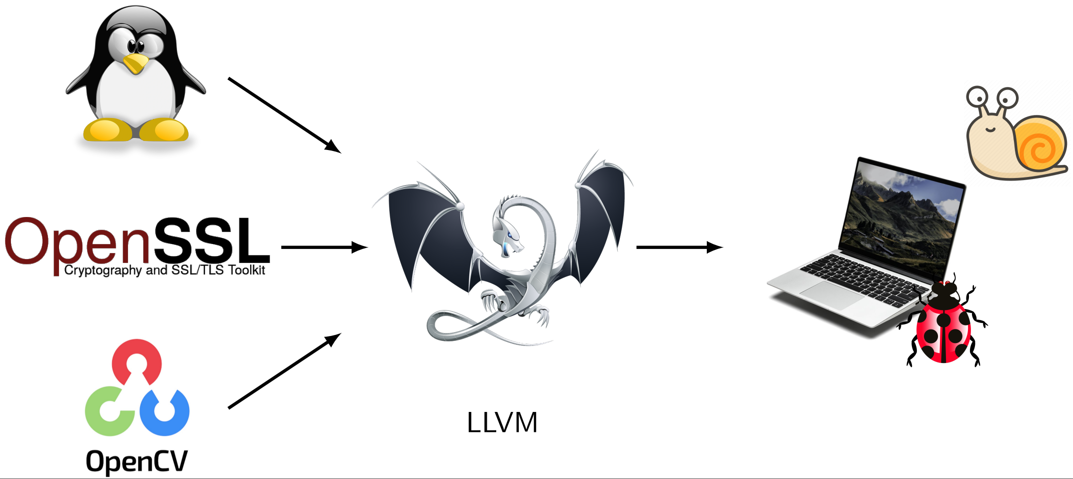

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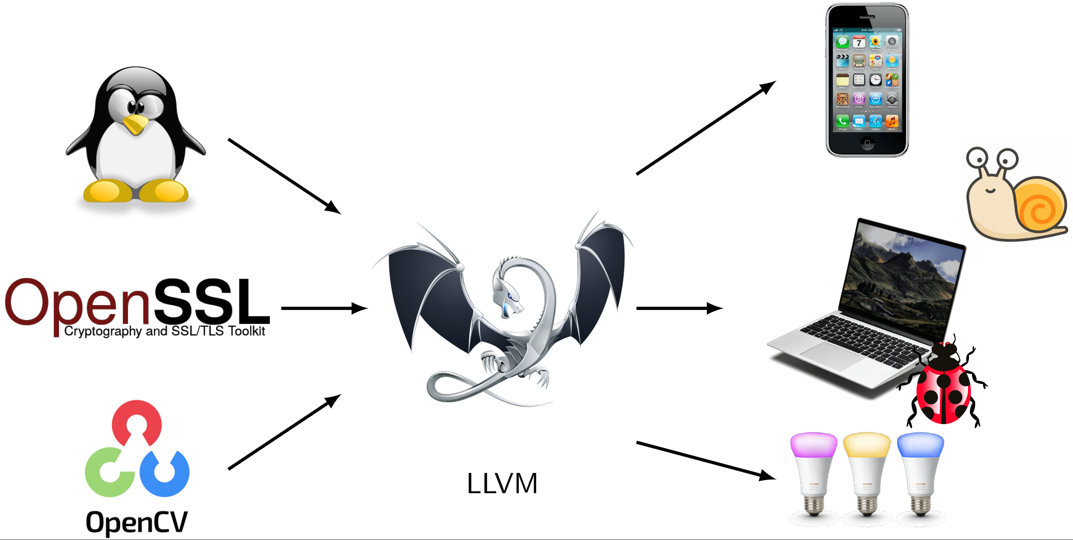

Code

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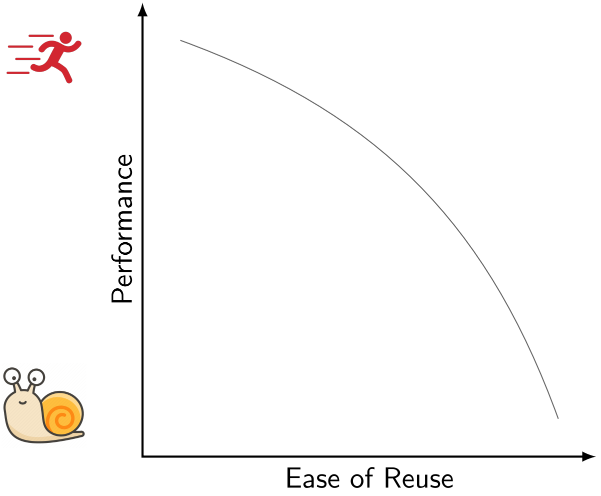

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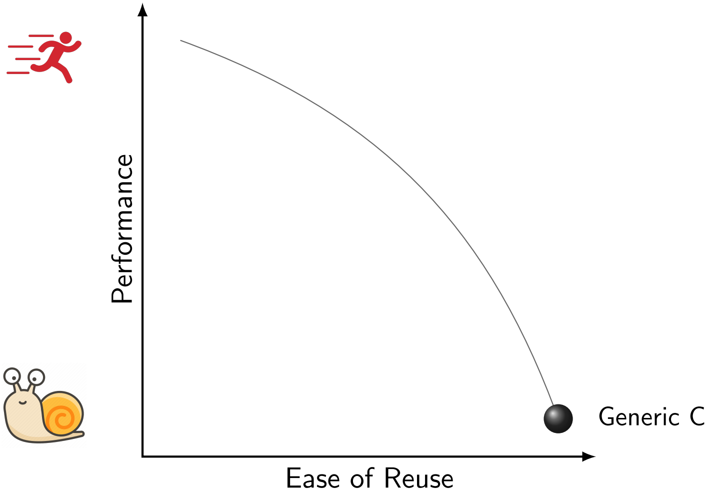

