CryptOpt: Automatic Cryptographic Code Optimization with Verified Compilation

Chitchanok Chuengsatiansup

The University of Melbourne, Australia

Cryptography, Robustness, and Provably Secure Schemes
for Female Young Researchers (CrossFyre)

About Me

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Efficient and Secure Cryptosystems

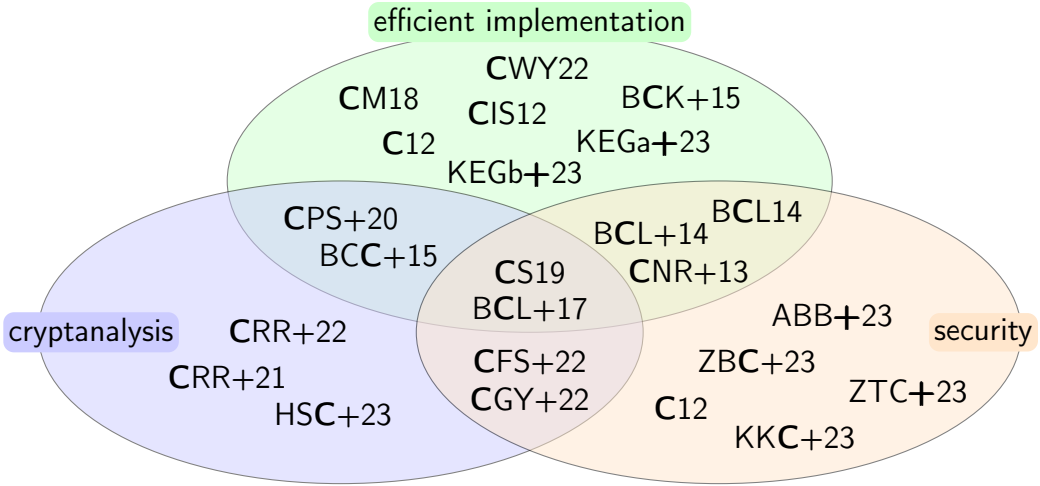
Efficient and Secure Cryptosystems

efficient implementation

cryptanalysis

security

Efficient and Secure Cryptosystems



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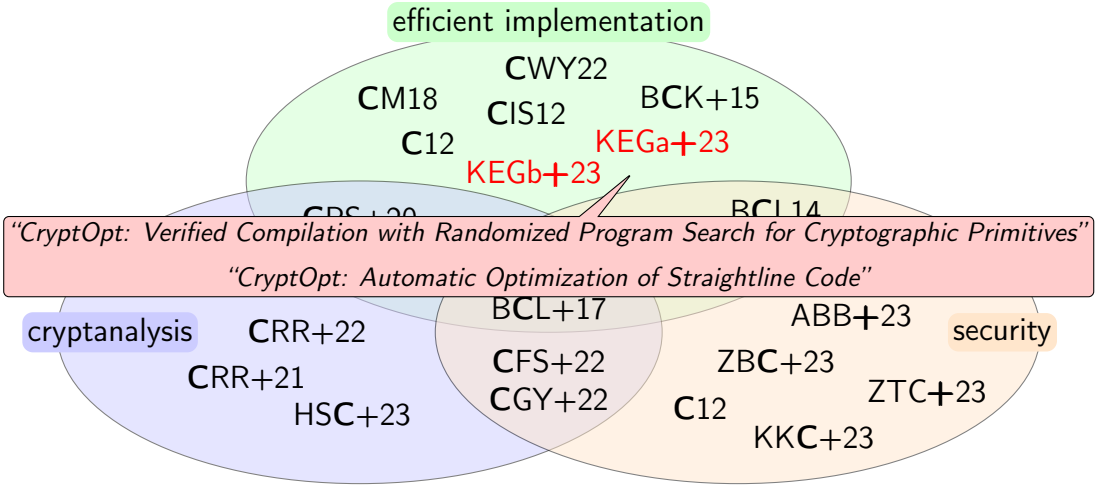

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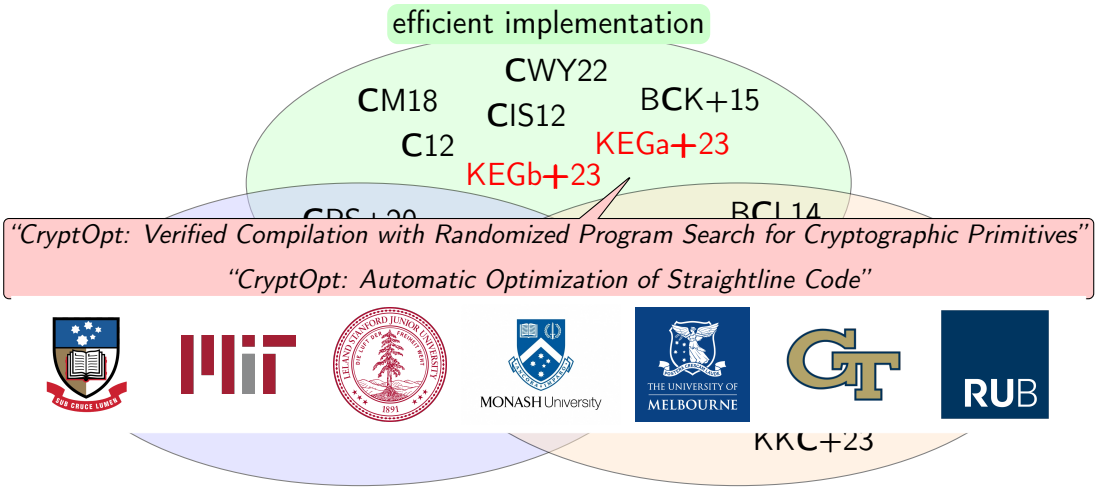

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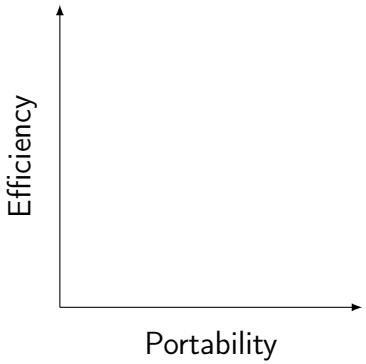

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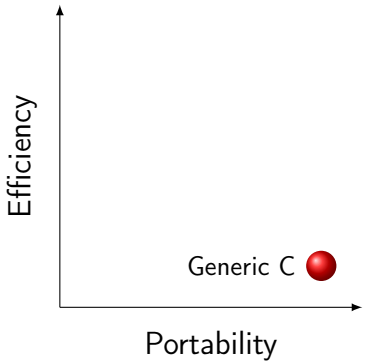

