Testing Side-Channel Security of Cryptographic Implementations against Future Microarchitectures

Chitchanok Chuengsatiansup and Marco Guarnieri

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Joint work with Gilles. Barthe, Marcel Böhme, Sunjay Cauligi,
Daniel Genkin, David Mateos Romero, Peter Schwabe, David Wu, and Yuval Yarom

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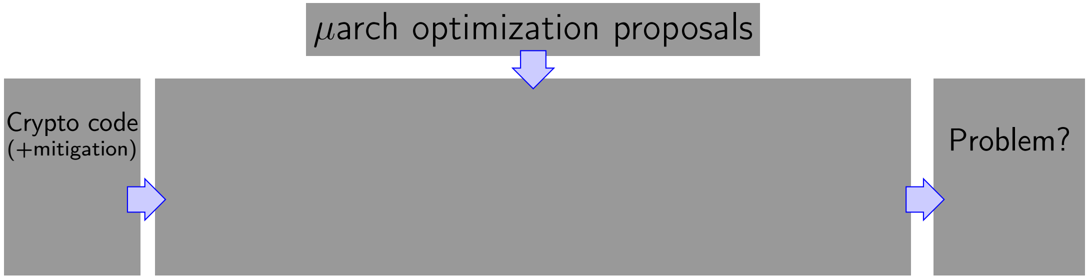
  - future microarchitectural optimizations

Our framework



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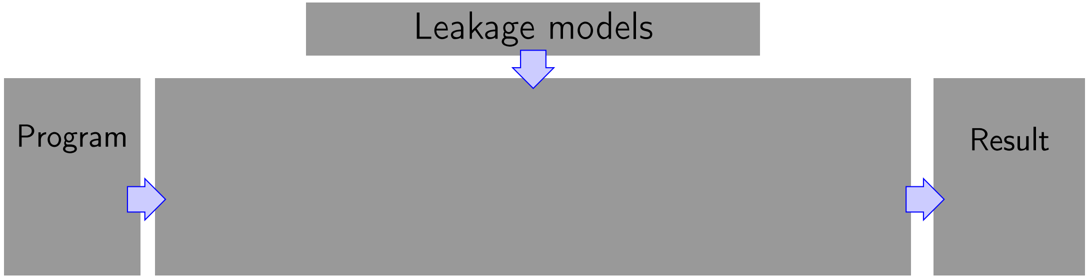

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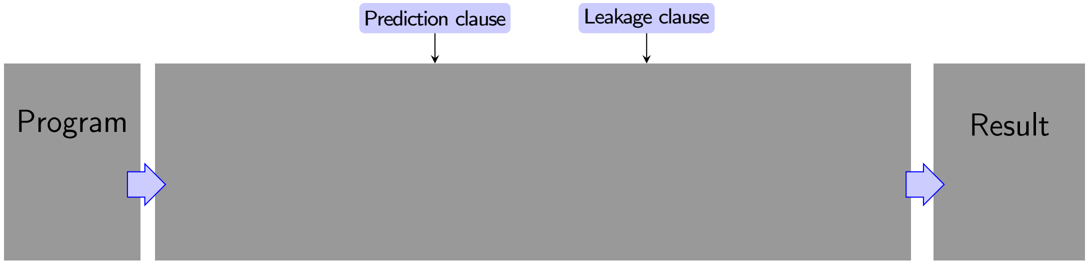

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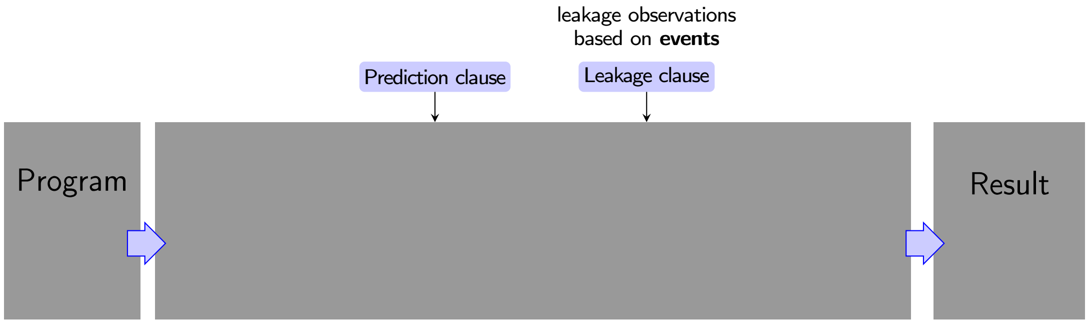

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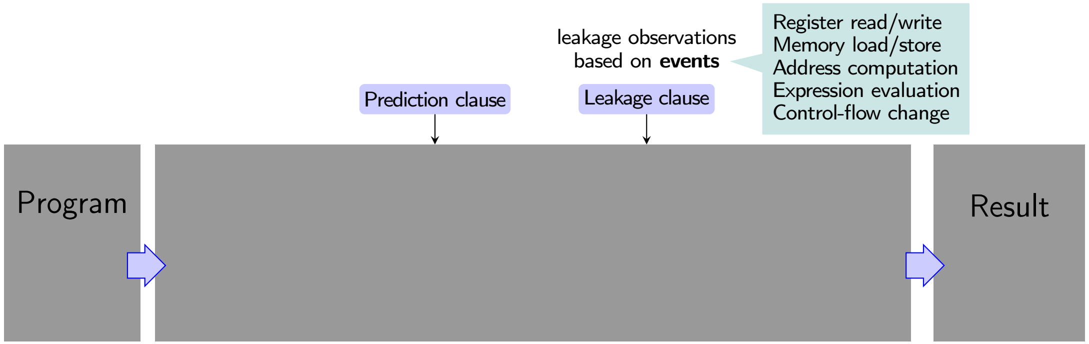

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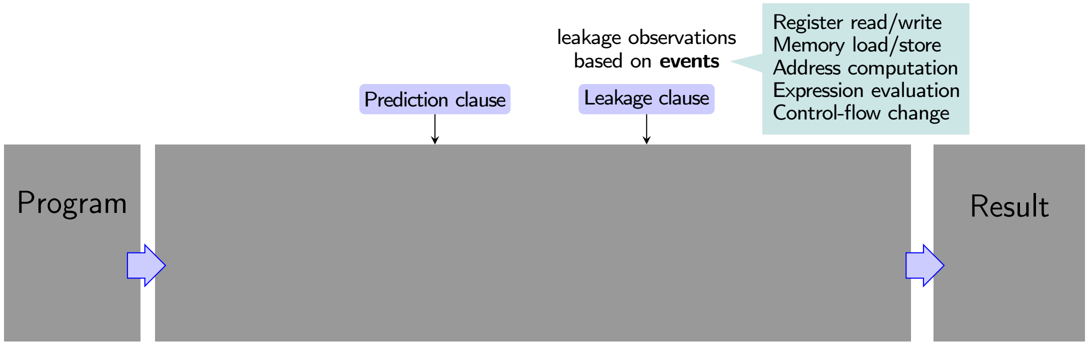

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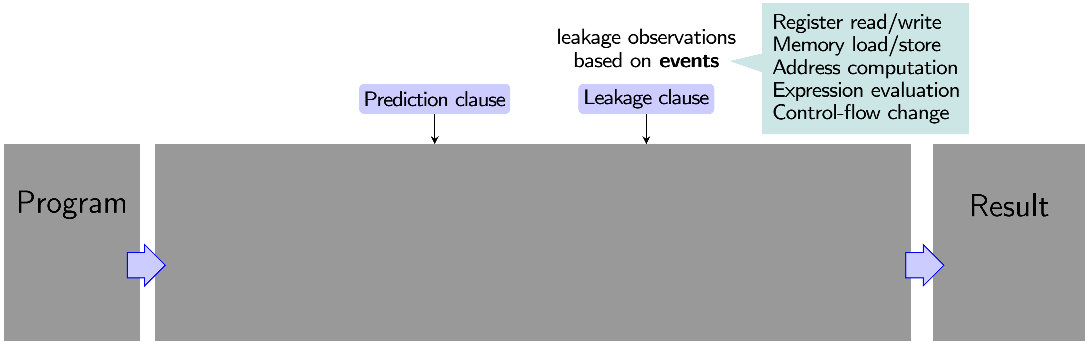