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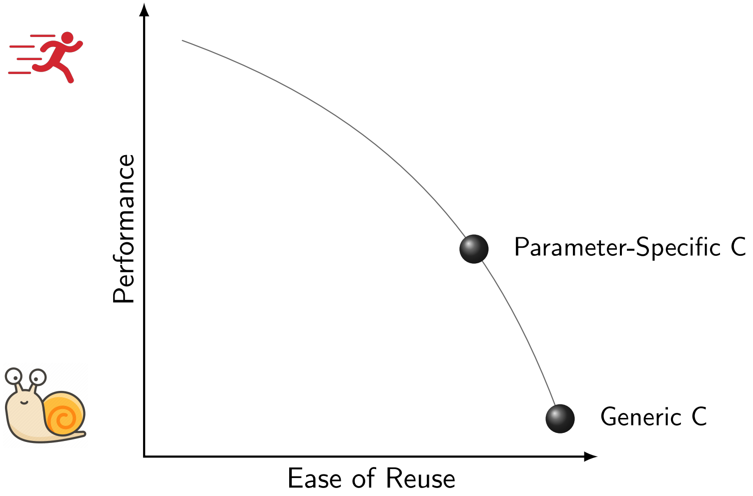

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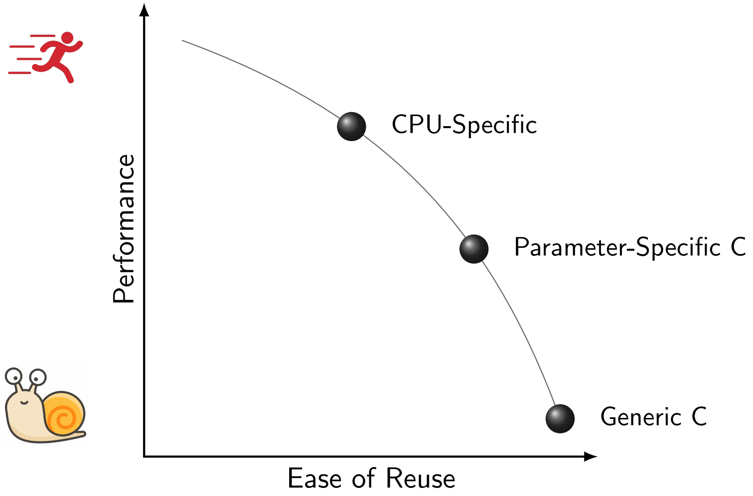
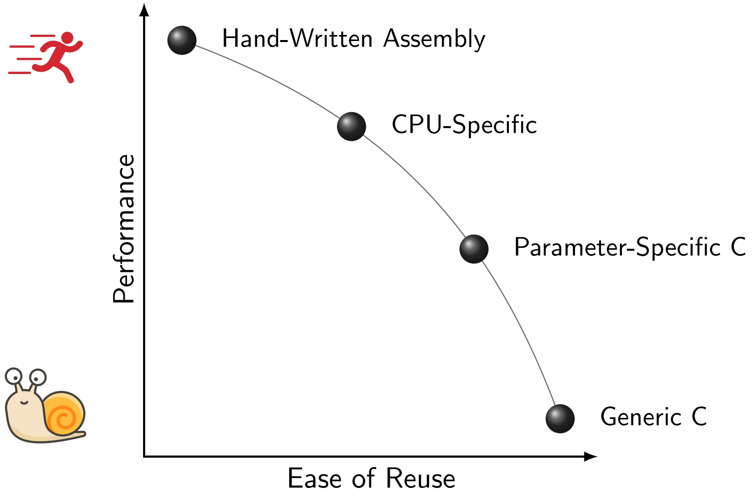

Performance
Ease of Reuse
CPU-Specific
Parameter-Specific C
Generic C

Code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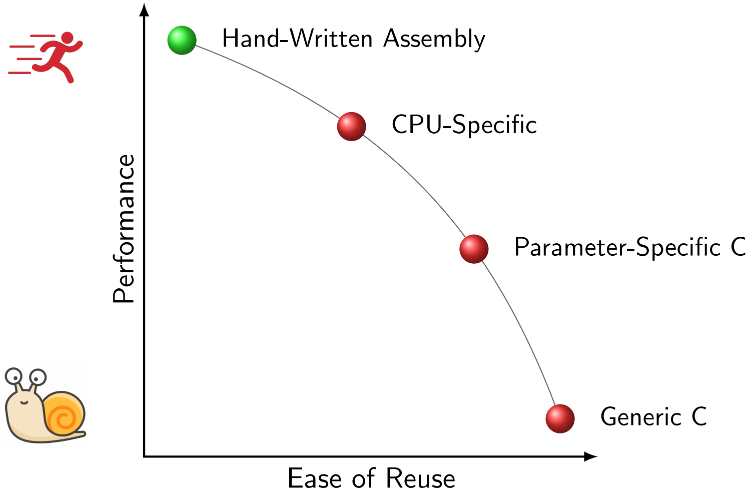
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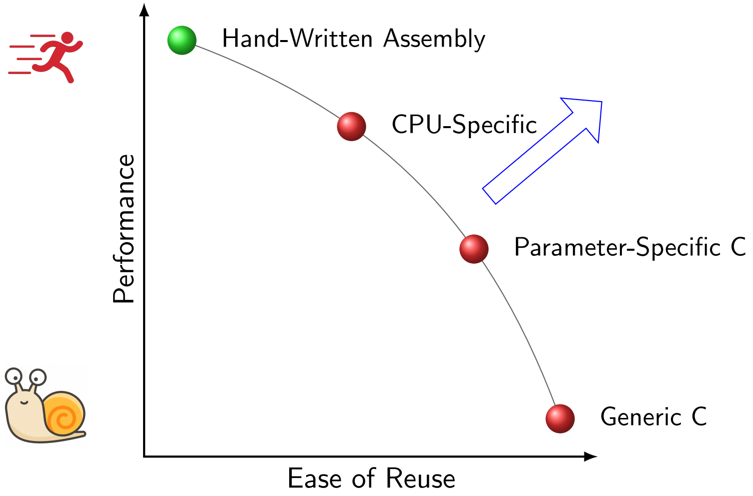
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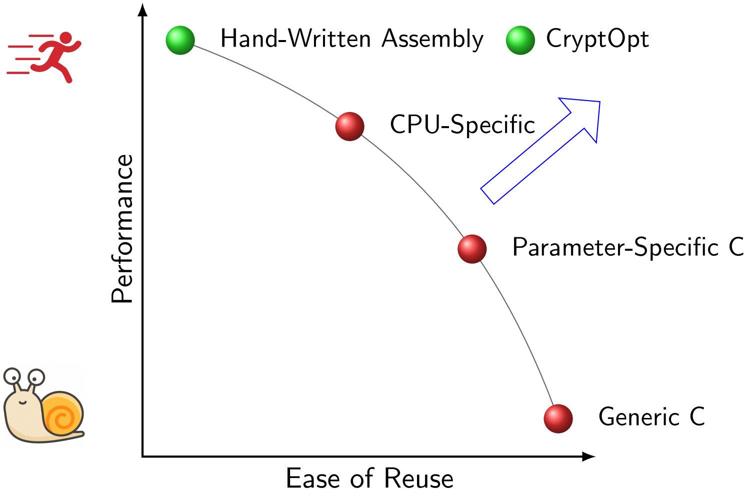
Hand-Written Assembly
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Idea

Observations:

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So. . .

