CryptOpt: Verified Compilation with Randomized Program Search for Cryptographic Primitives

Chitchanok Chuengsatiansup

The University of Klagenfurt, Austria

Joint work with A. Chlipala, O. Conoly, A. Erbsen, D. Genkin, J. Gross, J. Kuepper, C. Sun, S. Tian, M. Wagner, D. Wu and Y. Yarom






About Me

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2006 **Bachelor's Student:** Chulalongkorn University, Thailand

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2011 **Master's Student:** The University of Tokyo, Japan

2010 **Research Student:** The University of Tokyo, Japan

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Efficient and Secure Cryptosystems

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efficient implementation

cryptanalysis

security

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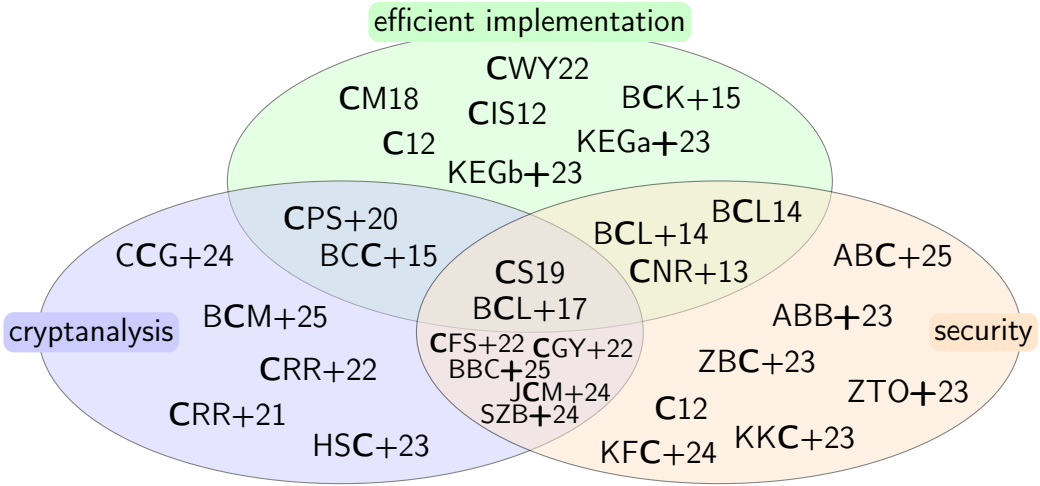

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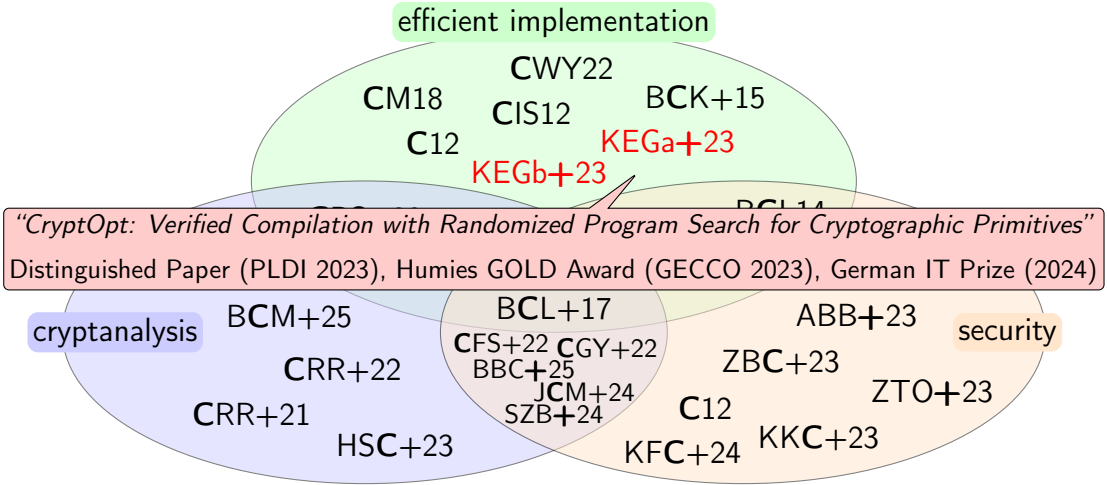

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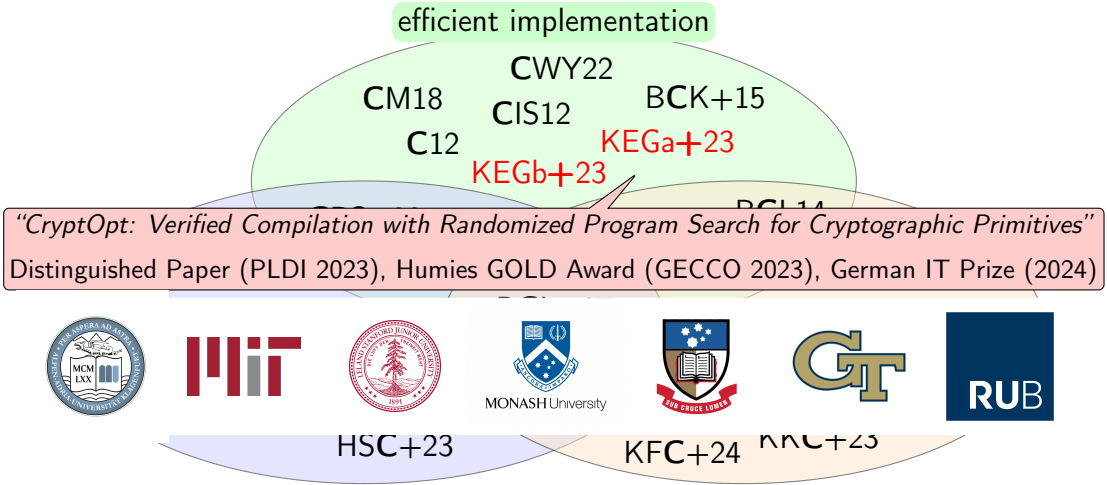

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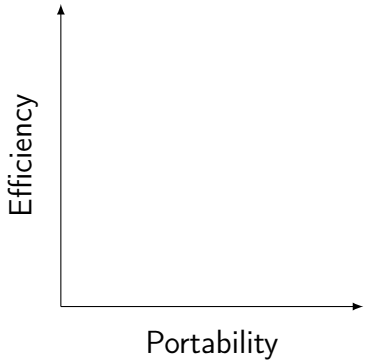