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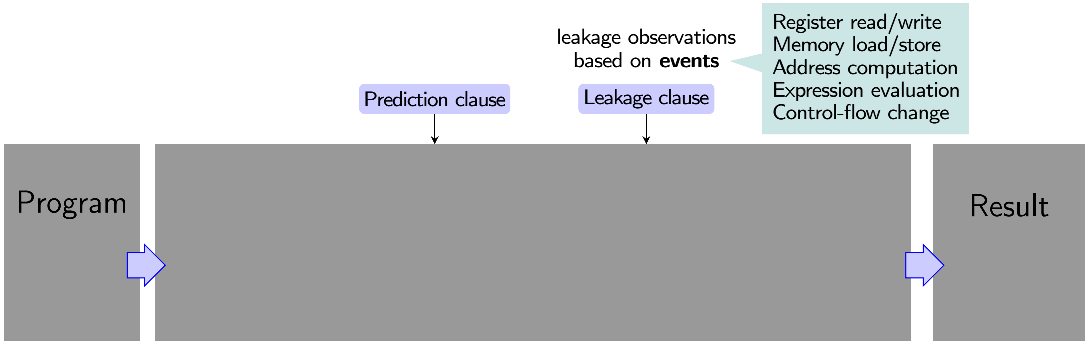

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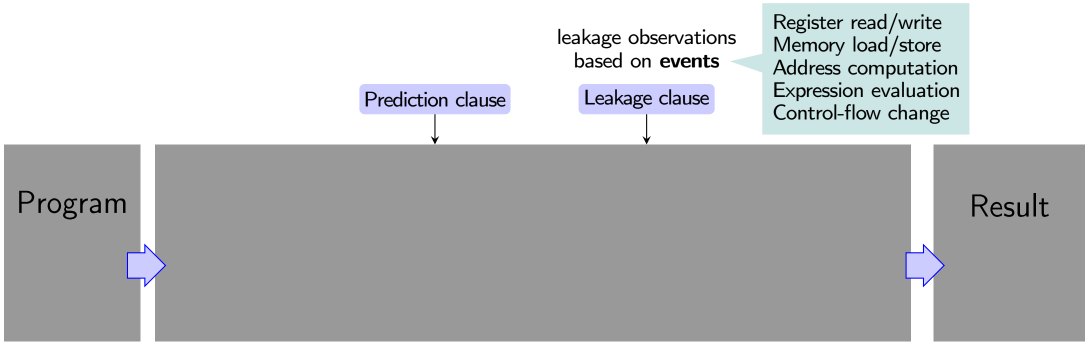

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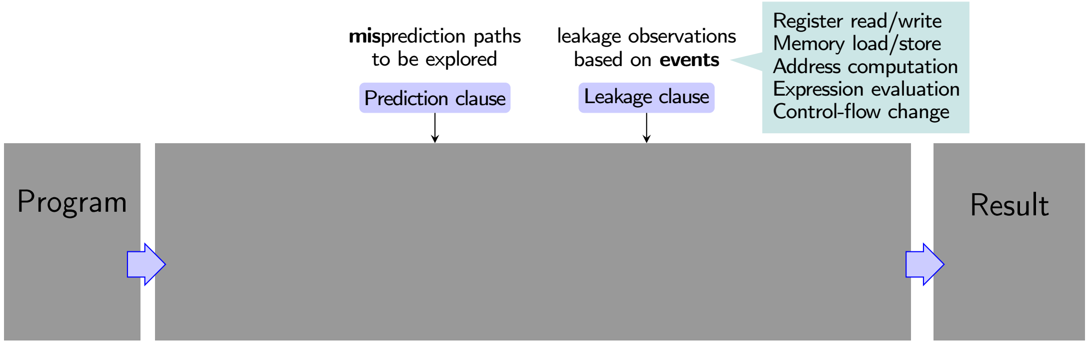

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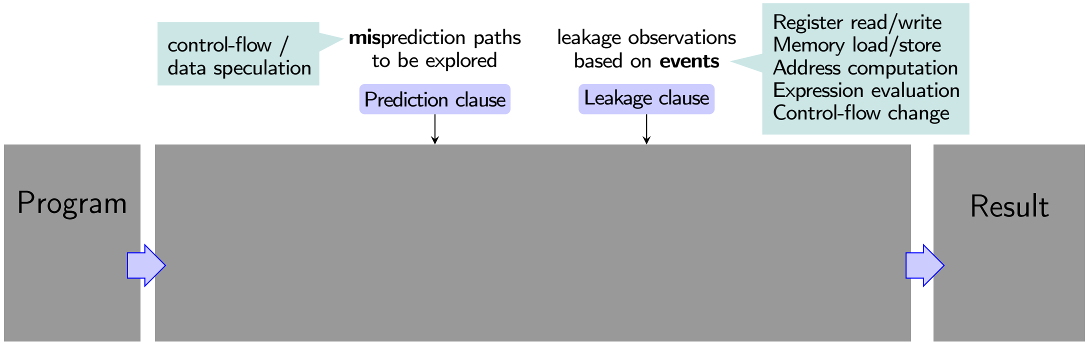

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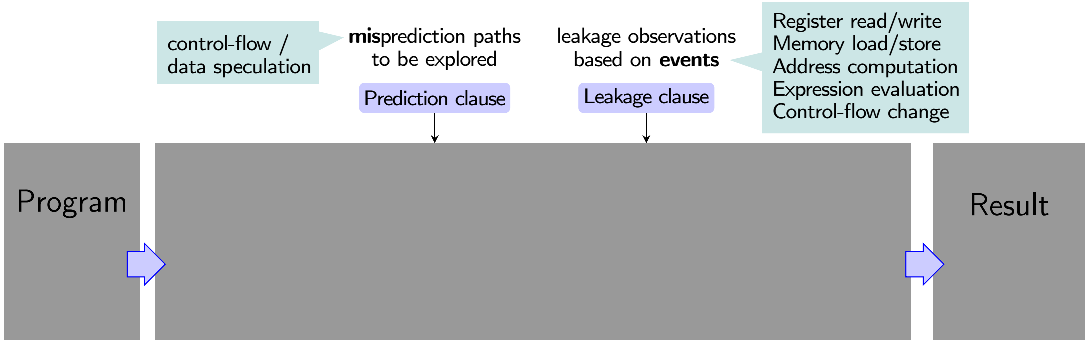

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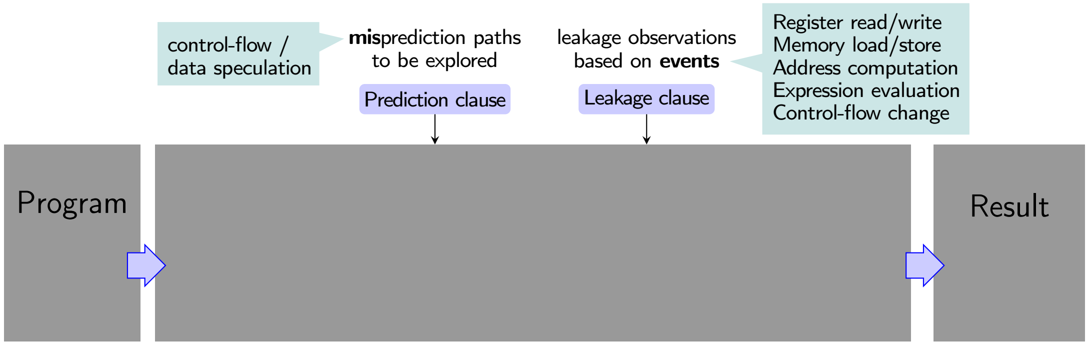