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(How) can we exploit this?

So...

1. ~~Compiling to~~ $\rightarrow$ search for a fast implementation.
2. Prove it correct.

Search for Fast Implementation

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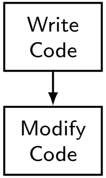

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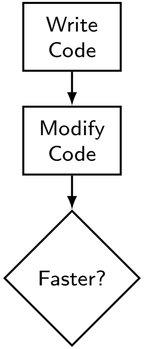

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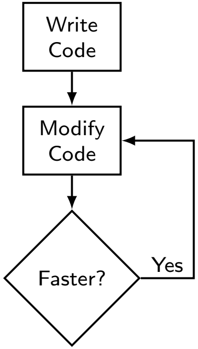

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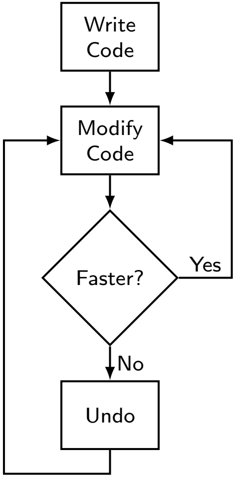

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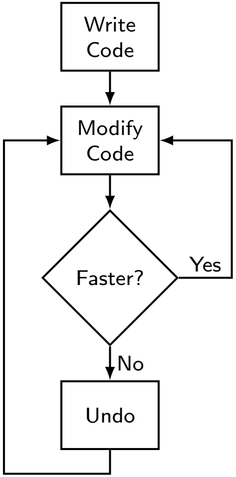

“Random Local Search”

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

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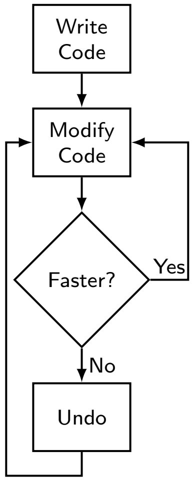

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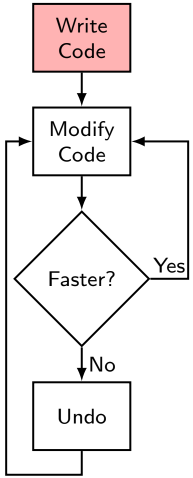

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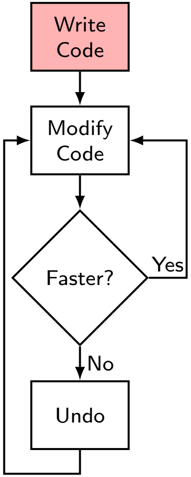

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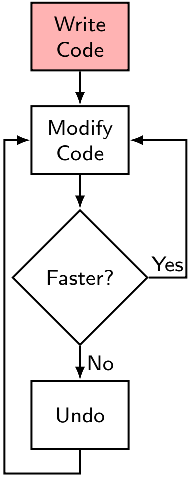

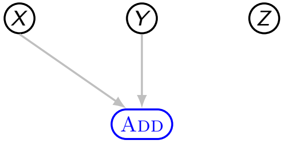

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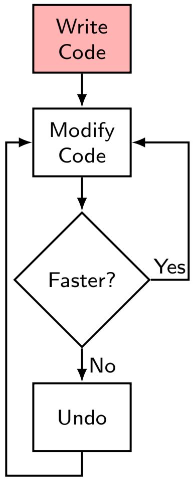

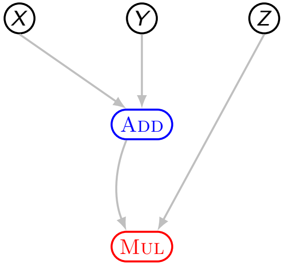

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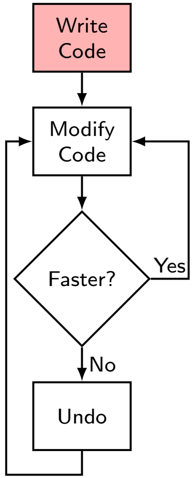

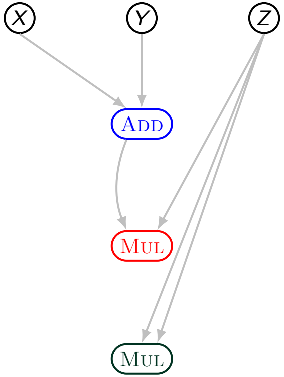

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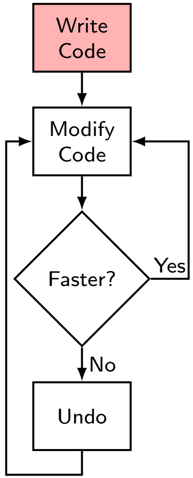

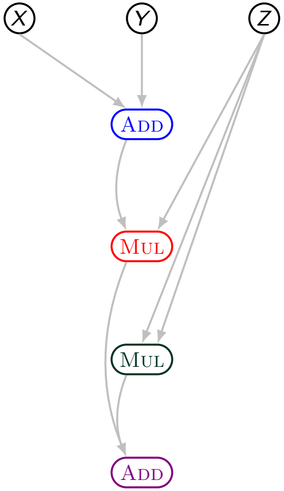

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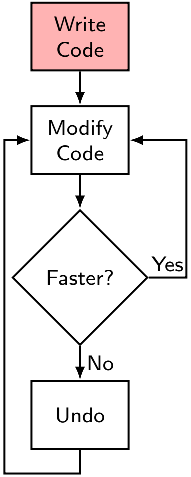

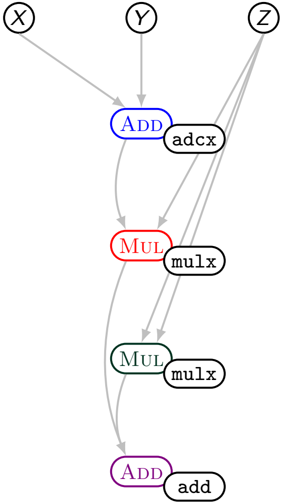

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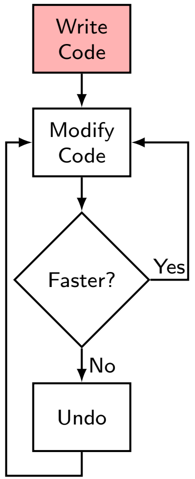