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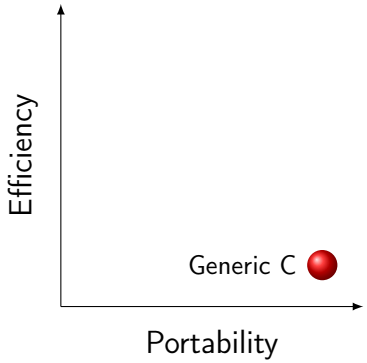

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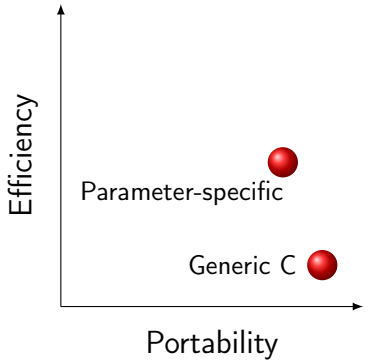

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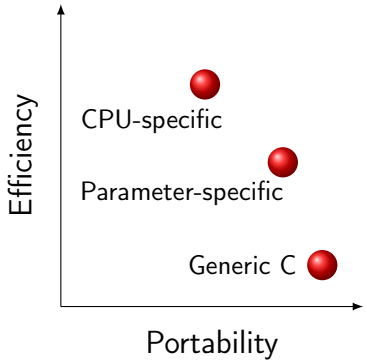

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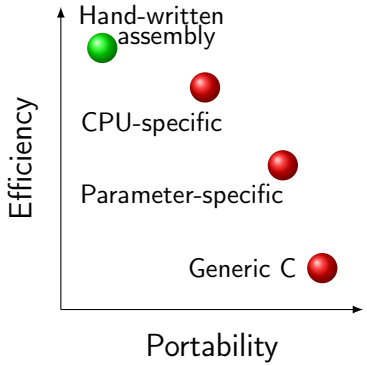

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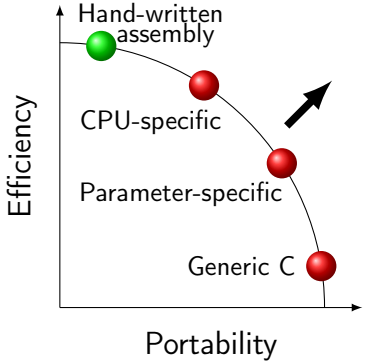

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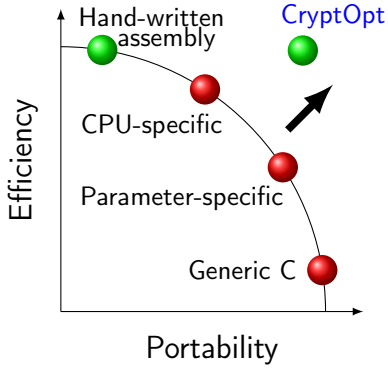

Observation

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- Cryptographic code has “special” structures

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  - CryptOpt: constant-time instruction

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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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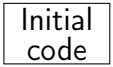

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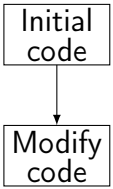

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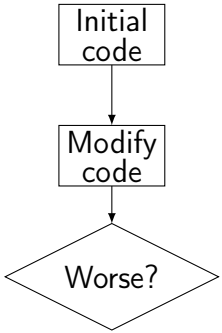

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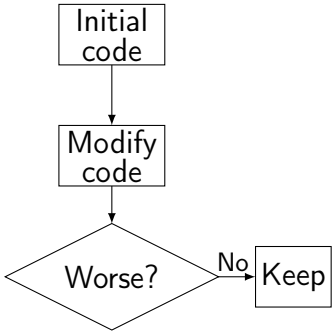

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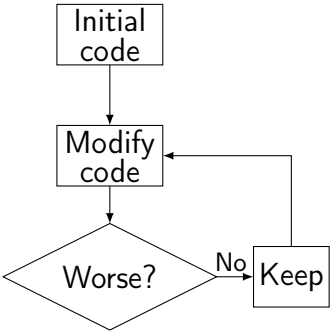

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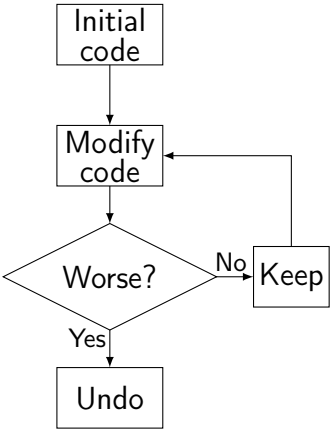

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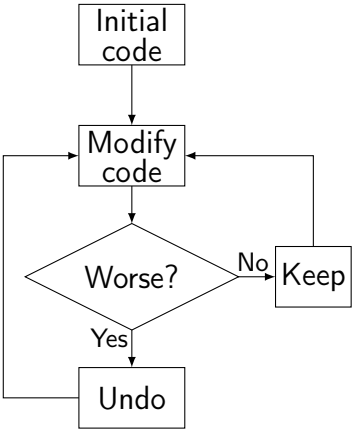

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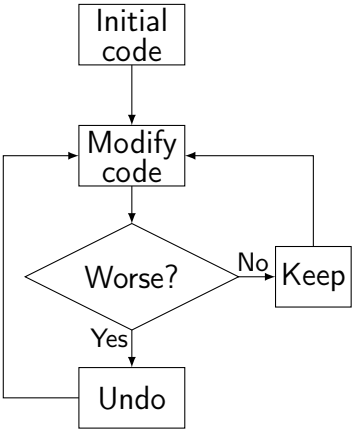

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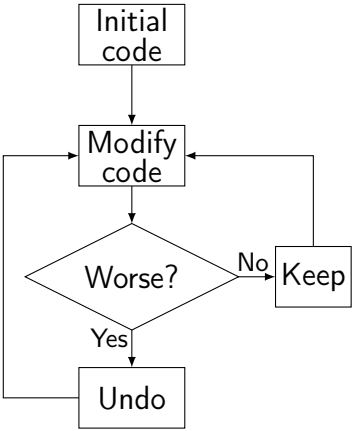

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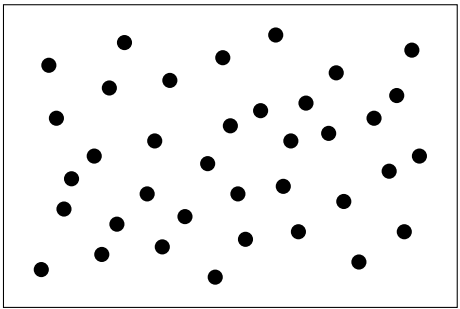