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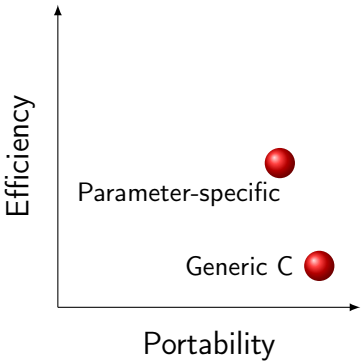

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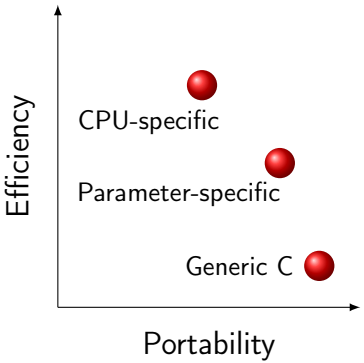

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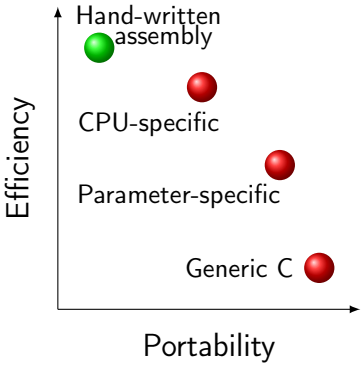

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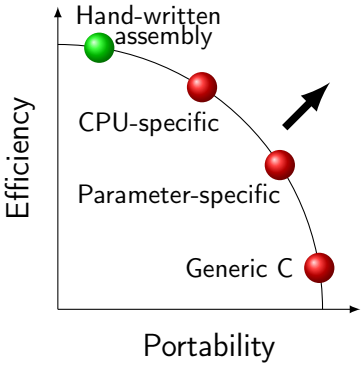

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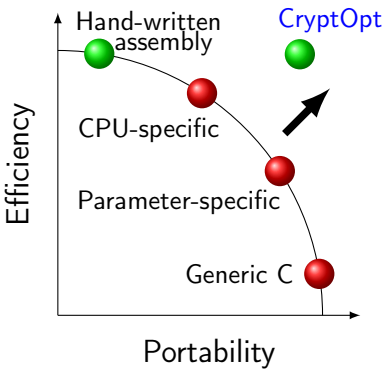

Observation

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- Cryptographic code has “special” structures

Constant-Time Programming

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  - CryptOpt: constant-time instruction

Optimization Strategies

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- Straight-line code in static single assignment (SSA)
  - ensure constant-time code
- Combinatorial optimization
  - search for best-performing implementation
- Random local search (RLS) with bet-and-run heuristic
  - "bet" explores up to budget then "run" continues from the best

Search for Fast Implementation

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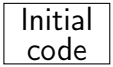

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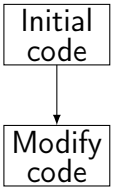

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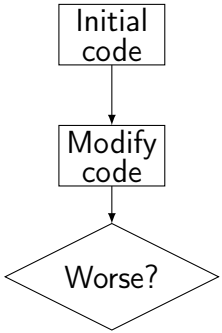

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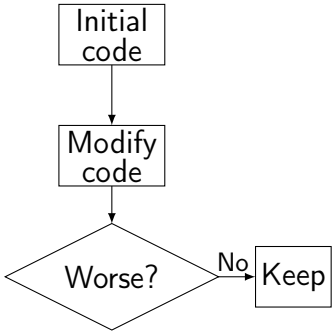

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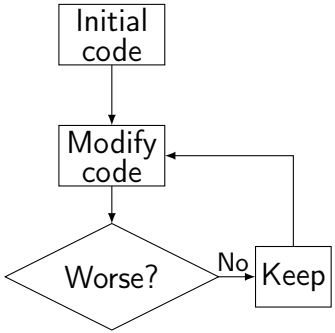

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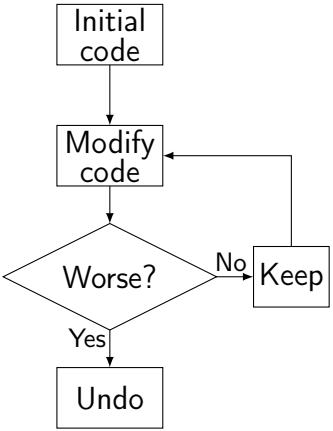

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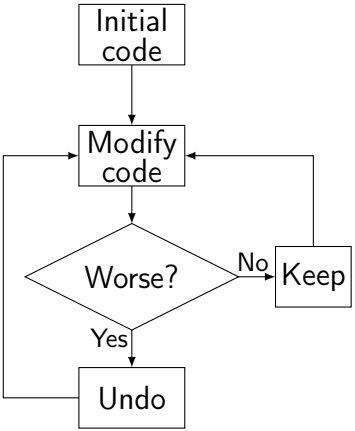

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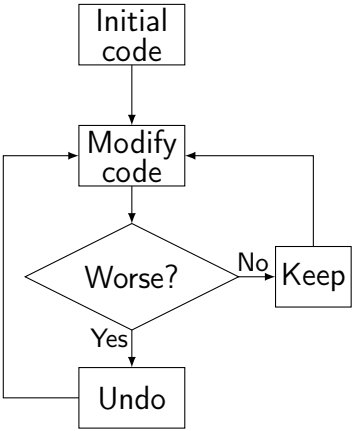

Random Local Search

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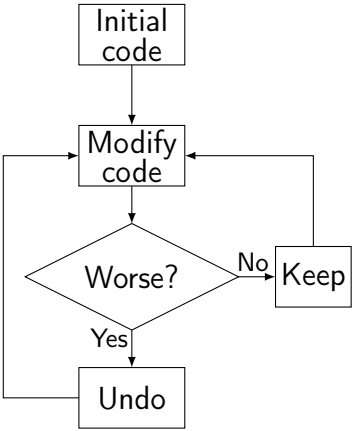

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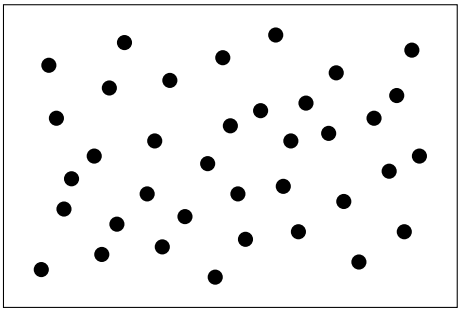