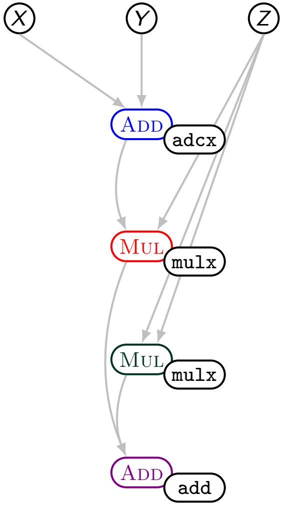

```
mov rax, [X]
clc
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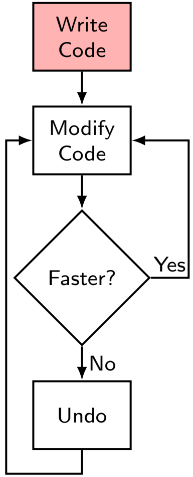

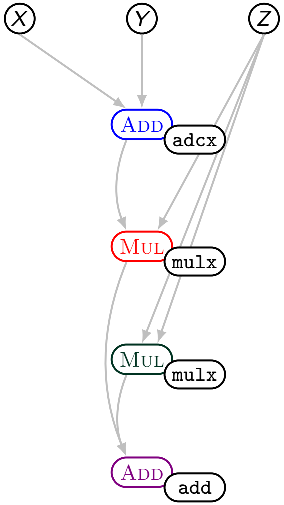

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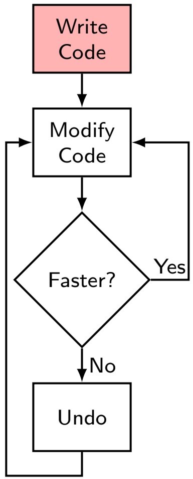

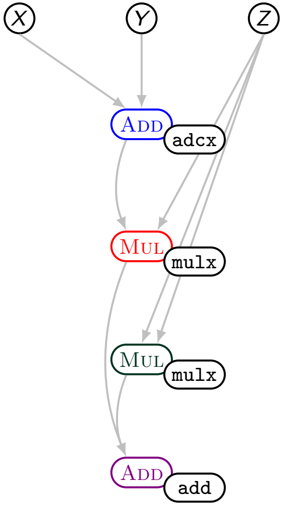

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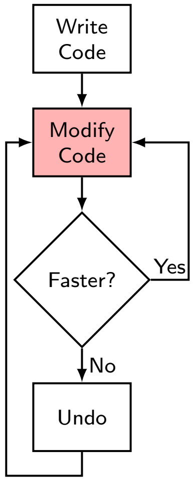

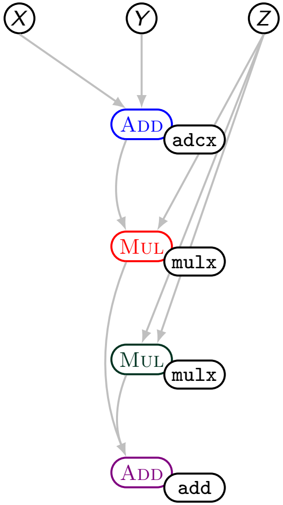

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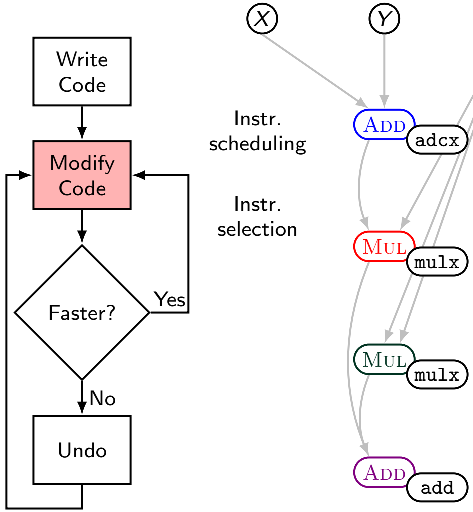

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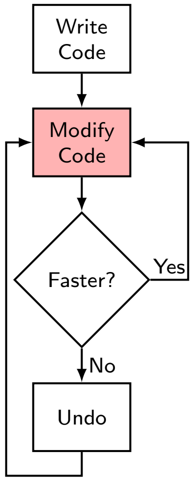
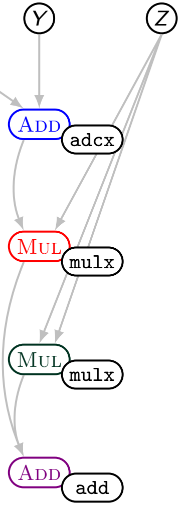


Instr. scheduling

Instr. selection



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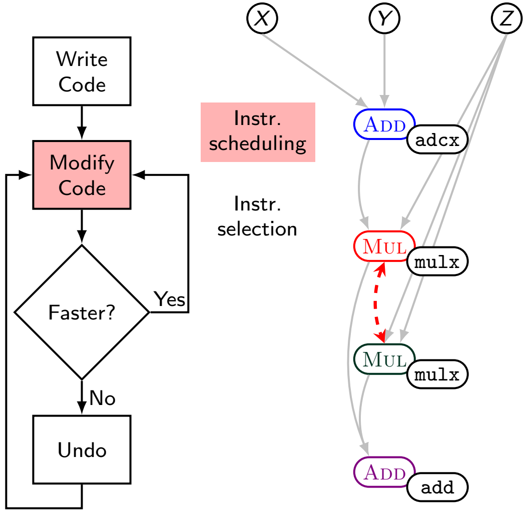