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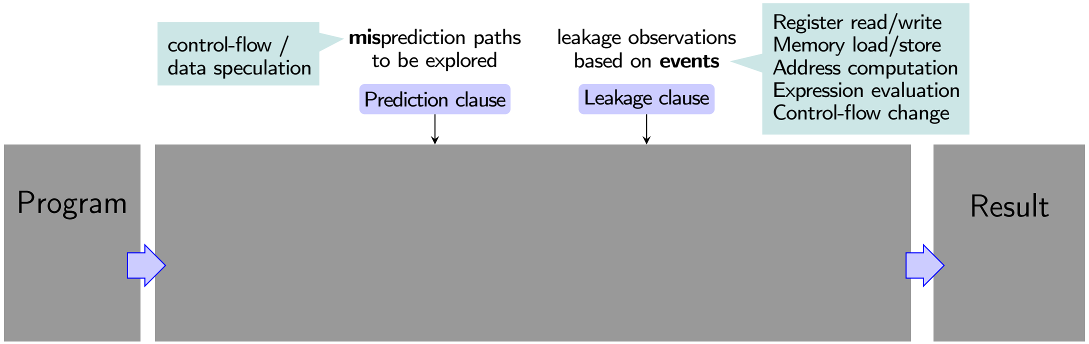

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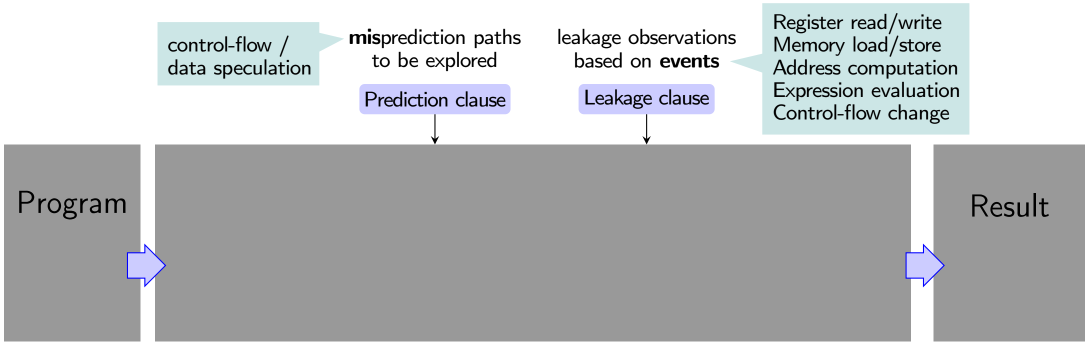

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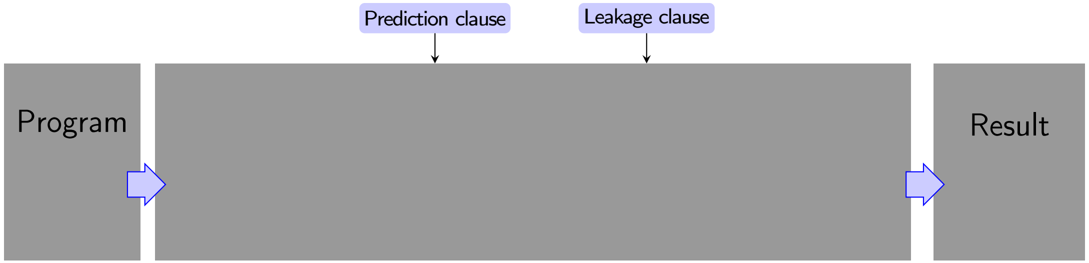

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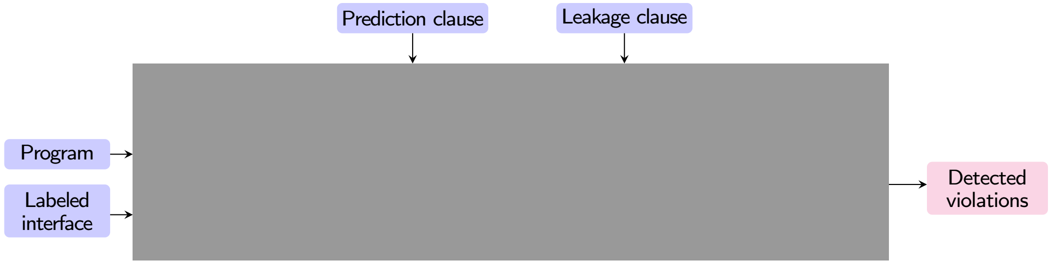

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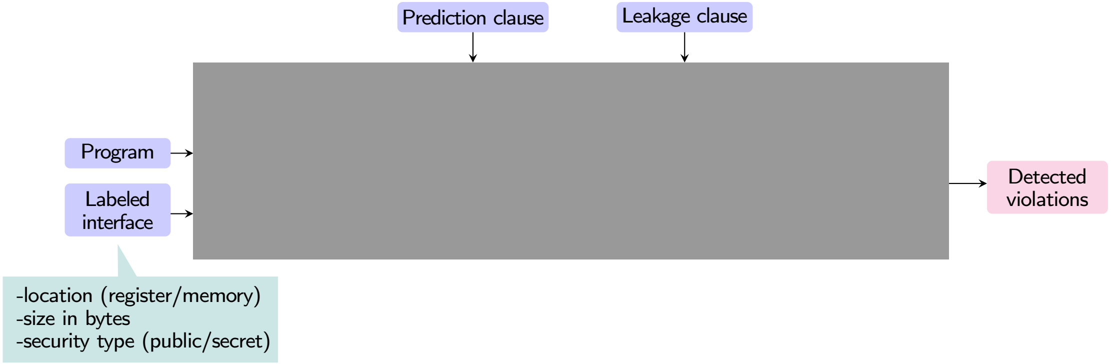

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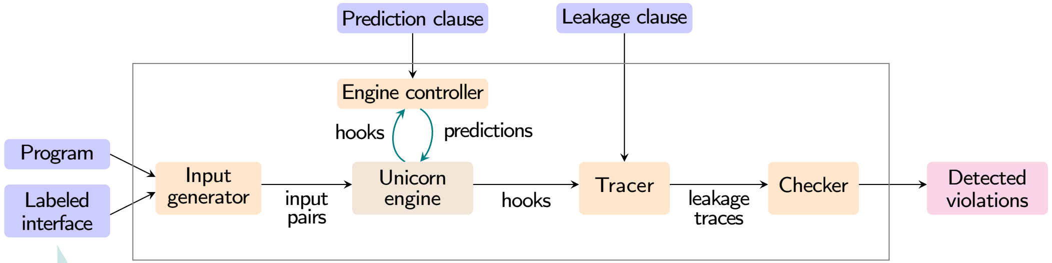

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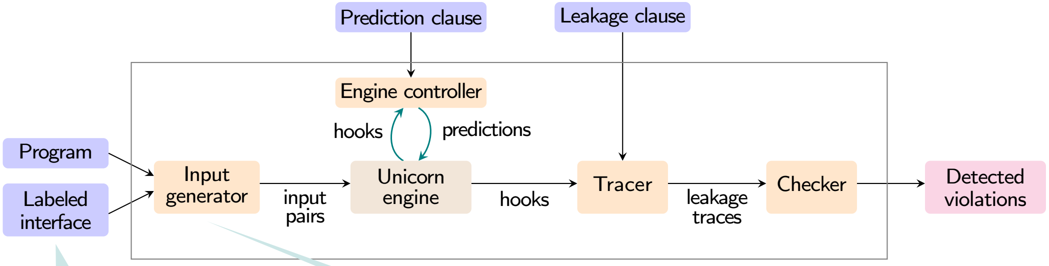