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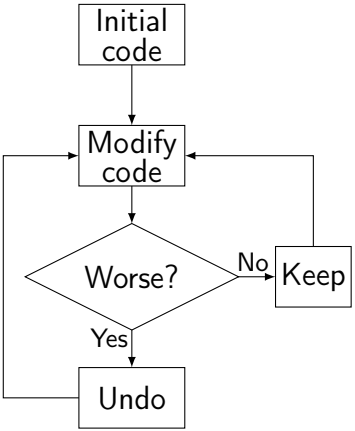

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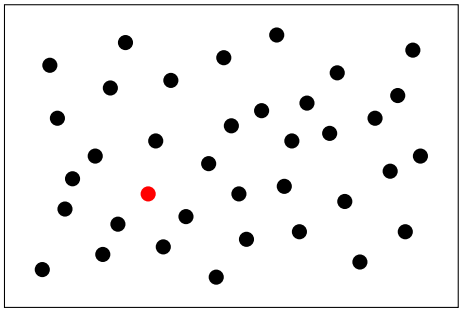

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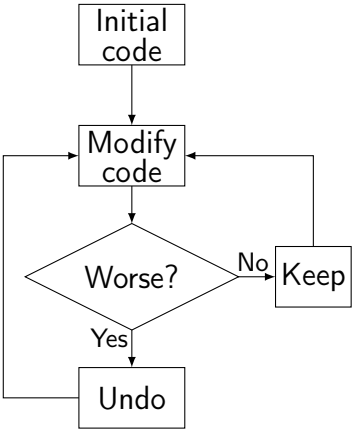

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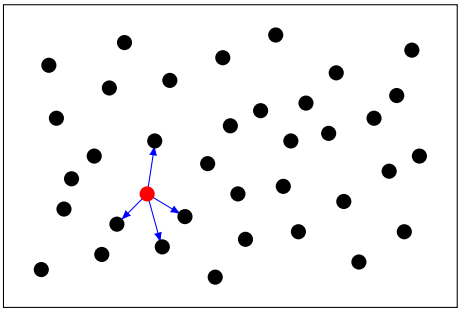

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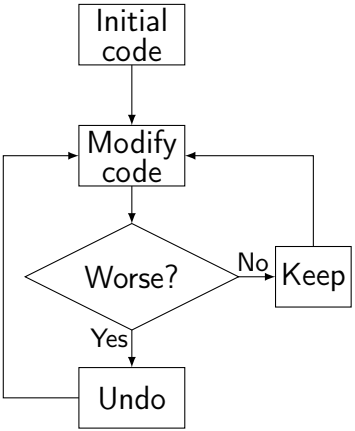

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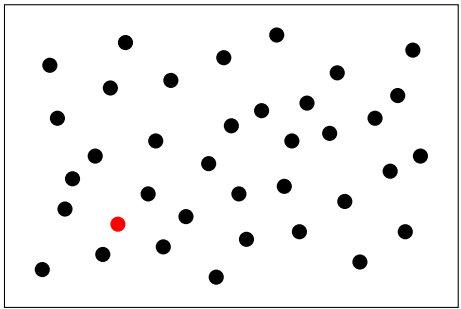

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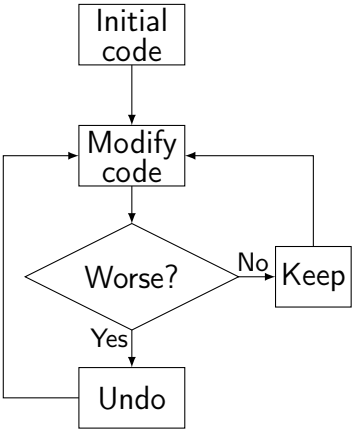

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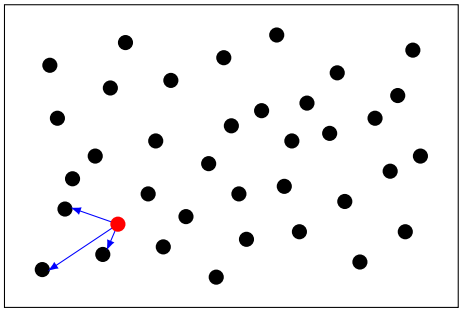

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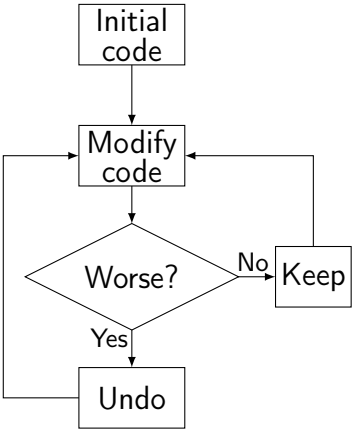

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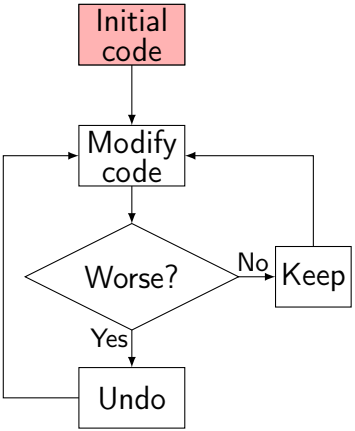

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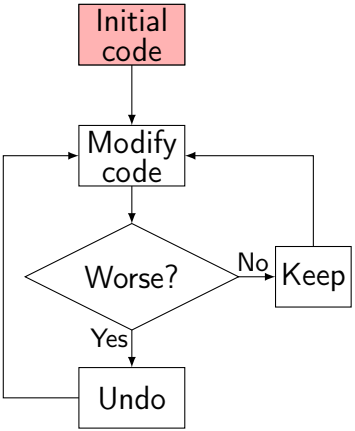

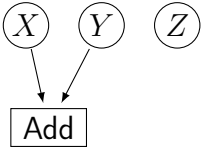

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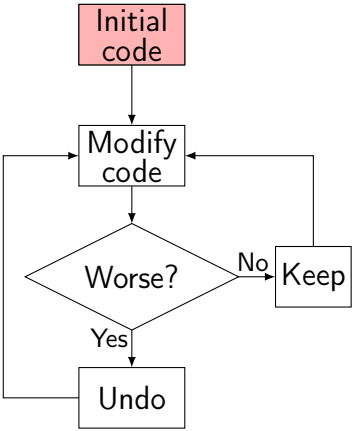