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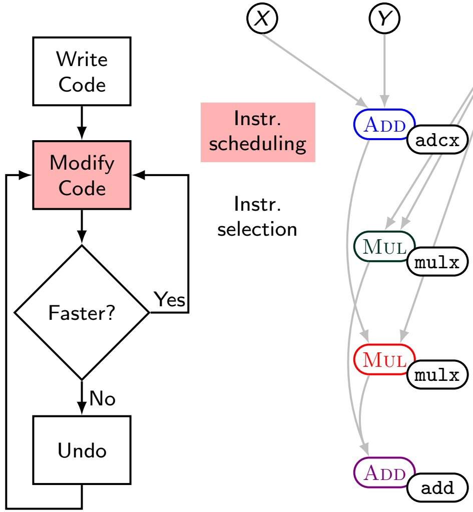

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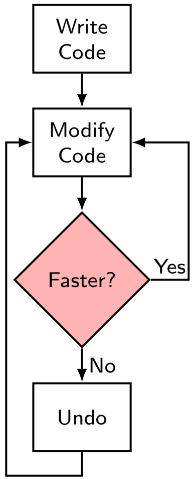

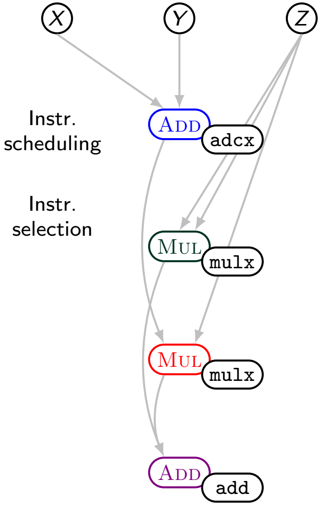

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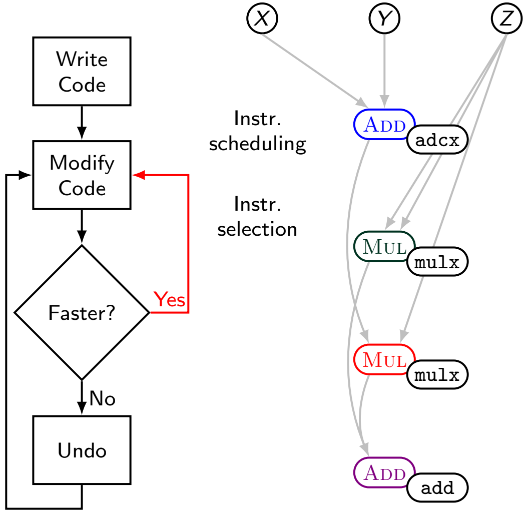

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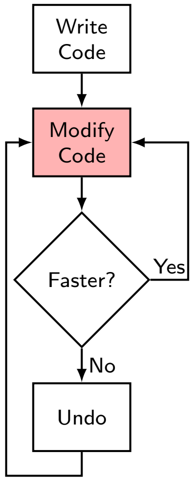

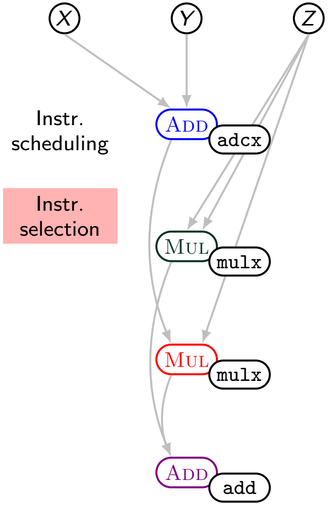

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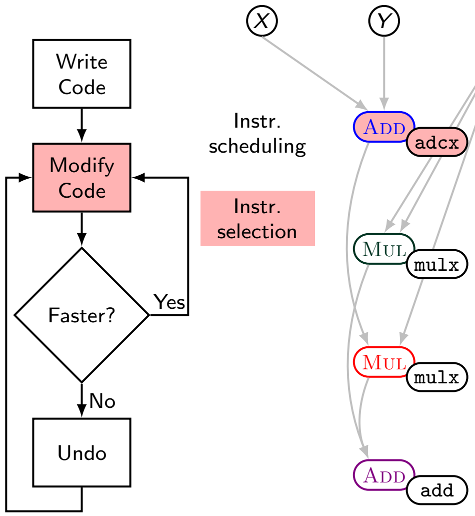

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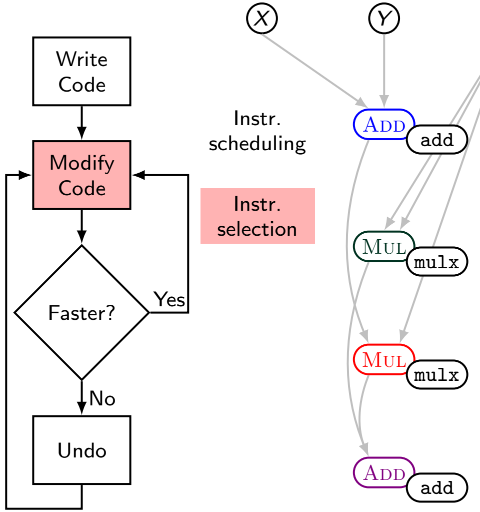

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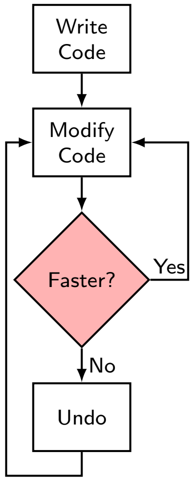

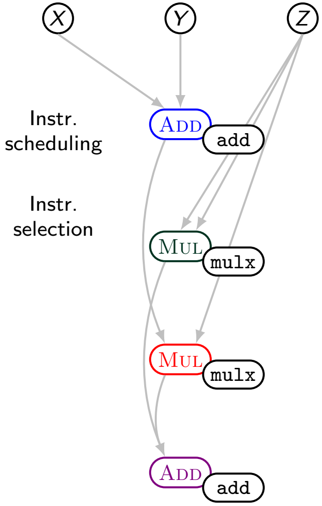