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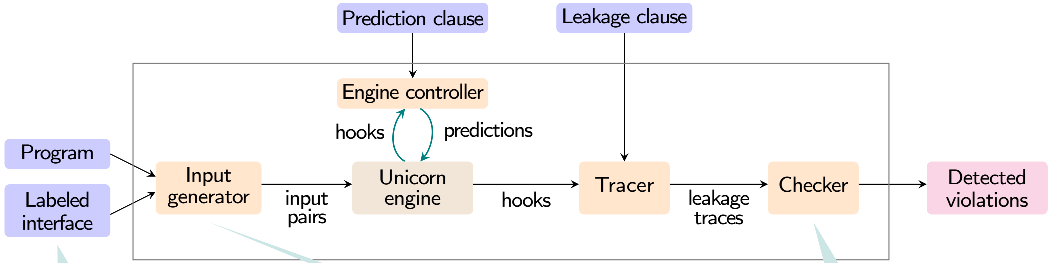

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Leak detected if leakage traces differ

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Evaluation results

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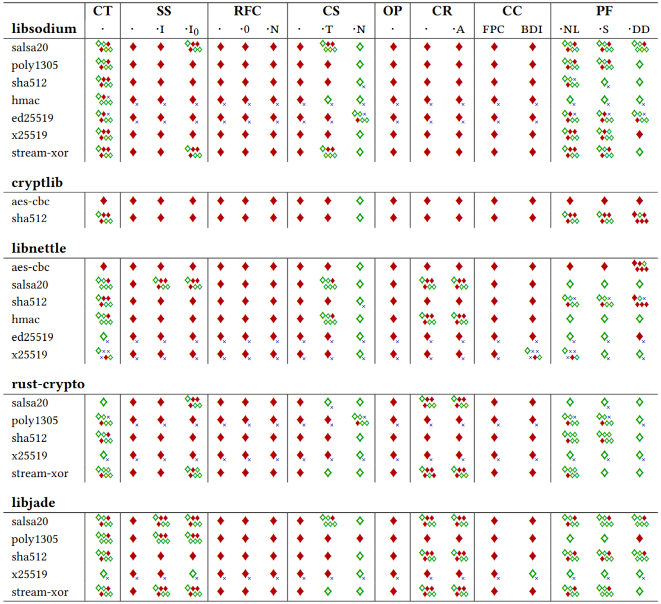


	CT	SS			RFC			CS			OP	CR		CC		PF		
libsodium	·	·	·I	·I_0	·	·0	·N	·	·T	·N	·	·	·A	FPC	BDI	·NL	·S	·DD
salsa20	◇◇◆/◆◇◇	◆	◆	◇◆◆/◆◇◇	◆	◆	◆	◆	◇◆◆/◇◇◇	◇	◆	◆	◆	◆	◆	◇◇◆/◆◇◇	◇◇◆/◆◇◇	◇◇◆/◇◇◇
poly1305	◇◇◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◇◆/◆◇◇	◇◇◆/◆◇◇	◇
sha512	◇◆◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇×	◆	◆	◆	◆	◆	◇◇×/◆◇◇	◇×	◇
hmac	◇◆×/◇◇◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◇×
ed25519	◇◆×/◆◇◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇◇×/◆◇◇	◆×	◆×	◆×	◆×	◆×	◇◆×/◆◇◇	◇◆×/◆◇◇	◇◇×/◆◇◇
x25519	◇◆◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◆◆/◆◇◇	◇◆◇/◆◇◇	◆
stream-xor	◇◆◆/◆◇◇	◆	◆	◇◆◆/◆◇◇	◆	◆	◆	◆	◇◆◆/◇◇◇	◇	◆	◆	◆	◆	◆	◇◆◆/◆◇◇	◇◇◆/◆◇◇	◇
cryptlib																		
aes-cbc	◆	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◆	◆	◆
sha512	◇◆◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆◇◆/◆◆◆
libnettle																		
aes-cbc	◆	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◆	◆	◆◆◇/◆◆◆
salsa20	◇◇◆/◇◇◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◆	◆	◇◇◆/◇◇◇	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇	◇	◇
sha512	◇◆◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇×	◆	◆	◆	◆	◆	◇◇×/◆◇◇	◇◇×/◆◇◇	◆◇×/◆◆◆
hmac	◇◇◆/◇◇◇	◆	◆	◆	◆	◆	◆	◆	◇◇◆/◇◇◇	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇	◇	◇
ed25519	◇×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◆×
x25519	◇××/×◆◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◇××/×◆◇	◇××/×◆◇	◇×	◇×
rust-crypto																		
salsa20	◇	◆	◆	◇◆◆/◆◇◇	◆	◆	◆	◆	◇×	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇	◇×	◇
poly1305	◇◇×/◆◇◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇◇×/◆◇◇	◆×	◆×	◆×	◆×	◆×	◇◇×/◆◇◇	◇◇×/◆◇◇	◇×
sha512	◇◇◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◇◇/◆◇◇	◇◇◇/◆◇◇	◇
x25519	◇×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◇×
stream-xor	◇◇◇/◆◇◇	◆	◆	◇◆◇/◆◇◇	◆	◆	◆	◆	◇	◇	◆	◇◆◆/◆◇◆	◇◆◆/◆◇◇	◆	◆	◇◇◇/◆◇◇	◇	◇
libjade																		
salsa20	◇◇◆/◆◇◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◆	◆	◇◇◆/◇◇◇	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇◇◆/◆◇◇	◇◇◆/◇◇◇	◇◇◆/◇◇◇
poly1305	◇◇◆/◇◇◇	◆	◇◆◆/◇◇◇	◇◆◆/◇◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◇	◇	◆
sha512	◇◇◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇◇◆/◆◇◇	◇◇◆/◆◇◇	◇◇◆/◇◇◇
x25519	◇×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◇×	◇×	◇×	◇×
stream-xor	◇◇◆/◆◇◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◆	◆	◇	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇◇◆/◆◇◇	◇◇◆/◇◇◇	◇