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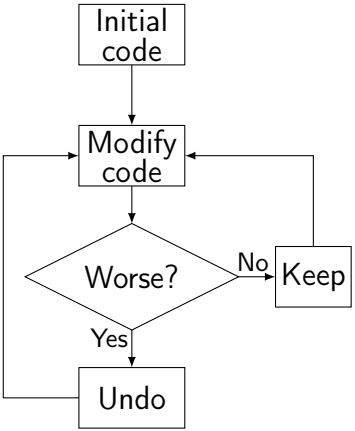

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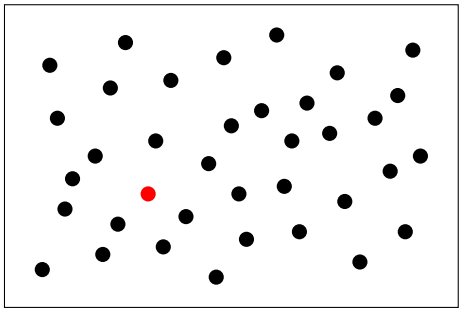

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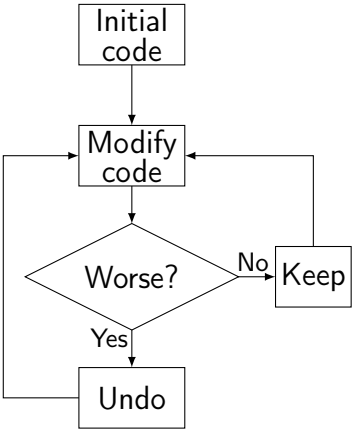

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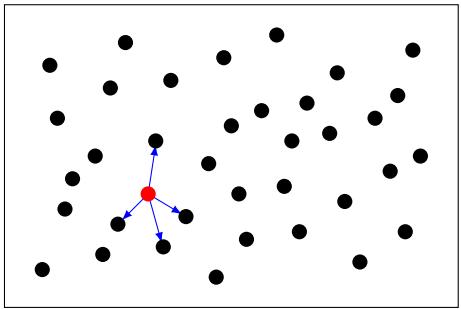

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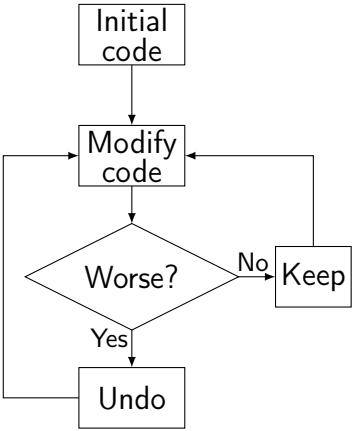

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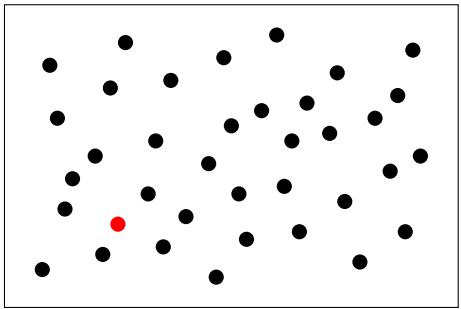

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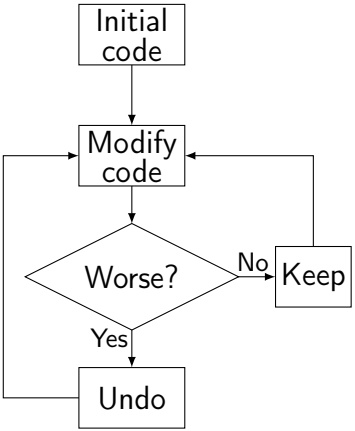

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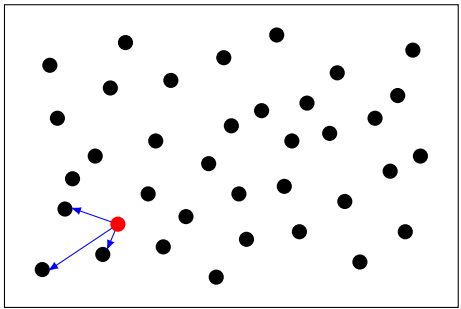

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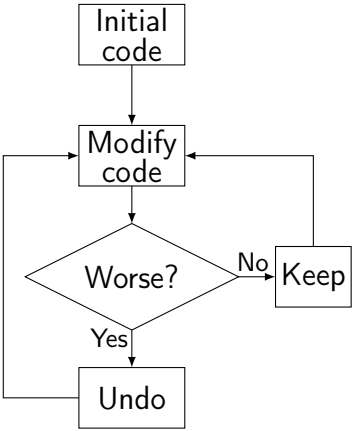

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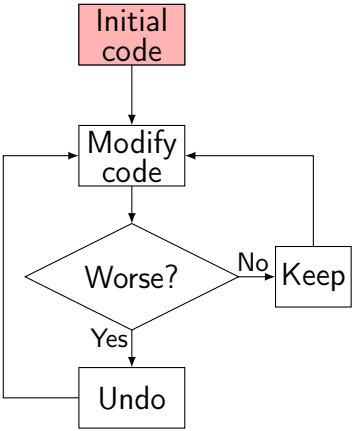

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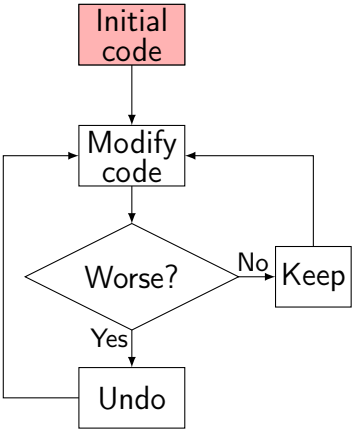

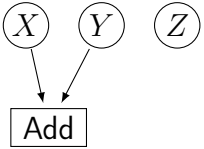

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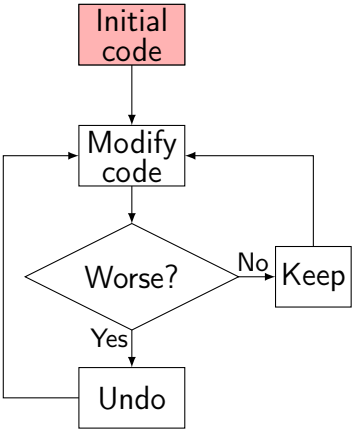