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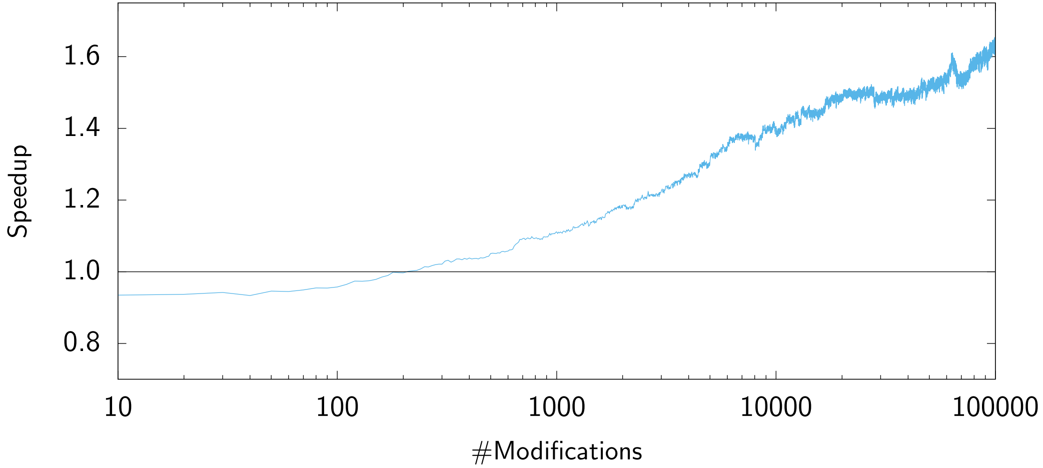
Performance



Fiat Cryptography

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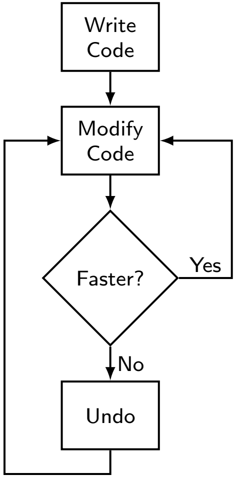
[Erbsen et al. 2019, IEEE S&P]

Fiat Cryptography

$$\text{Cryptographic Parameters} \longrightarrow \text{Fiat Cryptography [Erbsen et al. 2019, IEEE S\&P]}$$

Fiat Cryptography

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



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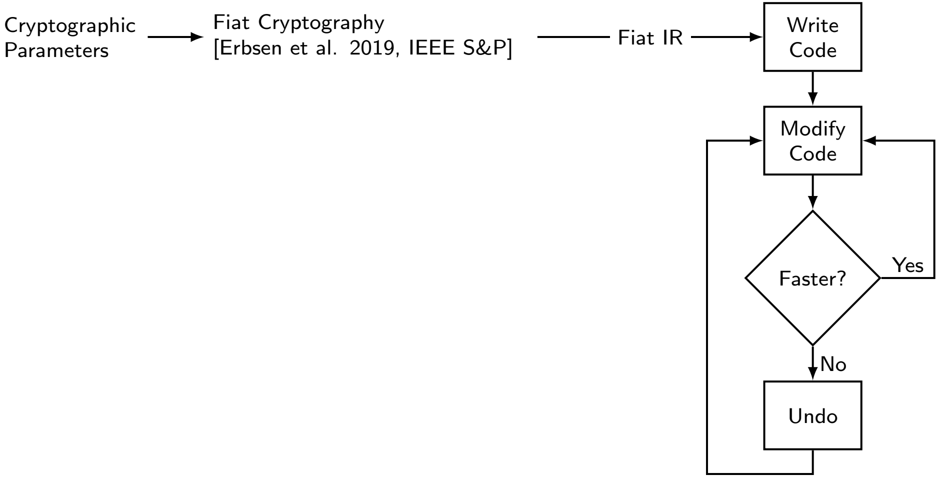

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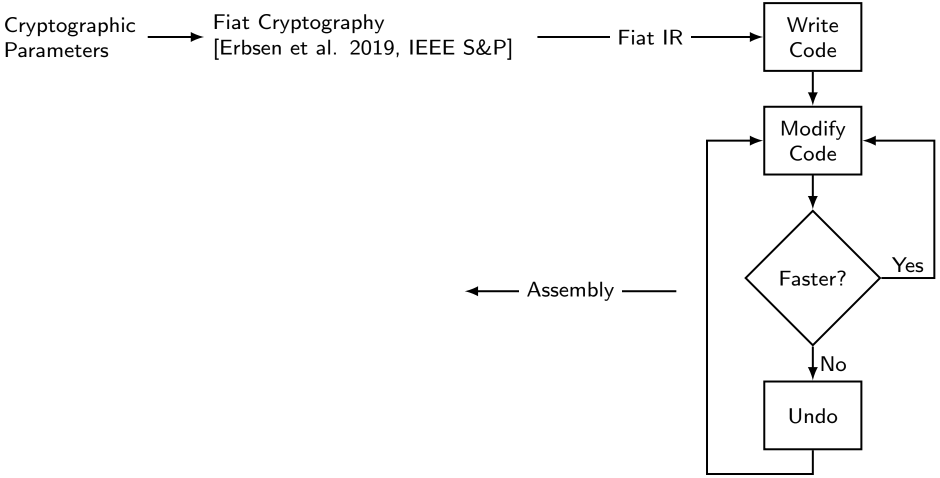

Performance: Field Arithmetic

Geometric Mean (10 μ-Architectures)

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

Performance: Field Arithmetic