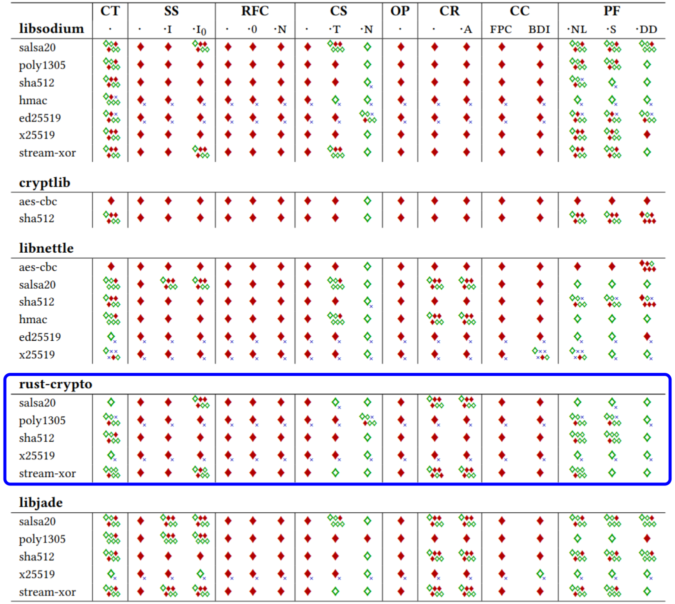
Evaluation results

- All analyzed implementations leak

	CT	SS			RFC			CS			OP	CR		CC		PF		
libsodium	·	·	·I	·I_0	·	·0	·N	·	·T	·N	·	·	·A	FPC	BDI	·NL	·S	·DD
salsa20	◇◇♦ ♦◇◇	♦	♦	◇♦♦ ♦◇◇	♦	♦	♦	♦	◇♦♦ ◇◇◇	◇	♦	♦	♦	♦	♦	◇◇♦ ♦◇◇	◇◇♦ ♦◇◇	◇◇♦ ◇◇◇
poly1305	◇◇♦ ♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	♦	♦	♦	♦	◇◇♦ ♦◇◇	◇◇♦ ♦◇◇	◇
sha512	◇♦♦ ♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇×	♦	♦	♦	♦	♦	◇◇× ♦◇◇	◇×	◇
hmac	◇♦× ◇◇◇	♦×	♦×	♦×	♦×	♦×	♦×	♦×	◇×	◇×	♦×	♦×	♦×	♦×	♦×	◇×	◇×	◇×
ed25519	◇♦× ♦◇◇	♦×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	◇◇× ♦◇◇	♦×	♦×	♦×	♦×	♦×	◇♦× ♦◇◇	◇♦× ♦◇◇	◇◇× ♦◇◇
x25519	◇♦♦ ♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	♦	♦	♦	♦	◇♦♦ ♦◇◇	◇♦◇ ♦◇◇	♦
stream-xor	◇♦♦ ♦◇◇	♦	♦	◇♦♦ ♦◇◇	♦	♦	♦	♦	◇♦♦ ◇◇◇	◇	♦	♦	♦	♦	♦	◇♦♦ ♦◇◇	◇◇♦ ♦◇◇	◇
cryptlib																		
aes-cbc	♦	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	♦	♦	♦	♦	♦	♦	♦
sha512	◇♦♦ ♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	♦	♦	♦	♦	◇♦♦ ♦◇◇	◇♦♦ ♦◇◇	♦◇♦ ♦♦♦
libnettle																		
aes-cbc	♦	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	♦	♦	♦	♦	♦	♦	♦♦◇ ♦♦♦
salsa20	◇◇♦ ◇◇◇	♦	◇♦♦ ♦◇◇	◇♦♦ ♦◇◇	♦	♦	♦	♦	◇◇♦ ◇◇◇	◇	♦	◇♦♦ ♦◇◇	◇♦♦ ♦◇◇	♦	♦	◇	◇	◇
sha512	◇♦♦ ♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇×	♦	♦	♦	♦	♦	◇◇× ♦◇◇	◇◇× ♦◇◇	♦◇× ♦♦♦
hmac	◇◇♦ ◇◇◇	♦	♦	♦	♦	♦	♦	♦	◇◇♦ ◇◇◇	◇	♦	◇♦♦ ♦◇◇	◇♦♦ ♦◇◇	♦	♦	◇	◇	◇
ed25519	◇×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	◇×	♦×	♦×	♦×	♦×	♦×	◇×	◇×	♦×
x25519	◇×× ×♦◇	♦×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	◇×	♦×	♦×	♦×	♦×	◇×× ×♦◇	◇×× ×♦◇	◇×	◇×
rust-crypto																		
salsa20	◇	♦	♦	◇♦♦ ♦◇◇	♦	♦	♦	♦	◇×	◇	♦	◇♦♦ ♦◇◇	◇♦♦ ♦◇◇	♦	♦	◇	◇×	◇
poly1305	◇◇× ♦◇◇	♦×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	◇◇× ♦◇◇	♦×	♦×	♦×	♦×	♦×	◇◇× ♦◇◇	◇◇× ♦◇◇	◇×
sha512	◇◇♦ ♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	♦	♦	♦	♦	◇◇◇ ♦◇◇	◇◇◇ ♦◇◇	◇
x25519	◇×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	◇×	♦×	♦×	♦×	♦×	♦×	◇×	◇×	◇×
stream-xor	◇◇◇ ♦◇◇	♦	♦	◇♦◇ ♦◇◇	♦	♦	♦	♦	◇	◇	♦	◇♦♦ ♦◇♦	◇♦♦ ♦◇◇	♦	♦	◇◇◇ ♦◇◇	◇	◇
libjade																		
salsa20	◇◇♦ ♦◇◇	♦	◇♦♦ ♦◇◇	◇♦♦ ♦◇◇	♦	♦	♦	♦	◇◇♦ ◇◇◇	◇	♦	◇♦♦ ♦◇◇	◇♦♦ ♦◇◇	♦	♦	◇◇♦ ♦◇◇	◇◇♦ ◇◇◇	◇◇♦ ◇◇◇
poly1305	◇◇♦ ◇◇◇	♦	◇♦♦ ◇◇◇	◇♦♦ ◇◇◇	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	◇	◇	♦
sha512	◇◇♦ ♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	◇♦♦ ♦◇◇	◇♦♦ ♦◇◇	♦	♦	◇◇♦ ♦◇◇	◇◇♦ ♦◇◇	◇◇♦ ◇◇◇
x25519	◇×	♦×	♦×	◇×	♦×	♦×	♦×	♦×	♦×	◇×	♦×	♦×	♦×	♦×	◇×	◇×	◇×	◇×
stream-xor	◇◇♦ ♦◇◇	♦	◇♦♦ ♦◇◇	◇♦♦ ♦◇◇	♦	♦	♦	♦	◇	◇	♦	◇♦♦ ♦◇◇	◇♦♦ ♦◇◇	♦	♦	◇◇♦ ♦◇◇	◇◇♦ ◇◇◇	◇

Evaluation results

- All analyzed implementations leak
- Memory-safe languages (e.g., Rust) not significantly mitigate leaks