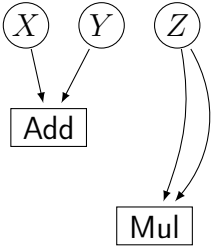

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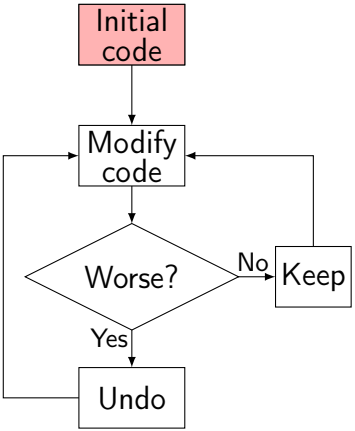

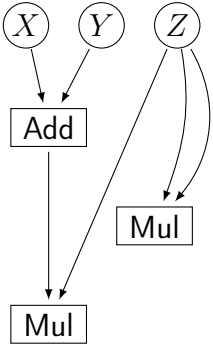

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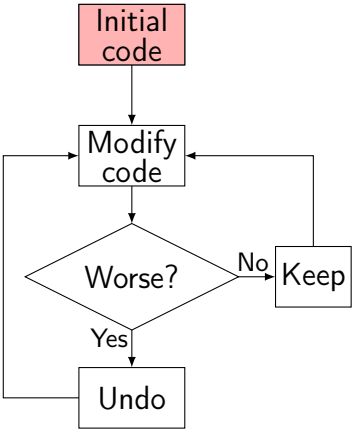

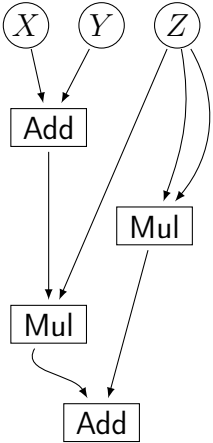

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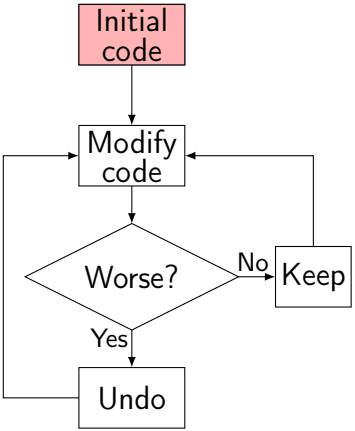
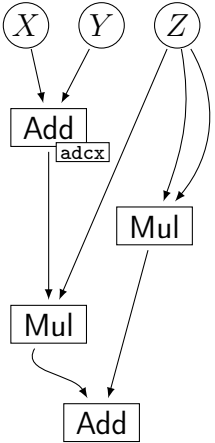
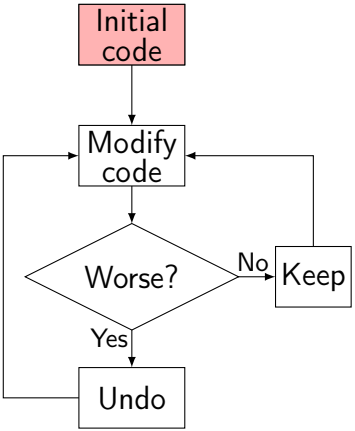
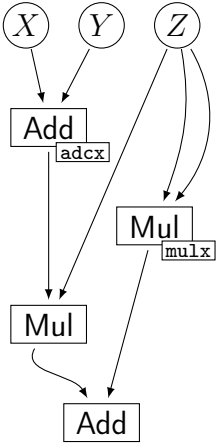





```
mov rax, [X]
clc
adcx rax, [Y]
```

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



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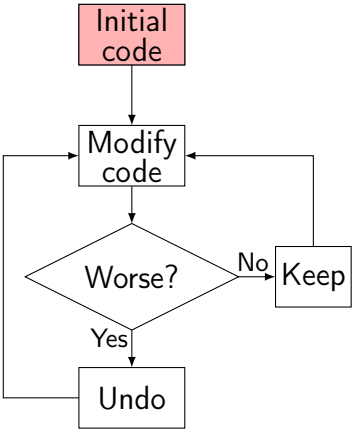
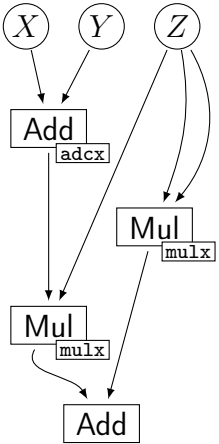
mov rax, [X]
clc
adcx rax, [Y]

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

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



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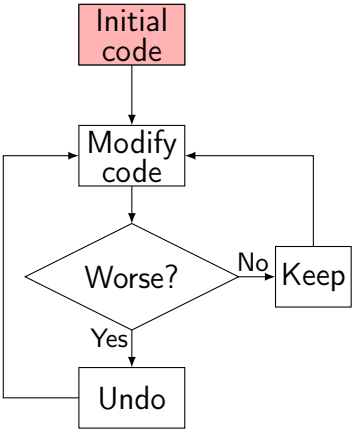

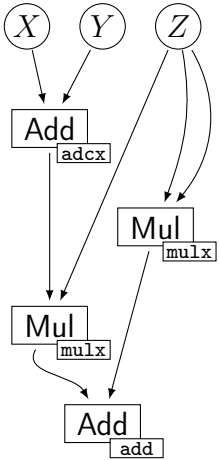


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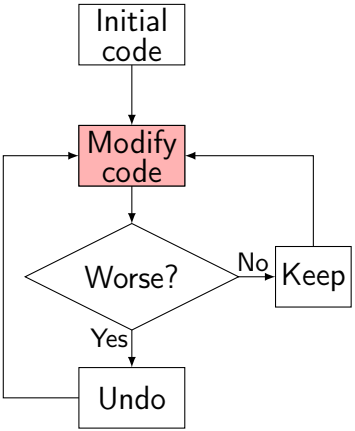
adcx rax, [Y]

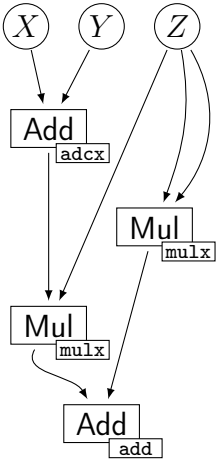
mov rdx, [Z]
mulx r8, r9, rax

mulx r10, r11, [Z]