Geometric Mean (10 μ-Architectures)

	Multiply		Square	
	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				

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Geometric Mean (10 μ-Architectures)

	Multiply		Square	
	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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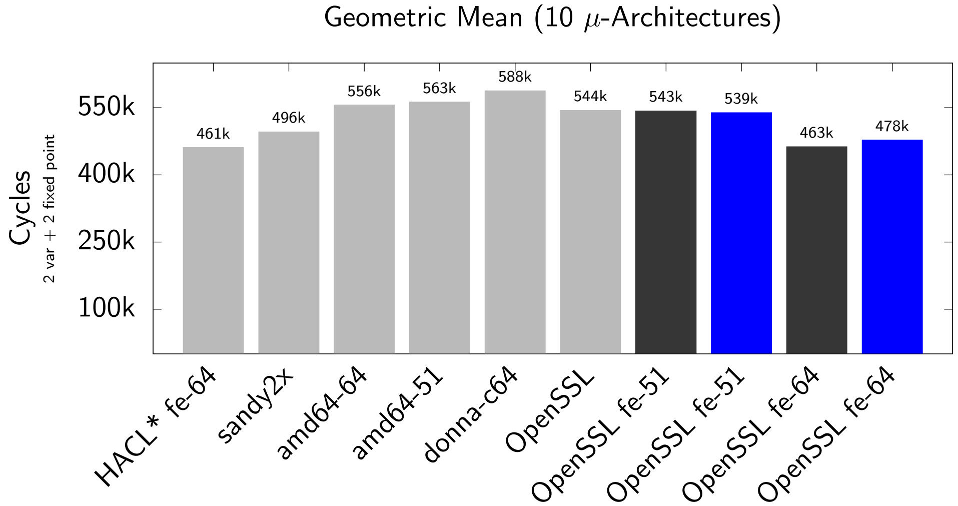

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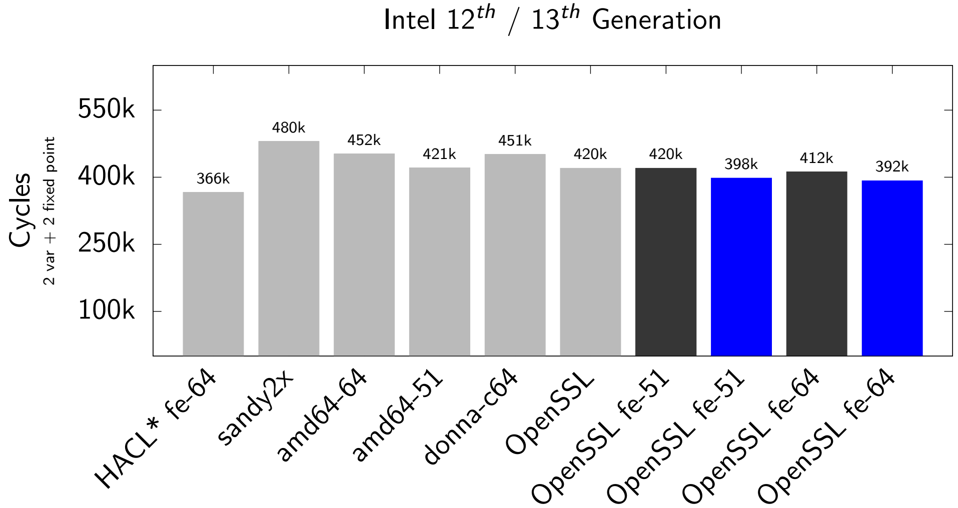
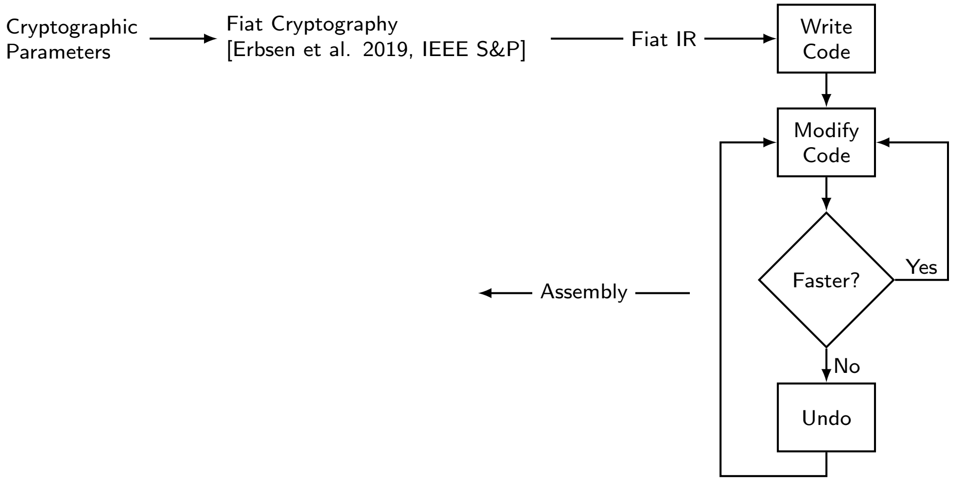
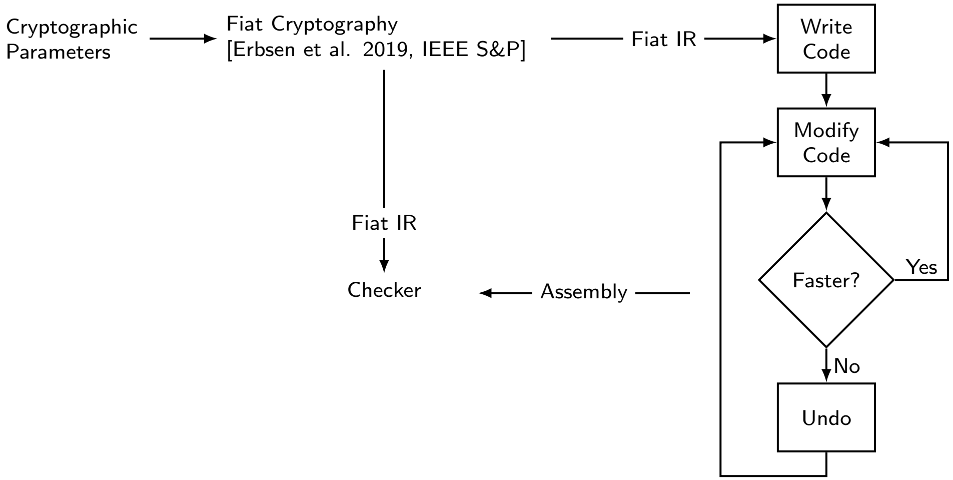


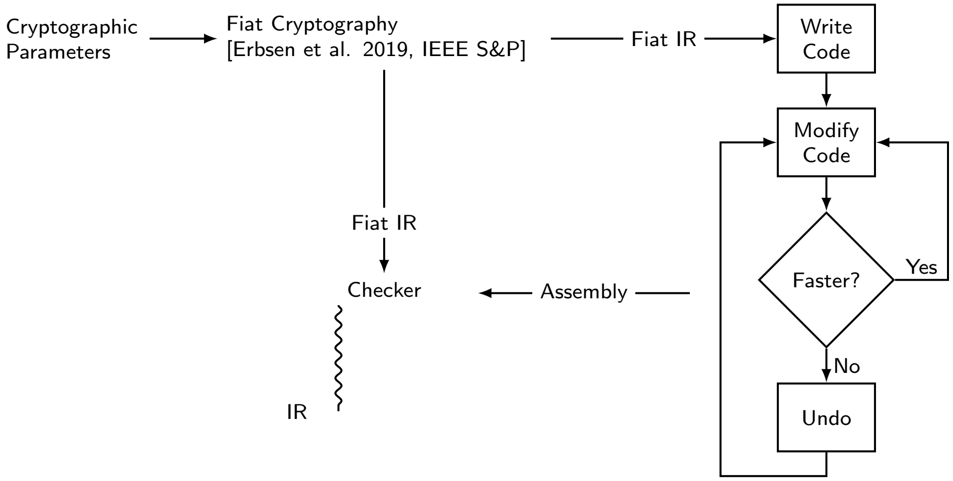
Correctness



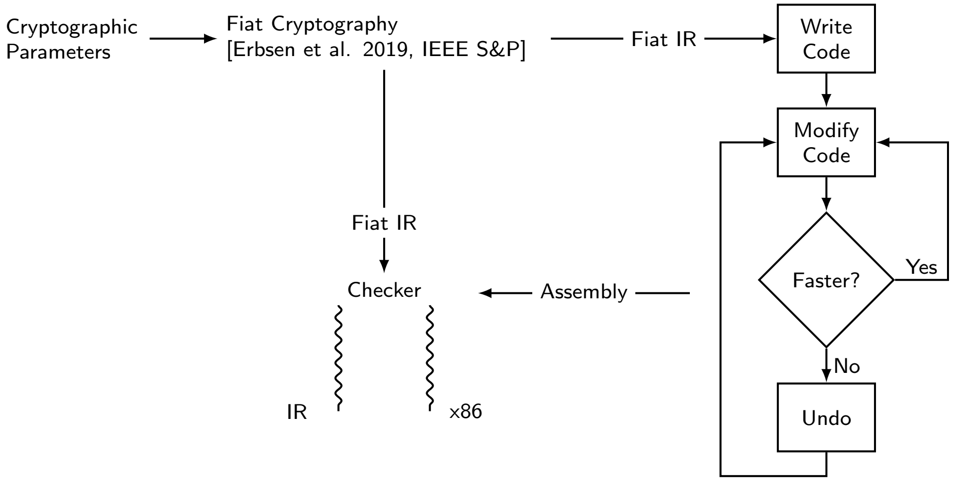
Correctness



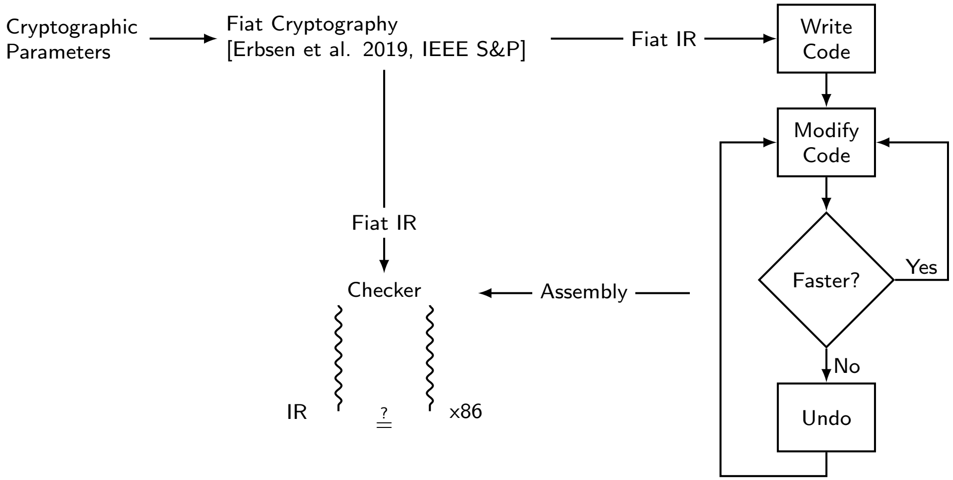
Correctness



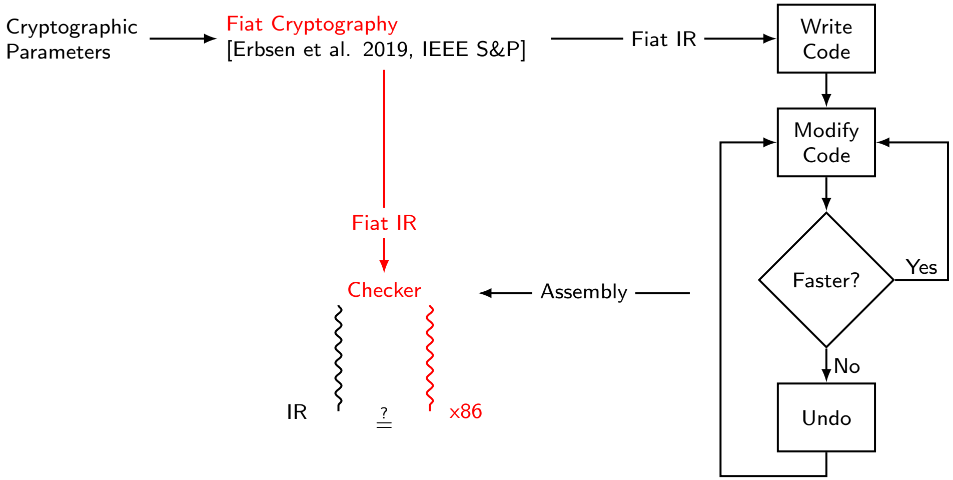
Correctness



Correctness



Correctness



Summary