	CT	SS			RFC			CS			OP	CR		CC		PF		
libsodium	·	·	·I	·I_0	·	·0	·N	·	·T	·N	·	·	·A	FPC	BDI	·NL	·S	·DD
salsa20	◇◇◆ ◆◇◇	◆	◆	◇◆◆ ◆◇◇	◆	◆	◆	◆	◇◆◆ ◇◇◇	◇	◆	◆	◆	◆	◆	◇◇◆ ◆◇◇	◇◇◆ ◆◇◇	◇◇◆ ◇◇◇
poly1305	◇◇◆ ◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◇◆ ◆◇◇	◇◇◆ ◆◇◇	◇
sha512	◇◆◆ ◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇×	◆	◆	◆	◆	◆	◇◇× ◆◇◇	◇×	◇
hmac	◇◆× ◇◇◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◇×
ed25519	◇◆× ◆◇◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇◇× ◆◇◇	◆×	◆×	◆×	◆×	◆×	◇◆× ◆◇◇	◇◆× ◆◇◇	◇◇× ◆◇◇
x25519	◇◆◆ ◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◆◆ ◆◇◇	◇◆◇ ◆◇◇	◆
stream-xor	◇◆◆ ◆◇◇	◆	◆	◇◆◆ ◆◇◇	◆	◆	◆	◆	◇◆◆ ◇◇◇	◇	◆	◆	◆	◆	◆	◇◆◆ ◆◇◇	◇◇◆ ◆◇◇	◇
cryptlib																		
aes-cbc	◆	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◆	◆	◆
sha512	◇◆◆ ◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◆◆ ◆◇◇	◇◆◆ ◆◇◇	◆◇◆ ◆◆◆
libnettle																		
aes-cbc	◆	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◆	◆	◆◇◇ ◆◆◆
salsa20	◇◇◆ ◇◇◇	◆	◇◆◆ ◆◇◇	◇◆◆ ◆◇◇	◆	◆	◆	◆	◇◇◆ ◇◇◇	◇	◆	◇◆◆ ◆◇◇	◇◆◆ ◆◇◇	◆	◆	◇	◇	◇
sha512	◇◆◆ ◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇×	◆	◆	◆	◆	◆	◇◇× ◆◇◇	◇◇× ◆◇◇	◆◇× ◆◆◆
hmac	◇◇◆ ◇◇◇	◆	◆	◆	◆	◆	◆	◆	◇◇◆ ◇◇◇	◇	◆	◇◆◆ ◆◇◇	◇◆◆ ◆◇◇	◆	◆	◇	◇	◇
ed25519	◇×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◆×
x25519	◇×× ×◆◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◇×× ×◆◇	◇×× ×◆◇	◇×	◇×
rust-crypto																		
salsa20	◇	◆	◆	◇◆◆ ◆◇◇	◆	◆	◆	◆	◇×	◇	◆	◇◆◆ ◆◇◇	◇◆◆ ◆◇◇	◆	◆	◇	◇×	◇
poly1305	◇◇× ◆◇◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇◇× ◆◇◇	◆×	◆×	◆×	◆×	◆×	◇◇× ◆◇◇	◇◇× ◆◇◇	◇×
sha512	◇◇◆ ◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◇◇ ◆◇◇	◇◇◇ ◆◇◇	◇
x25519	◇×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◇×
stream-xor	◇◇◇ ◆◇◇	◆	◆	◇◆◇ ◆◇◇	◆	◆	◆	◆	◇	◇	◆	◇◆◆ ◆◇◆	◇◆◆ ◆◇◇	◆	◆	◇◇◇ ◆◇◇	◇	◇
libjade																		
salsa20	◇◇◆ ◆◇◇	◆	◇◆◆ ◆◇◇	◇◆◆ ◆◇◇	◆	◆	◆	◆	◇◇◆ ◇◇◇	◇	◆	◇◆◆ ◆◇◇	◇◆◆ ◆◇◇	◆	◆	◇◇◆ ◆◇◇	◇◇◆ ◇◇◇	◇◇◆ ◇◇◇
poly1305	◇◇◆ ◇◇◇	◆	◇◆◆ ◇◇◇	◇◆◆ ◇◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◇	◇	◆
sha512	◇◇◆ ◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◇◆◆ ◆◇◇	◇◆◆ ◆◇◇	◆	◆	◇◇◆ ◆◇◇	◇◇◆ ◆◇◇	◇◇◆ ◇◇◇
x25519	◇×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◇×	◇×	◇×	◇×
stream-xor	◇◇◆ ◆◇◇	◆	◇◆◆ ◆◇◇	◇◆◆ ◆◇◇	◆	◆	◆	◆	◇	◇	◆	◇◆◆ ◆◇◇	◇◆◆ ◆◇◇	◆	◆	◇◇◆ ◆◇◇	◇◇◆ ◇◇◇	◇

Evaluation results

- All analyzed implementations leak
- Memory-safe languages (e.g., Rust) not significantly mitigate leaks
- CT programming (e.g., libsodium, libjade) does not fully prevent leaks

	CT	SS			RFC			CS			OP	CR		CC		PF		
libsodium	·	·	·I	·I$_0$	·	·0	·N	·	·T	·N	·	·	·A	FPC	BDI	·NL	·S	·DD
salsa20	◇◇◆/◆◇◇	◆	◆	◇◆◆/◆◇◇	◆	◆	◆	◆	◇◆◆/◇◇◇	◇	◆	◆	◆	◆	◆	◇◇◆/◆◇◇	◇◇◆/◆◇◇	◇◇◆/◇◇◇
poly1305	◇◇◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◇◆/◆◇◇	◇◇◆/◆◇◇	◇
sha512	◇◆◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇×	◆	◆	◆	◆	◆	◇◇×/◆◇◇	◇×	◇
hmac	◇◆×/◇◇◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◇×
ed25519	◇◆×/◆◇◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇◇×/◆◇◇	◆×	◆×	◆×	◆×	◆×	◇◆×/◆◇◇	◇◆×/◆◇◇	◇◇×/◆◇◇
x25519	◇◆◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◆◆/◆◇◇	◇◆◇/◆◇◇	◆
stream-xor	◇◆◆/◆◇◇	◆	◆	◇◆◆/◆◇◇	◆	◆	◆	◆	◇◆◆/◇◇◇	◇	◆	◆	◆	◆	◆	◇◆◆/◆◇◇	◇◇◆/◆◇◇	◇
cryptlib																		
aes-cbc	◆	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◆	◆	◆
sha512	◇◆◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆◇◆/◆◆◆
libnettle																		
aes-cbc	◆	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◆	◆	◆◆◇/◆◆◆
salsa20	◇◇◆/◇◇◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◆	◆	◇◇◆/◇◇◇	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇	◇	◇
sha512	◇◆◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇×	◆	◆	◆	◆	◆	◇◇×/◆◇◇	◇◇×/◆◇◇	◆◇×/◆◆◆
hmac	◇◇◆/◇◇◇	◆	◆	◆	◆	◆	◆	◆	◇◇◆/◇◇◇	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇	◇	◇
ed25519	◇×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◆×
x25519	◇××/×◆◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◇××/×◆◇	◇××/×◆◇	◇×	◇×
rust-crypto																		
salsa20	◇	◆	◆	◇◆◆/◆◇◇	◆	◆	◆	◆	◇×	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇	◇×	◇
poly1305	◇◇×/◆◇◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇◇×/◆◇◇	◆×	◆×	◆×	◆×	◆×	◇◇×/◆◇◇	◇◇×/◆◇◇	◇×
sha512	◇◇◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◇◇/◆◇◇	◇◇◇/◆◇◇	◇
x25519	◇×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◇×
stream-xor	◇◇◇/◆◇◇	◆	◆	◇◆◇/◆◇◇	◆	◆	◆	◆	◇	◇	◆	◇◆◆/◆◇◆	◇◆◆/◆◇◇	◆	◆	◇◇◇/◆◇◇	◇	◇
libjade																		
salsa20	◇◇◆/◆◇◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◆	◆	◇◇◆/◇◇◇	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇◇◆/◆◇◇	◇◇◆/◇◇◇	◇◇◆/◇◇◇
poly1305	◇◇◆/◇◇◇	◆	◇◆◆/◇◇◇	◇◆◆/◇◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◇	◇	◆
sha512	◇◇◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇◇◆/◆◇◇	◇◇◆/◆◇◇	◇◇◆/◇◇◇
x25519	◇×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◇×	◇×	◇×	◇×
stream-xor	◇◇◆/◆◇◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◆	◆	◇	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇◇◆/◆◇◇	◇◇◆/◇◇◇	◇

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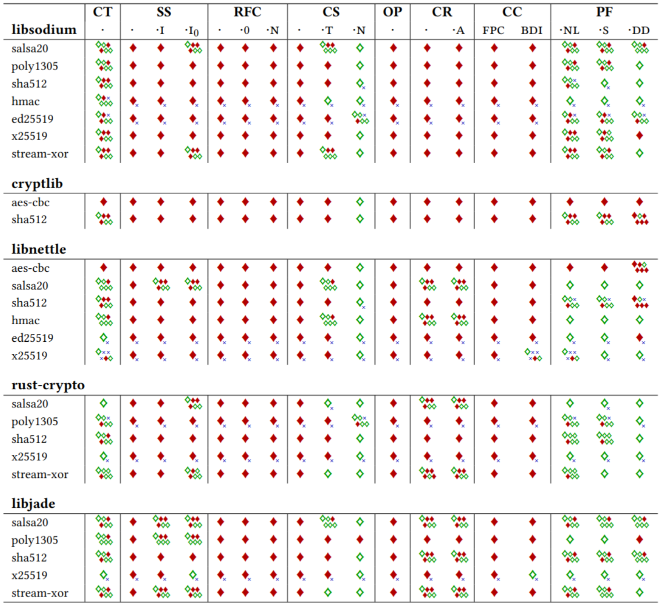