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

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



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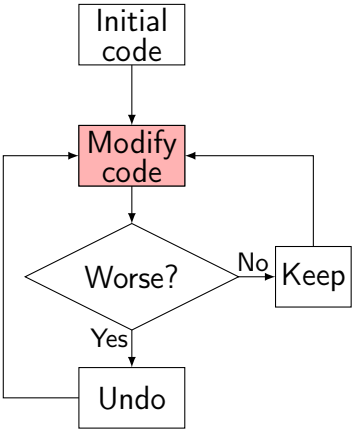

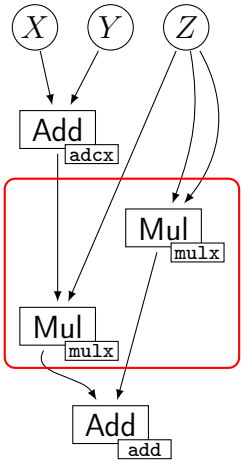


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clc
adcx rax, [Y]

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

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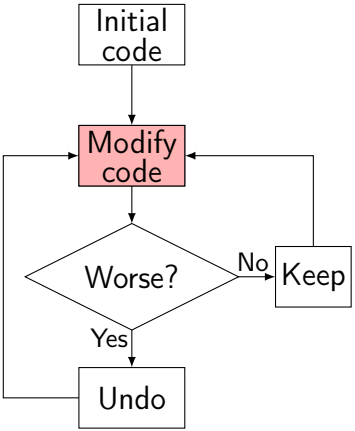
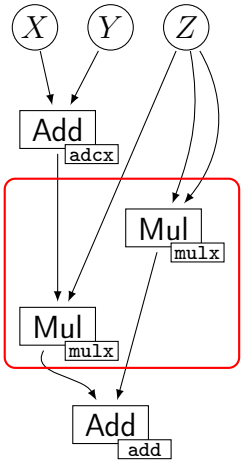
Example Function: $(X + Y) \cdot Z + Z^2$



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adcx rax, [Y]

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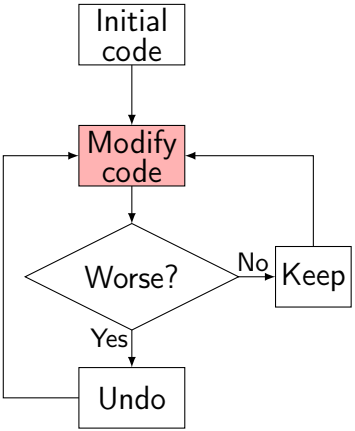
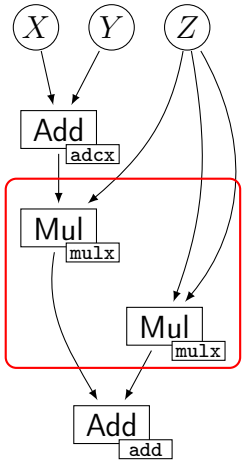
mulx r10, r11, [Z]

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

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





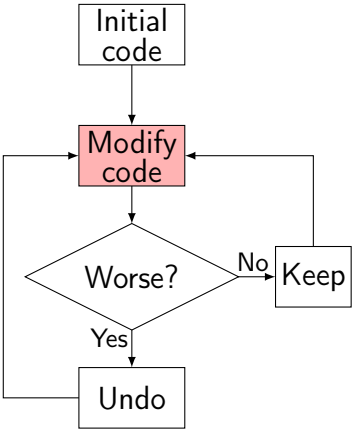

```
mov rax, [X]
clc
adcx rax, [Y]

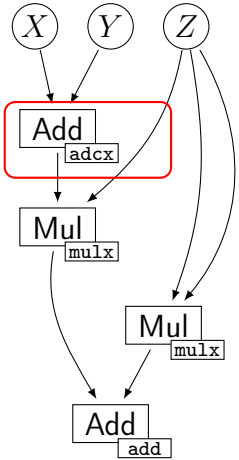
mov rdx, [Z]
mulx r10, r11, [Z]


mulx r8, r9, rax

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

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



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clc
adcx rax, [Y]

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

mulx r8, r9, rax

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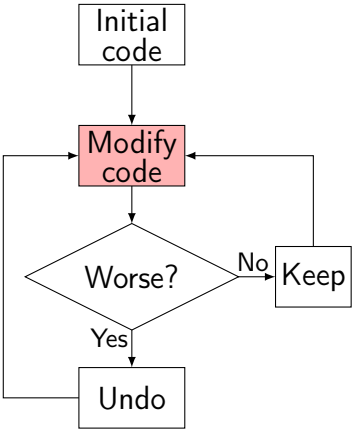
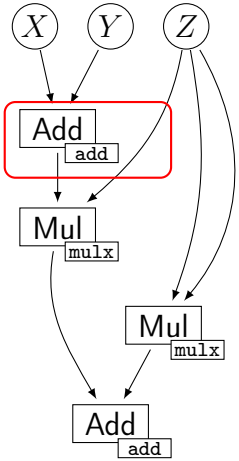
mov [out], r11
```

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



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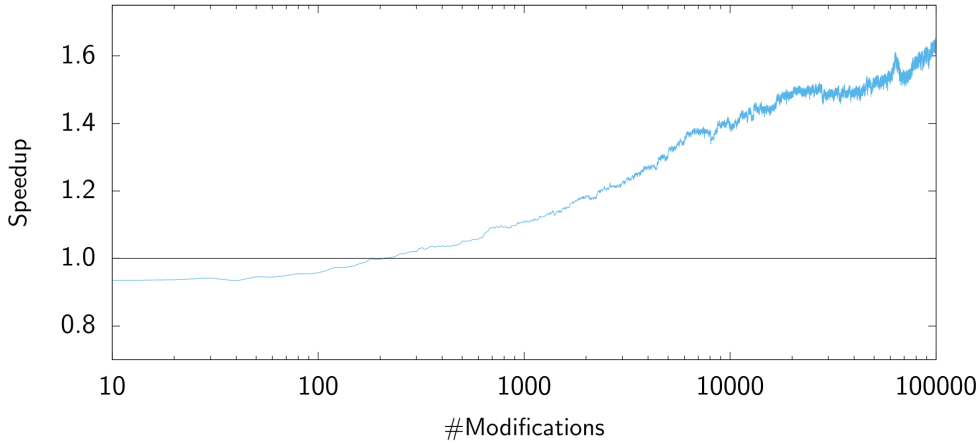
mov rax, [X]
clc
add rax, [Y]