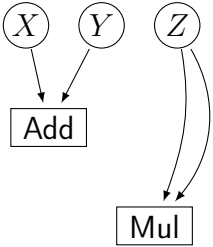

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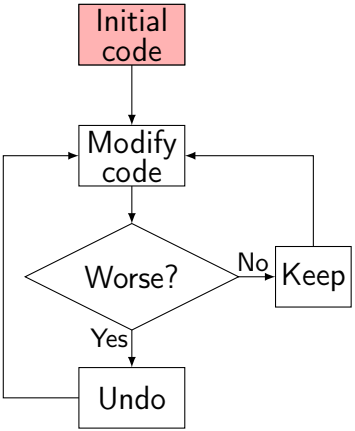

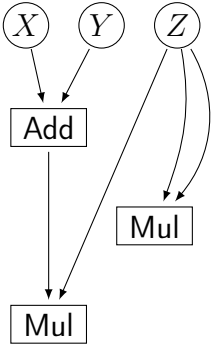

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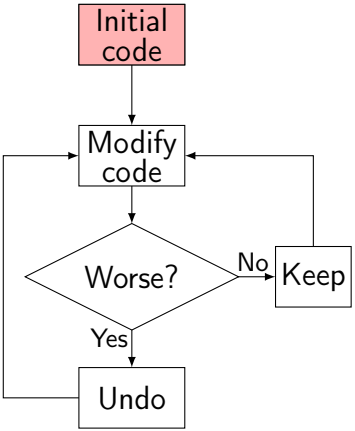

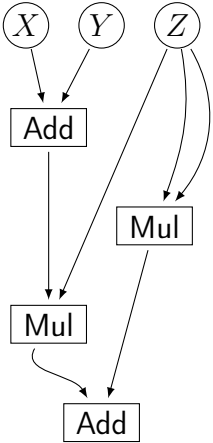

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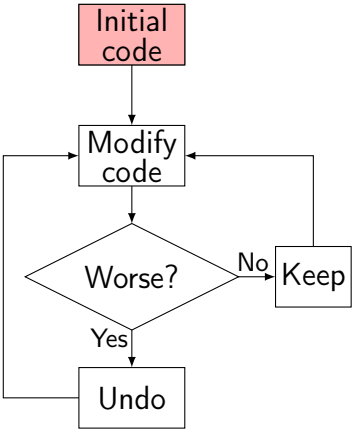

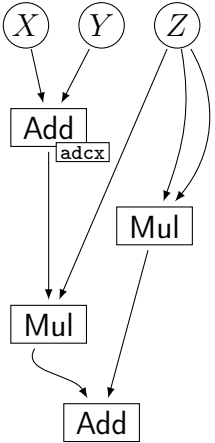


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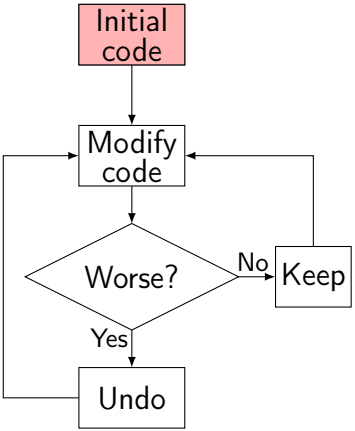

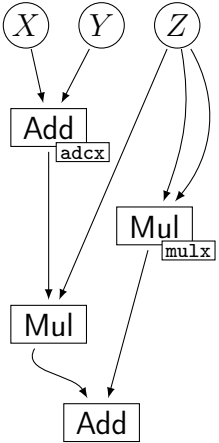


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mov rax, [X]
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adcx rax, [Y]

mov rdx, [Z]
mulx r8, r9, rax
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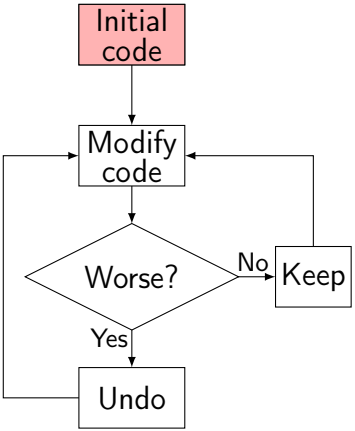

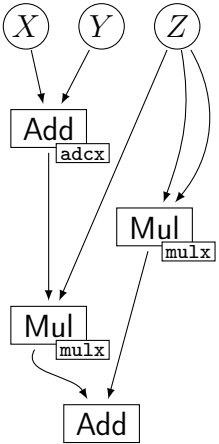


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mulx r8, r9, rax


mulx r10, r11, [Z]
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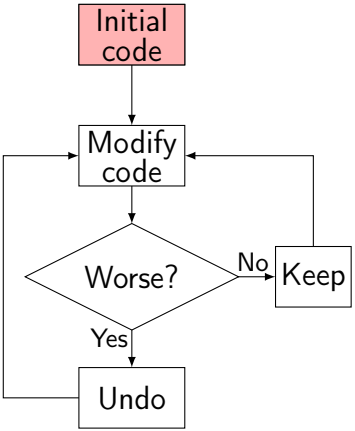

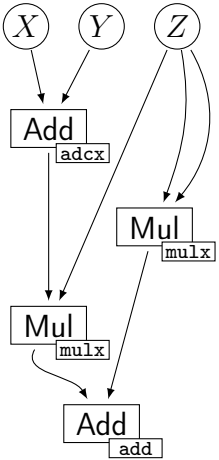


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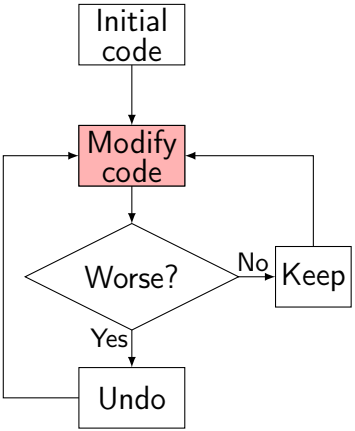
clc
adcx rax, [Y]

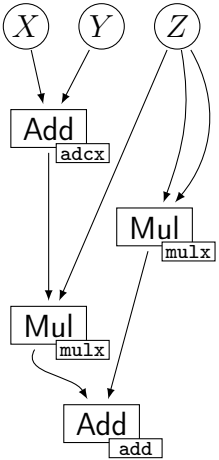
mov rdx, [Z]
mulx r8, r9, rax

mulx r10, r11, [Z]