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Compilation of cryptographic code
$\Longrightarrow$ Search

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Compilation of cryptographic code
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Random Local Search $+$ Runtime

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$\implies$ Search

Random Local Search $+$ Runtime

Proven-correct assembly for field arithmetic by Fiat Cryptography

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Random Local Search + Runtime

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

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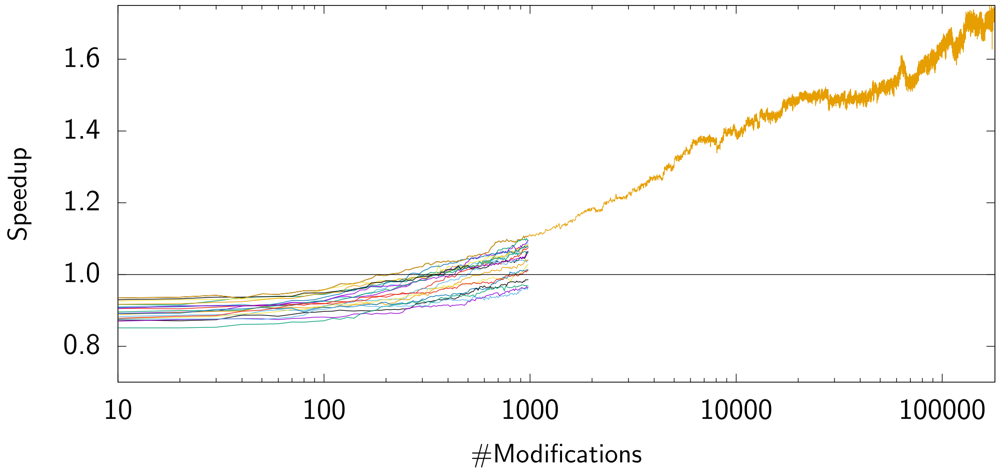
GitHub Project

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

Bet and Run


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