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

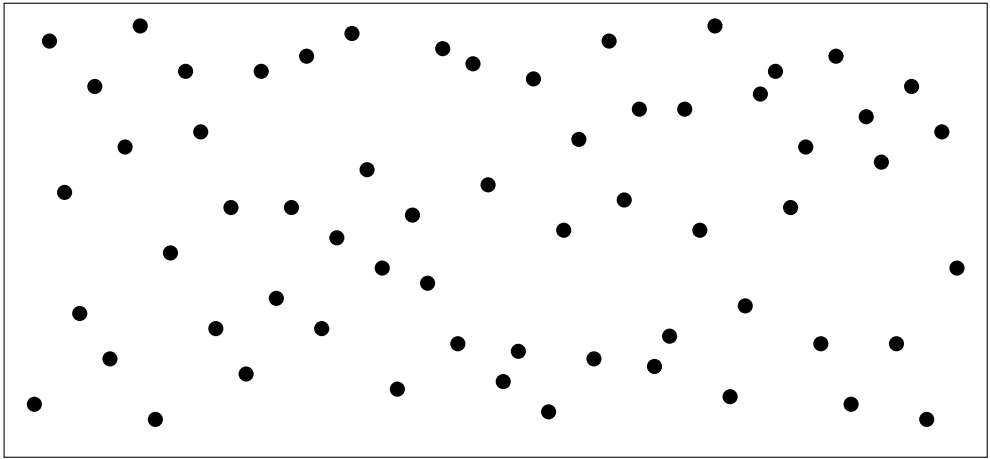
mulx r8, r9, rax

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

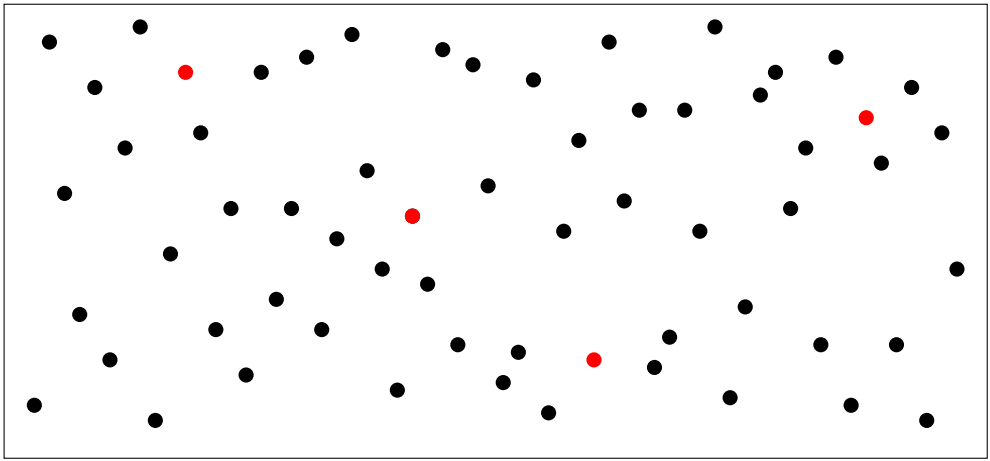
Optimization Progress



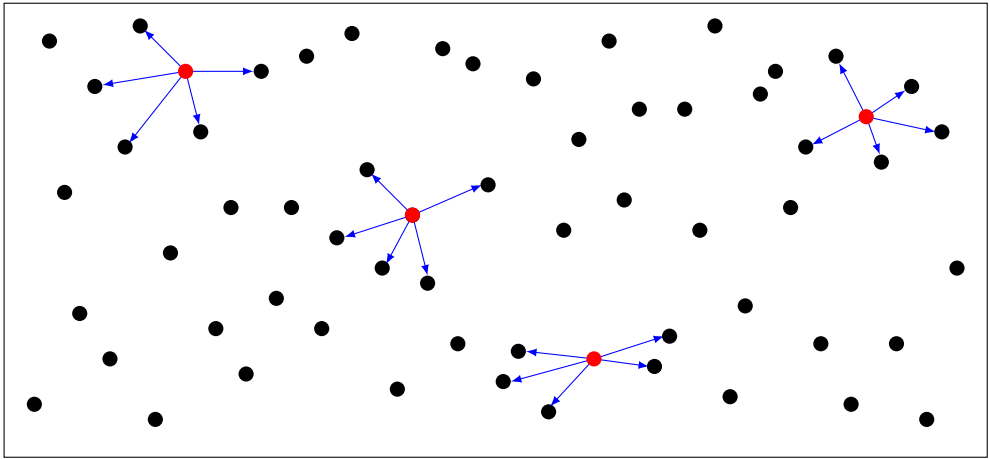
Random Local Search with Bet-and-Run



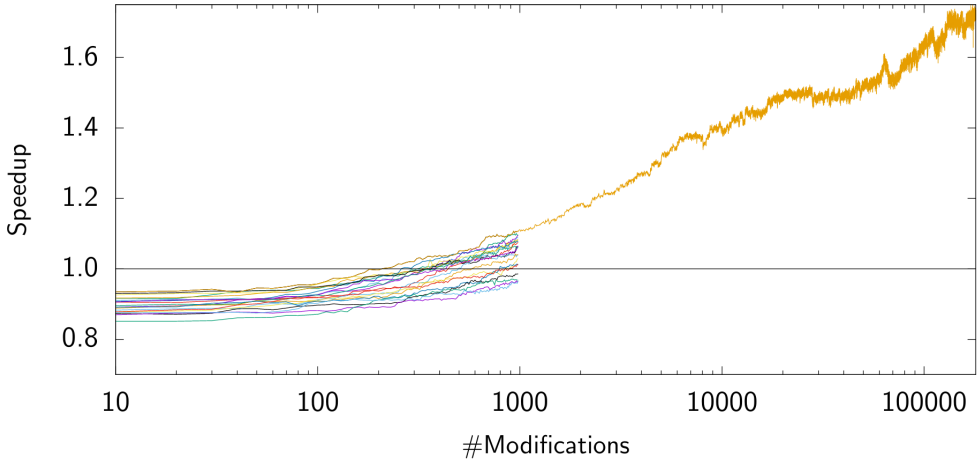
Random Local Search with Bet-and-Run



Random Local Search with Bet-and-Run



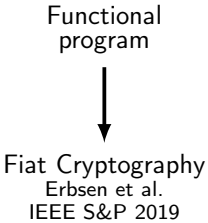
Bet-and-Run in Action



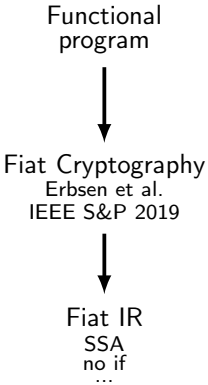
Fiat Cryptography

Fiat Cryptography
Erbsen et al.
IEEE S&P 2019

Fiat Cryptography



Fiat Cryptography



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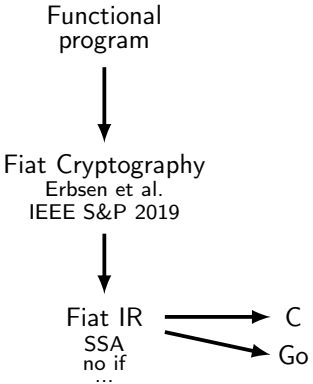