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

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





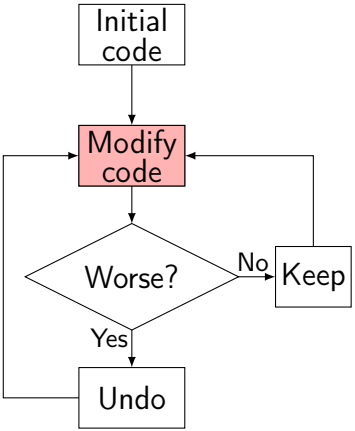

```
mov rax, [X]
clc
adcx rax, [Y]

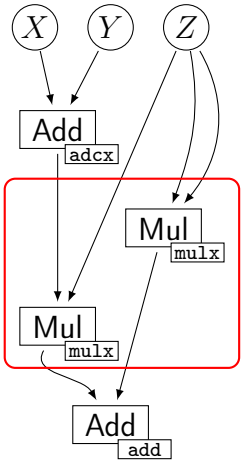
mov rdx, [Z]
mulx r8, r9, rax

mulx r10, r11, [Z]

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

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



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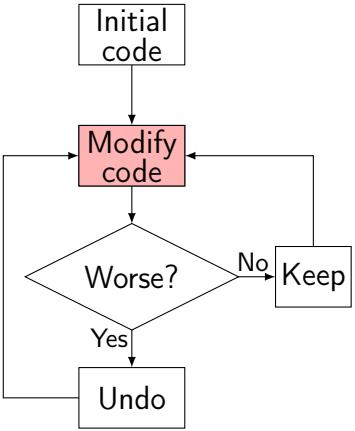
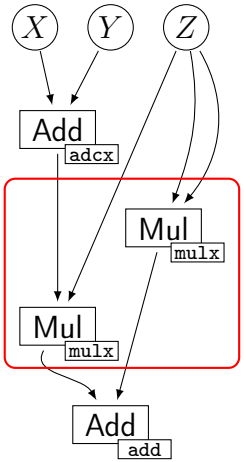
```

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



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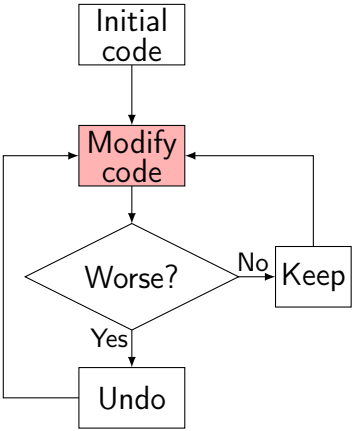
clc
adcx rax, [Y]

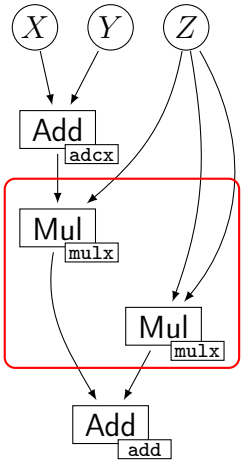
mov rdx, [Z]
mulx r8, r9, rax


mulx r10, r11, [Z]

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

Example Function: $(X + Y) \cdot Z + Z^2$ [reorder]





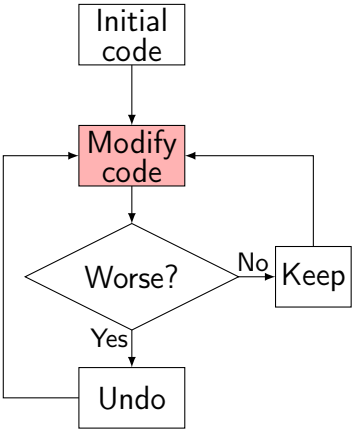

```
mov rax, [X]
clc
adcx rax, [Y]

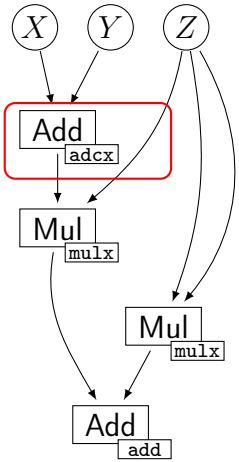
mov rdx, [Z]
mulx r10, r11, [Z]


mulx r8, r9, rax

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

Example Function: $(X + Y) \cdot Z + Z^2$ [template]





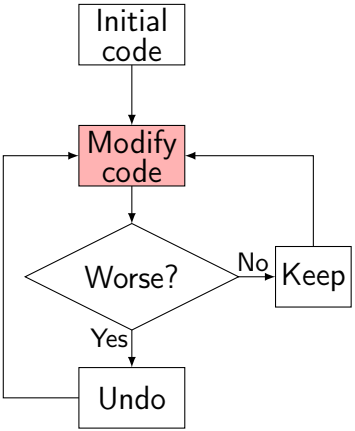

```
mov rax, [X]
clc
adcx rax, [Y]

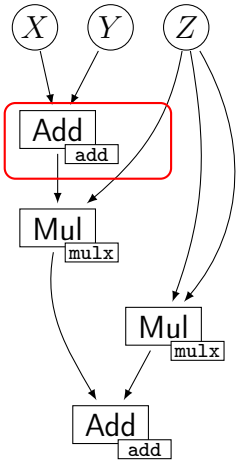
mov rdx, [Z]
mulx r10, r11, [Z]

mulx r8, r9, rax

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

Example Function: $(X + Y) \cdot Z + Z^2$ [template]