	CT	SS			RFC			CS			OP	CR		CC		PF		
libsodium	·	·	·I	·I_0	·	·0	·N	·	·T	·N	·	·	·A	FPC	BDI	·NL	·S	·DD
salsa20	◇◇◆/◆◇◇	◆	◆	◇◆◆/◆◇◇	◆	◆	◆	◆	◇◆◆/◇◇◇	◇	◆	◆	◆	◆	◆	◇◇◆/◆◇◇	◇◇◆/◆◇◇	◇◇◆/◇◇◇
poly1305	◇◇◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◇◆/◆◇◇	◇◇◆/◆◇◇	◇
sha512	◇◆◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇×	◆	◆	◆	◆	◆	◇◇×/◆◇◇	◇×	◇
hmac	◇◆×/◇◇◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◇×
ed25519	◇◆×/◆◇◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇◇×/◆◇◇	◆×	◆×	◆×	◆×	◆×	◇◆×/◆◇◇	◇◆×/◆◇◇	◇◇×/◆◇◇
x25519	◇◆◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◆◆/◆◇◇	◇◆◇/◆◇◇	◆
stream-xor	◇◆◆/◆◇◇	◆	◆	◇◆◆/◆◇◇	◆	◆	◆	◆	◇◆◆/◇◇◇	◇	◆	◆	◆	◆	◆	◇◆◆/◆◇◇	◇◇◆/◆◇◇	◇
cryptlib																		
aes-cbc	◆	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◆	◆	◆
sha512	◇◆◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆◇◆/◆◆◆
libnettle																		
aes-cbc	◆	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◆	◆	◆◆◇/◆◆◆
salsa20	◇◇◆/◇◇◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◆	◆	◇◇◆/◇◇◇	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇	◇	◇
sha512	◇◆◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇×	◆	◆	◆	◆	◆	◇◇×/◆◇◇	◇◇×/◆◇◇	◆◇×/◆◆◆
hmac	◇◇◆/◇◇◇	◆	◆	◆	◆	◆	◆	◆	◇◇◆/◇◇◇	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇	◇	◇
ed25519	◇×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◆×
x25519	◇××/×◆◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◇××/×◆◇	◇××/×◆◇	◇×	◇×
rust-crypto																		
salsa20	◇	◆	◆	◇◆◆/◆◇◇	◆	◆	◆	◆	◇×	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇	◇×	◇
poly1305	◇◇×/◆◇◇	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇◇×/◆◇◇	◆×	◆×	◆×	◆×	◆×	◇◇×/◆◇◇	◇◇×/◆◇◇	◇×
sha512	◇◇◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◆	◆	◆	◆	◇◇◇/◆◇◇	◇◇◇/◆◇◇	◇
x25519	◇×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◇×	◇×
stream-xor	◇◇◇/◆◇◇	◆	◆	◇◆◇/◆◇◇	◆	◆	◆	◆	◇	◇	◆	◇◆◆/◆◇◆	◇◆◆/◆◇◇	◆	◆	◇◇◇/◆◇◇	◇	◇
libjade																		
salsa20	◇◇◆/◆◇◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◆	◆	◇◇◆/◇◇◇	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇◇◆/◆◇◇	◇◇◆/◇◇◇	◇◇◆/◇◇◇
poly1305	◇◇◆/◇◇◇	◆	◇◆◆/◇◇◇	◇◆◆/◇◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◇	◇	◆
sha512	◇◇◆/◆◇◇	◆	◆	◆	◆	◆	◆	◆	◆	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇◇◆/◆◇◇	◇◇◆/◆◇◇	◇◇◆/◇◇◇
x25519	◇×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◆×	◇×	◆×	◆×	◆×	◆×	◇×	◇×	◇×	◇×
stream-xor	◇◇◆/◆◇◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◆	◆	◇	◇	◆	◇◆◆/◆◇◇	◇◆◆/◆◇◇	◆	◆	◇◇◆/◆◇◇	◇◇◆/◇◇◇	◇

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$\langle\textsc{Seq}\rangle\ \langle\textsc{Pht}\rangle\ \langle\textsc{Sls}\rangle$
$\langle\textsc{Stl}\rangle\ \langle\textsc{Rsb}_\perp\rangle\ \langle\textsc{Rsb}_\circ\rangle$

◇◇×
♦◇◇

	CT	SS			RFC			CS			OP	CR		CC		PF		
libsodium	·	·	·I	·I$_0$	·	·0	·N	·	·T	·N	·	·	·A	FPC	BDI	·NL	·S	·DD
salsa20	◇◇♦/♦◇◇	♦	♦	◇♦♦/♦◇◇	♦	♦	♦	♦	◇♦♦/◇◇◇	◇	♦	♦	♦	♦	♦	◇◇♦/♦◇◇	◇◇♦/♦◇◇	◇◇♦/◇◇◇
poly1305	◇◇♦/♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	♦	♦	♦	♦	◇◇♦/♦◇◇	◇◇♦/♦◇◇	◇
sha512	◇♦♦/♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇×	♦	♦	♦	♦	♦	◇◇×/♦◇◇	◇×	◇
hmac	◇♦×/◇◇◇	♦×	♦×	♦×	♦×	♦×	♦×	♦×	◇×	◇×	♦×	♦×	♦×	♦×	♦×	◇×	◇×	◇×
ed25519	◇♦×/♦◇◇	♦×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	◇◇×/♦◇◇	♦×	♦×	♦×	♦×	♦×	◇♦×/♦◇◇	◇♦×/♦◇◇	◇◇×/♦◇◇
x25519	◇♦♦/♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	♦	♦	♦	♦	◇♦♦/♦◇◇	◇♦◇/♦◇◇	♦
stream-xor	◇♦♦/♦◇◇	♦	♦	◇♦♦/♦◇◇	♦	♦	♦	♦	◇♦♦/◇◇◇	◇	♦	♦	♦	♦	♦	◇♦♦/♦◇◇	◇◇♦/♦◇◇	◇
cryptlib																		
aes-cbc	♦	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	♦	♦	♦	♦	♦	♦	♦
sha512	◇♦♦/♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	♦	♦	♦	♦	◇♦♦/♦◇◇	◇♦♦/♦◇◇	♦◇♦/♦♦♦
libnettle																		
aes-cbc	♦	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	♦	♦	♦	♦	♦	♦	♦♦◇/♦♦♦
salsa20	◇◇♦/◇◇◇	♦	◇♦♦/♦◇◇	◇♦♦/♦◇◇	♦	♦	♦	♦	◇◇♦/◇◇◇	◇	♦	◇♦♦/♦◇◇	◇♦♦/♦◇◇	♦	♦	◇	◇	◇
sha512	◇♦♦/♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇×	♦	♦	♦	♦	♦	◇◇×/♦◇◇	◇◇×/♦◇◇	♦◇×/♦♦♦
hmac	◇◇♦/◇◇◇	♦	♦	♦	♦	♦	♦	♦	◇◇♦/◇◇◇	◇	♦	◇♦♦/♦◇◇	◇♦♦/♦◇◇	♦	♦	◇	◇	◇
ed25519	◇×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	◇×	♦×	♦×	♦×	♦×	♦×	◇×	◇×	♦×
x25519	◇××/×♦◇	♦×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	◇×	♦×	♦×	♦×	♦×	◇××/×♦◇	◇××/×♦◇	◇×	◇×
rust-crypto																		
salsa20	◇	♦	♦	◇♦♦/♦◇◇	♦	♦	♦	♦	◇×	◇	♦	◇♦♦/♦◇◇	◇♦♦/♦◇◇	♦	♦	◇	◇×	◇
poly1305	◇◇×/♦◇◇	♦×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	◇◇×/♦◇◇	♦×	♦×	♦×	♦×	♦×	◇◇×/♦◇◇	◇◇×/♦◇◇	◇×
sha512	◇◇♦/♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	♦	♦	♦	♦	◇◇◇/♦◇◇	◇◇◇/♦◇◇	◇
x25519	◇×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	♦×	◇×	♦×	♦×	♦×	♦×	♦×	◇×	◇×	◇×
stream-xor	◇◇◇/♦◇◇	♦	♦	◇♦◇/♦◇◇	♦	♦	♦	♦	◇	◇	♦	◇♦♦/♦◇♦	◇♦♦/♦◇◇	♦	♦	◇◇◇/♦◇◇	◇	◇
libjade																		
salsa20	◇◇♦/♦◇◇	♦	◇♦♦/♦◇◇	◇♦♦/♦◇◇	♦	♦	♦	♦	◇◇♦/◇◇◇	◇	♦	◇♦♦/♦◇◇	◇♦♦/♦◇◇	♦	♦	◇◇♦/♦◇◇	◇◇♦/◇◇◇	◇◇♦/◇◇◇
poly1305	◇◇♦/◇◇◇	♦	◇♦♦/◇◇◇	◇♦♦/◇◇◇	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	◇	◇	♦
sha512	◇◇♦/♦◇◇	♦	♦	♦	♦	♦	♦	♦	♦	◇	♦	◇♦♦/♦◇◇	◇♦♦/♦◇◇	♦	♦	◇◇♦/♦◇◇	◇◇♦/♦◇◇	◇◇♦/◇◇◇
x25519	◇×	♦×	♦×	◇×	♦×	♦×	♦×	♦×	♦×	◇×	♦×	♦×	♦×	♦×	◇×	◇×	◇×	◇×
stream-xor	◇◇♦/♦◇◇	♦	◇♦♦/♦◇◇	◇♦♦/♦◇◇	♦	♦	♦	♦	◇	◇	♦	◇♦♦/♦◇◇	◇♦♦/♦◇◇	♦	♦	◇◇♦/♦◇◇	◇◇♦/◇◇◇	◇