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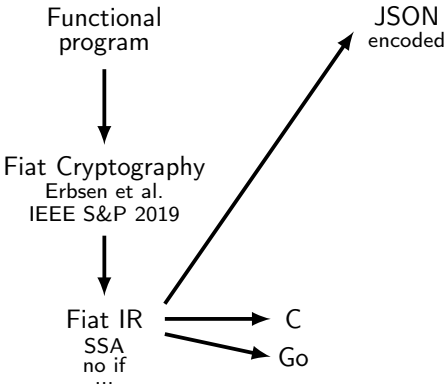

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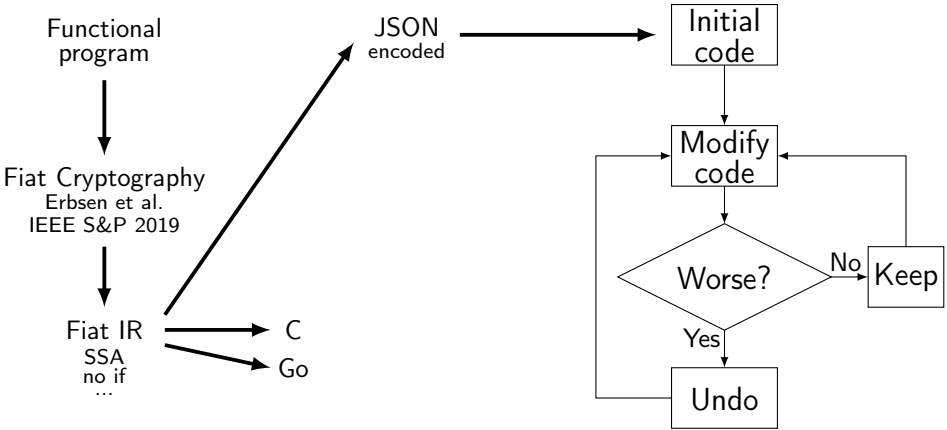

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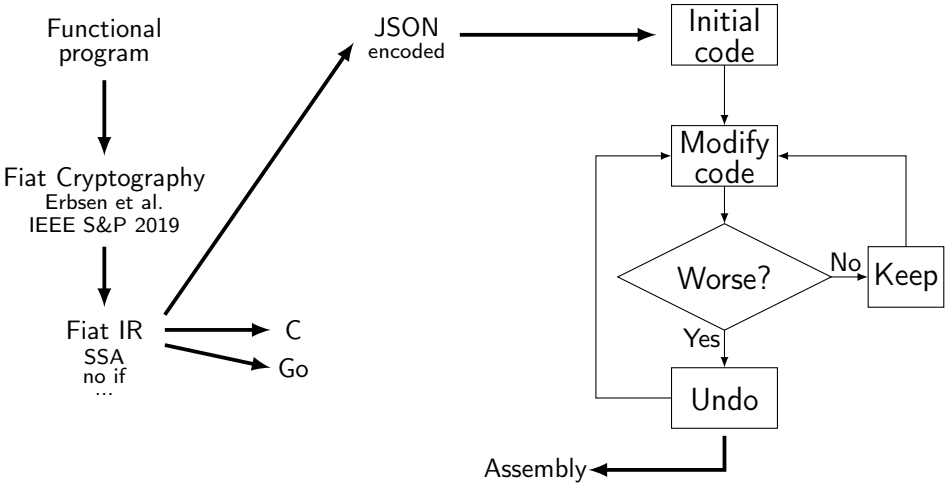

Performance: Field Arithmetic

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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Geometric Mean (4x AMD, 6x Intel)

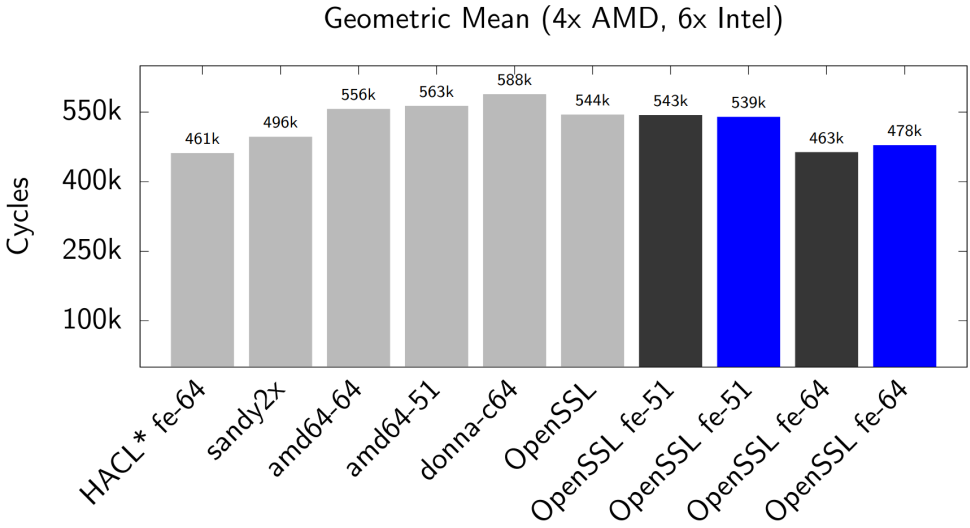
	Multiply		Square	
Curve	Clang	GCC	Clang	GCC
Curve25519	1.19	1.14	1.14	1.18
P-224				
P-256				
P-384				
SIKEp434				
Curve448				
P-521				
Poly1305				
secp256k1				