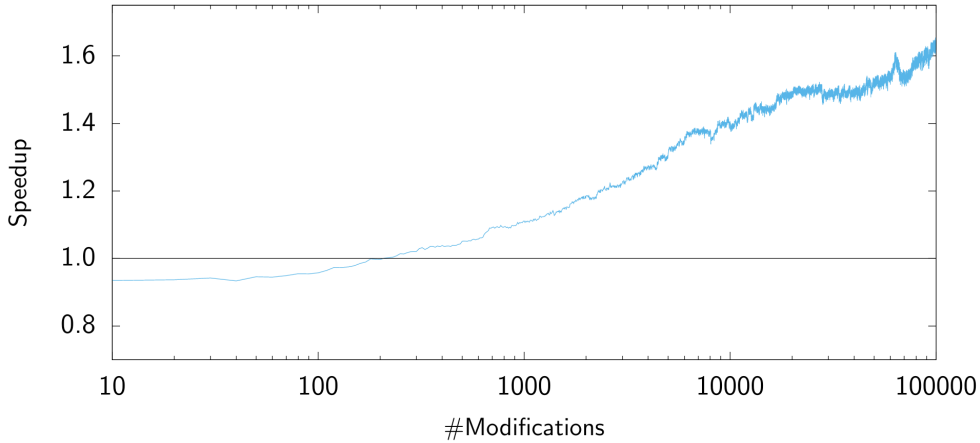

```
mov rax, [X]
clc
add rax, [Y]

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

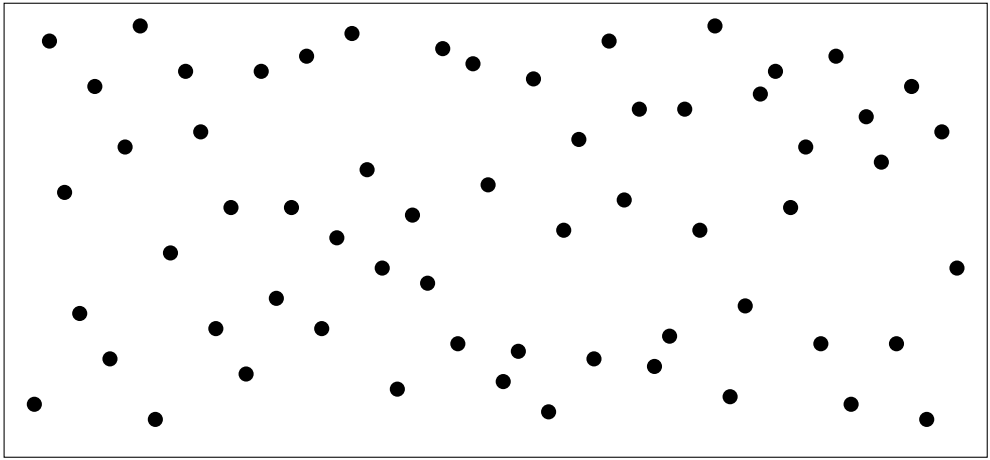
mulx r8, r9, rax

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

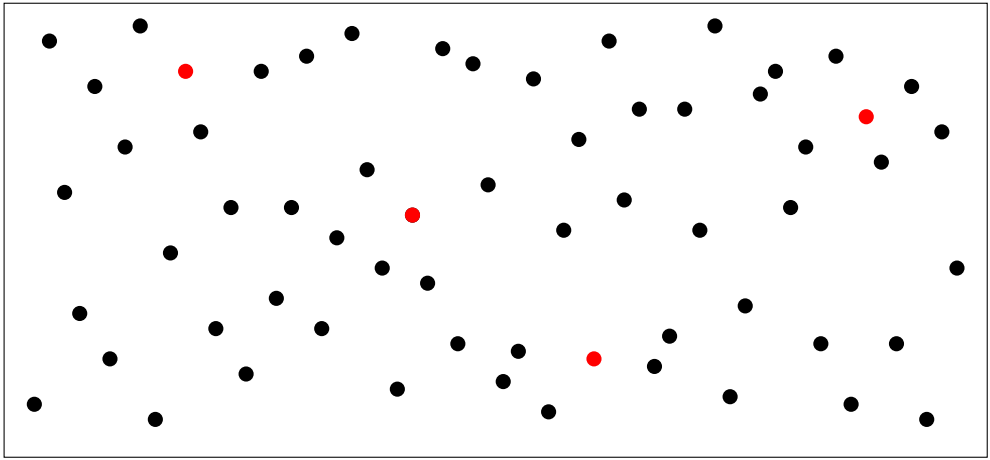
Optimization Progress



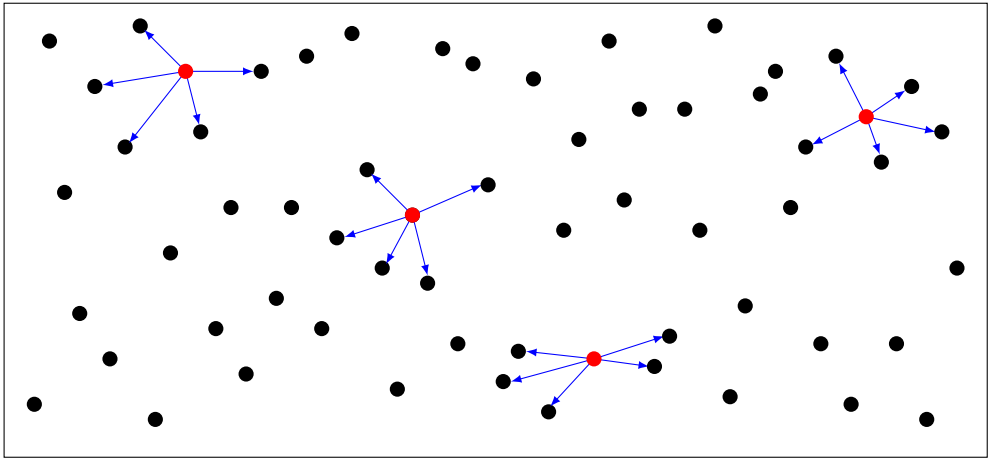
Random Local Search with Bet-and-Run



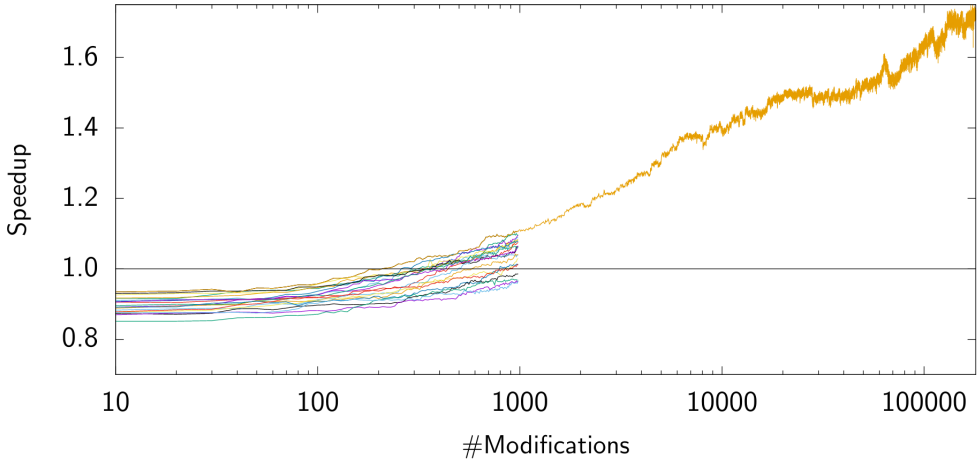
Random Local Search with Bet-and-Run



Random Local Search with Bet-and-Run



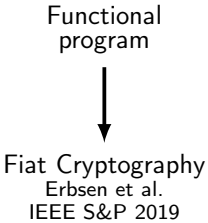
Bet-and-Run in Action



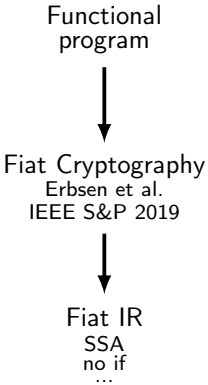
Fiat Cryptography

Fiat Cryptography
Erbsen et al.
IEEE S&P 2019

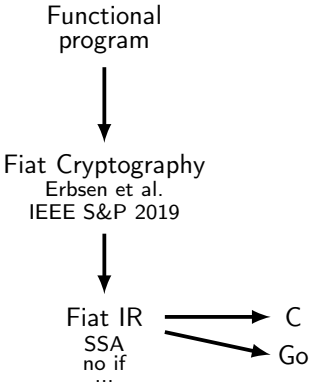