Example: leak from constant-time swap

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fe25519_cswap(fe25519_limb f[5], fe25519_limb g[5], bool b)
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    mask = (-(int64_t) b);

    x[0..5] = f[0..5] ^ g[0..5];

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mask $= 0 \rightarrow$ result $= 0$
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mask $= 0 \rightarrow$ x $= 0 \rightarrow$ xor 0 not changed
CS: xor is simplified

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`mask` $= 0 \rightarrow$ result $= 0$
RFC: compress to zero register

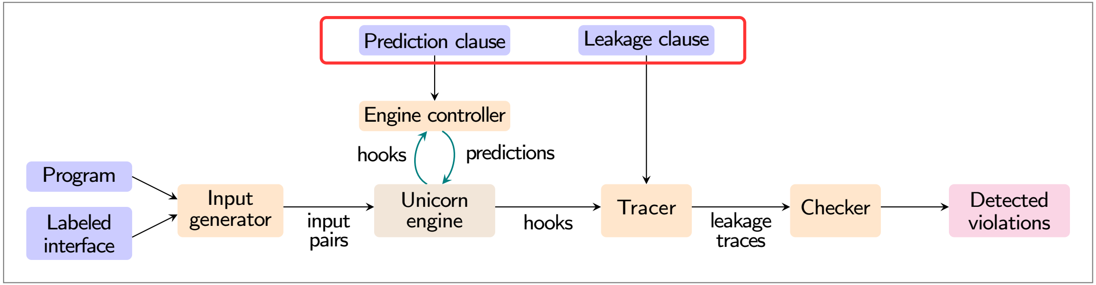
`mask` $= 0 \rightarrow$ `x` $= 0 \rightarrow$ `xor` 0 not changed
CS: `xor` is simplified

values not swapped $\rightarrow$ memory not modified
SS: stores are suppressed

Summary

Summary

- LmSpec: Language for specifying leakage models at the ISA level



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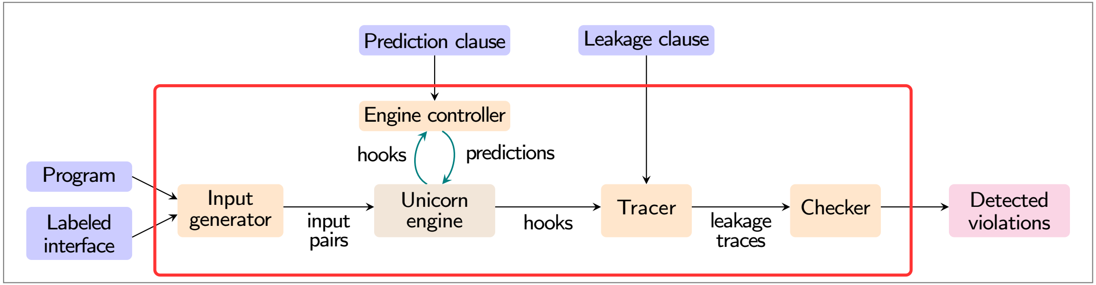
- LmTest: Testing framework for automatically detecting leaks



Summary

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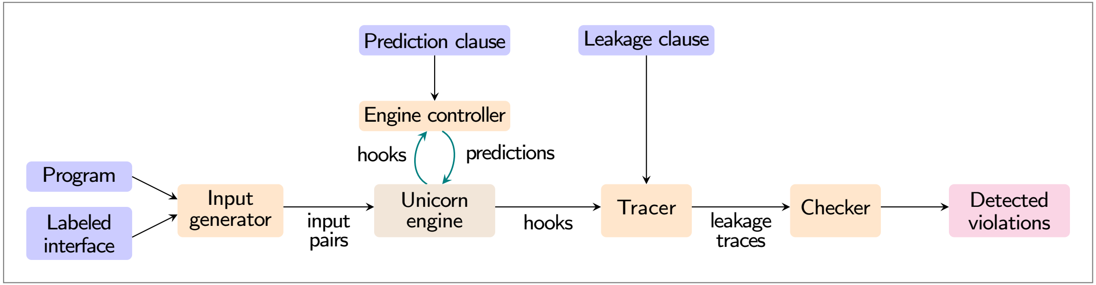
- Extensive evaluation on cryptographic algorithms → *all leak!* 😱



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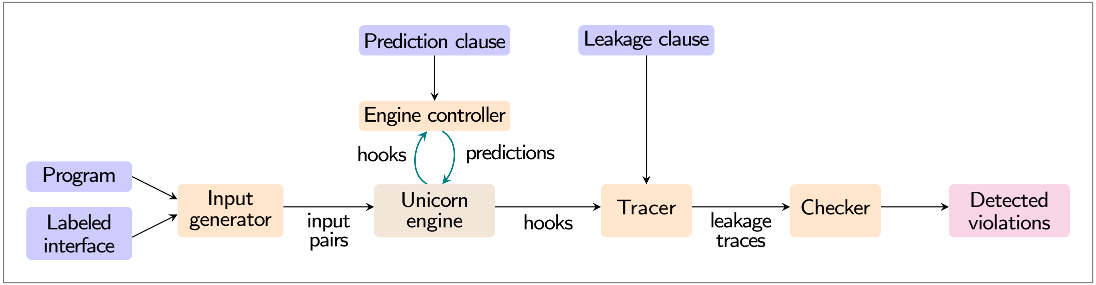
- For more details, see `https://arxiv.org/pdf/2402.00641`


Prediction clause
Leakage clause
Engine controller
hooks
predictions
Program
Labeled interface
Input generator
input pairs
Unicorn engine
hooks
Tracer
leakage traces
Checker
Detected violations