Performance: Field Arithmetic

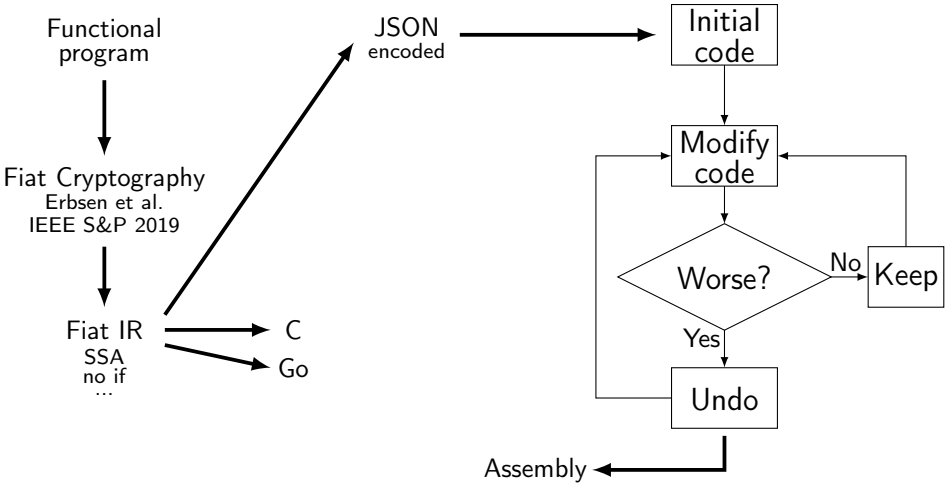
Geometric Mean (4x AMD, 6x Intel)

	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

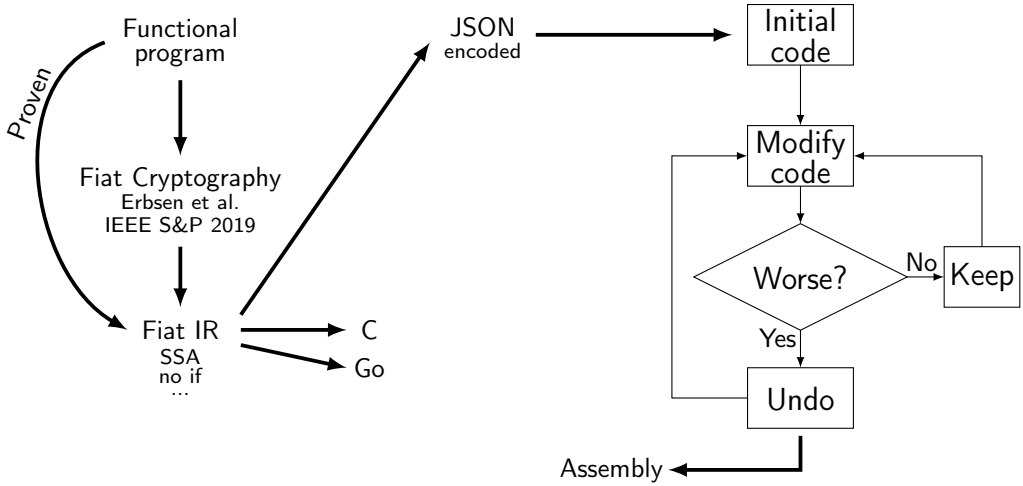
Performance: Scalar Multiplication



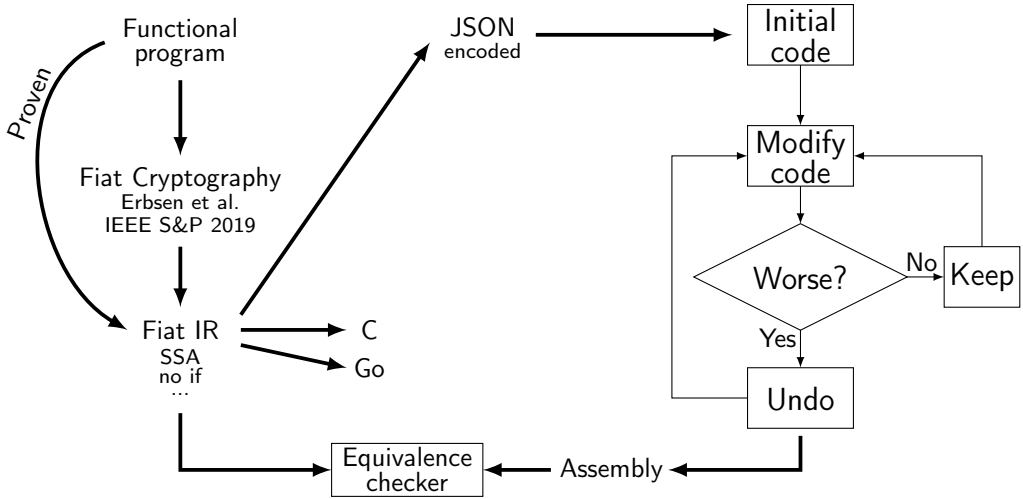
Correctness



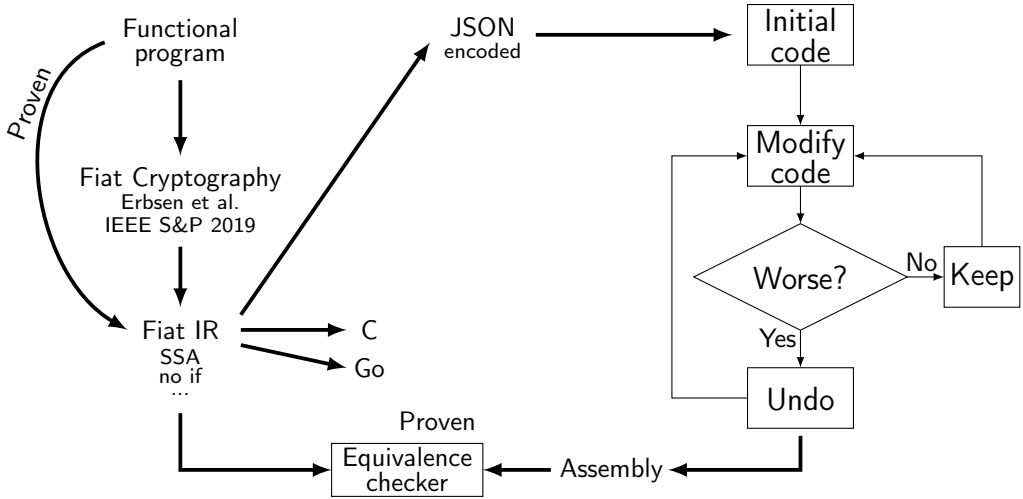
Correctness



Correctness



Correctness



Achievements

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- CryptOpt: automatic cryptographic code optimizer

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GitHub Project

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GitHub Project

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GitHub Project

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- Verified compilation of the generated code
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- Won the first prize of the 10^{th} Deutschen IT-Sicherheitspreis
- Integrated in Google's products including Chromium-base browsers