Fiat Cryptography



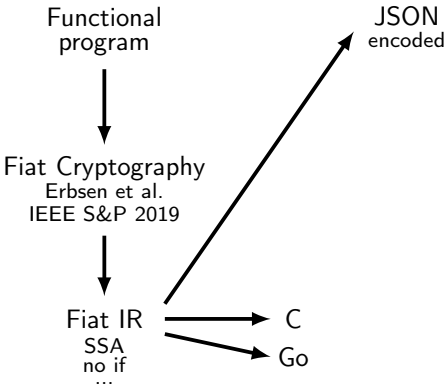
Fiat Cryptography



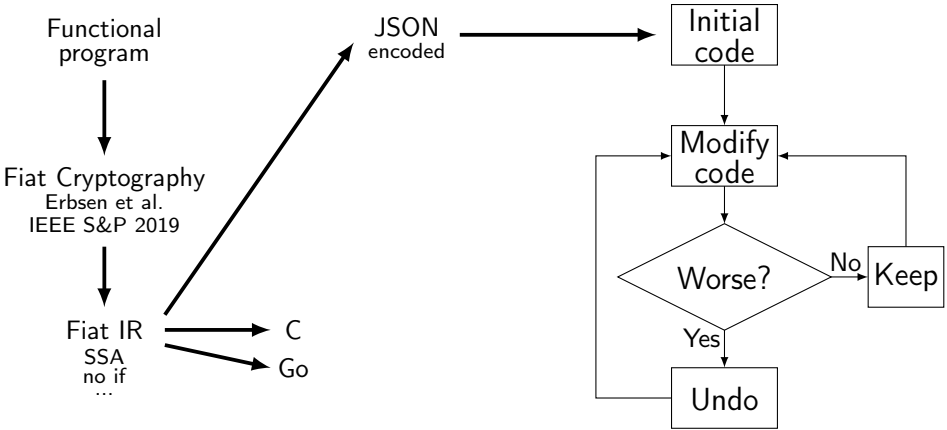
Fiat Cryptography



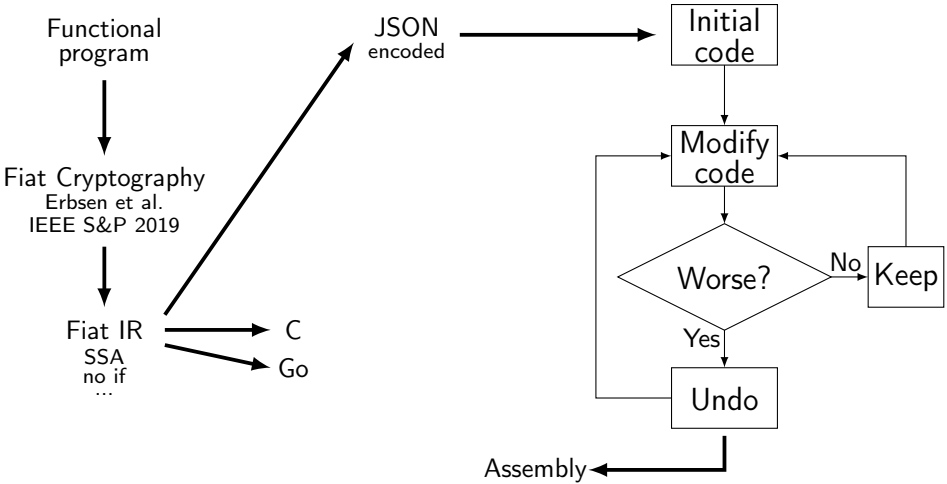
Fiat Cryptography



Fiat Cryptography



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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Geometric Mean (4x AMD, 6x Intel)

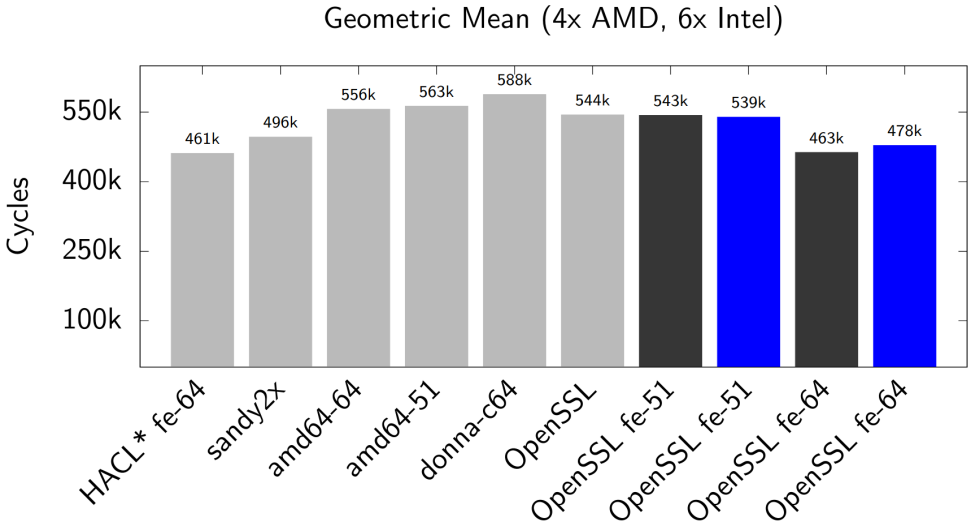
	Multiply		Square	
Curve	Clang	GCC	Clang	GCC
Curve25519	1.19	1.14	1.14	1.18
P-224				
P-256				
P-384				
SIKEp434				
Curve448				
P-521				
Poly1305				
secp256k1				

Performance: Field Arithmetic

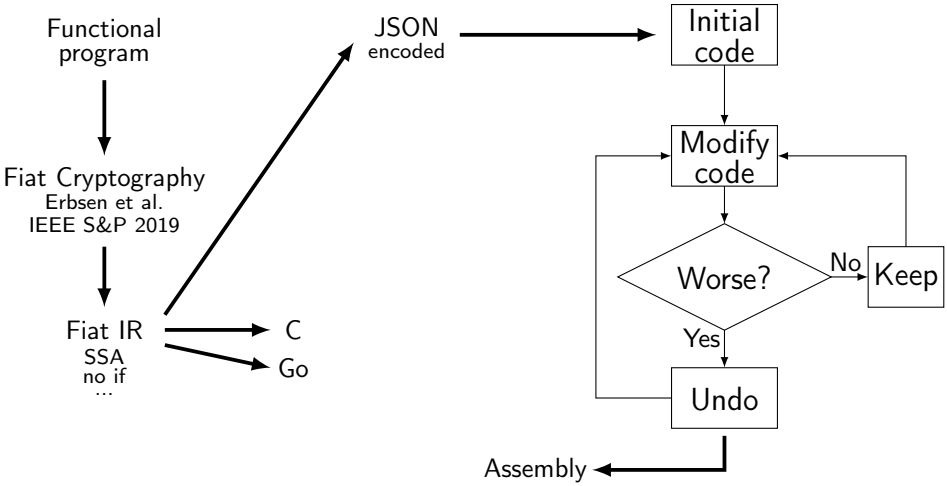
Geometric Mean (4x AMD, 6x Intel)

	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

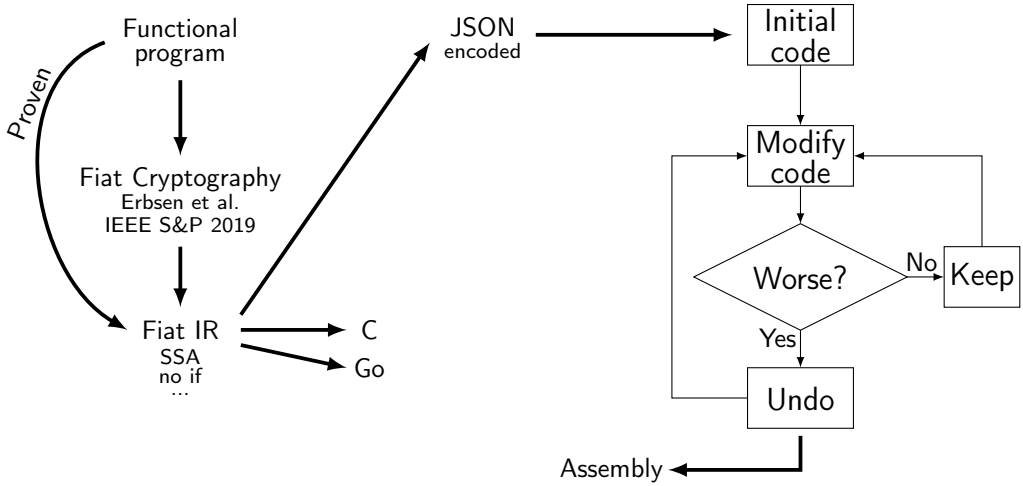
Performance: Scalar Multiplication



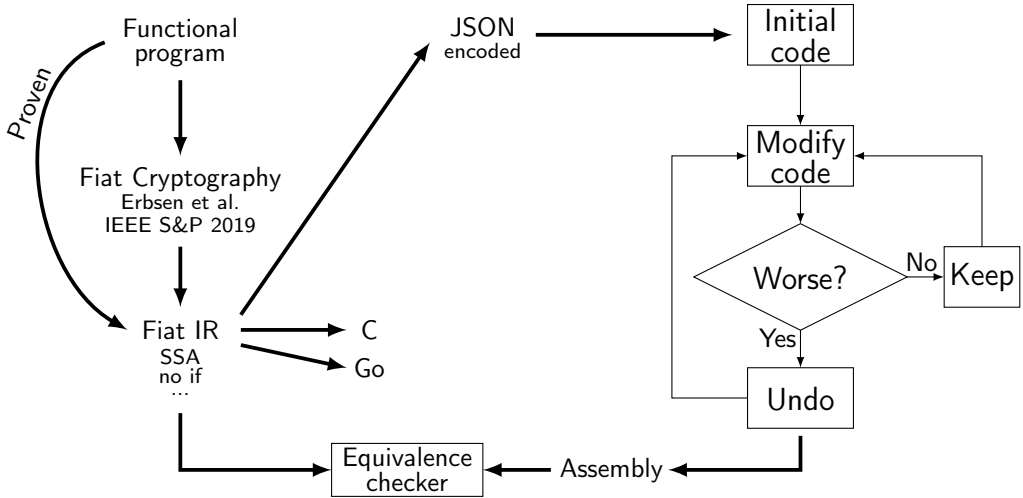
Correctness



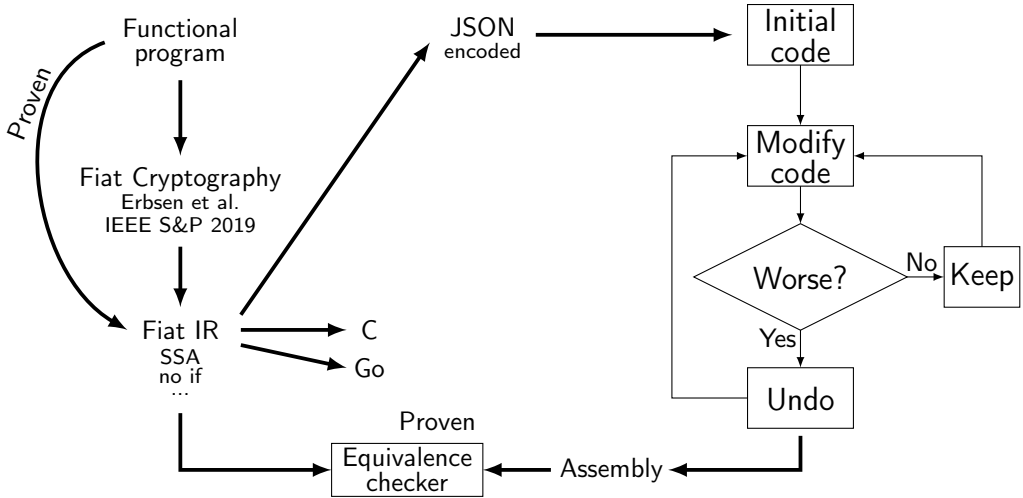
Correctness



Correctness



Correctness



Achievements

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- CryptOpt: automatic cryptographic code optimizer

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- Competitive performance with hand-written assembly
- Verified compilation of the generated code
- Resistant to timing side channels
- https://0xade1a1de.github.io/CryptOpt

GitHub Project

The Journey

The Journey

- Be confident

The Journey

- Be confident
- Be assertive

The Journey

- Be confident
- Be assertive
- Learn to say ‘no’