Hash Gone Bad:

Automated discovery of protocol attacks that exploit hash function weaknesses






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Hashes in security protocols

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In security analysis hashes are often assumed to be “perfect”

- meets all desired cryptographic properties
- both in the computational and symbolic setting

Random Oracle Model (ROM)

And in the real world?

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Collisions do exist!

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Collisions for Hash Functions

MD4, MD5, HAVAL-128 and RIPEMD

Xiaoyun Wang[1], Dengguo Feng[2], Xuejia Lai[3], Hongbo Yu[1]
The School of Mathematics and System Science, Shandong University, Jinan250100, China[1]
Institute of Software, Chinese Academy of Sciences, Beijing100080, China[2]
Dept. of Computer Science and Engineering, Shanghai Jiaotong University, Shanghai, China[3]
xywang@sdu.edu.cn[1]
revised on August 17, 2004

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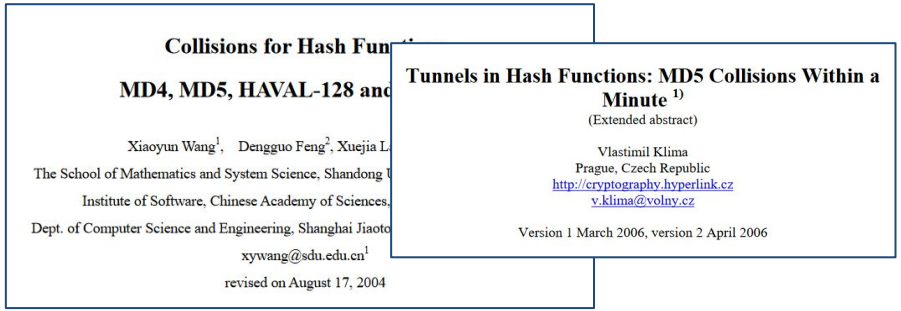

Collisions for Hash Fun

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Tunnels in Hash Functions: MD5 Collisions Within a Minute [1)]

(Extended abstract)

Vlastimil Klima

Prague, Czech Republic

http://cryptography.hyperlink.cz

v.klima@volny.cz

Version 1 March 2006, version 2 April 2006

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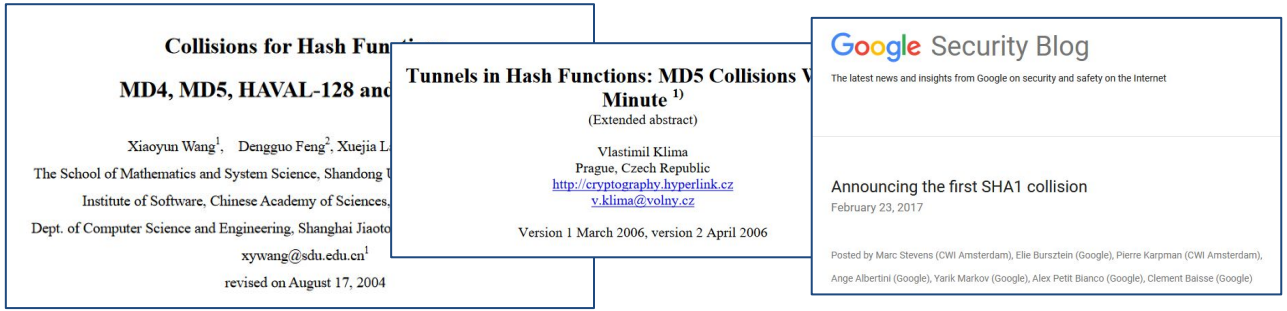

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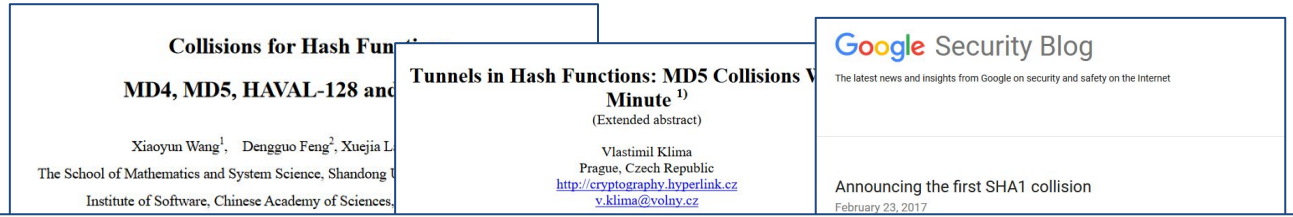

Lifetimes of popular cryptographic hashes (the rainbow chart)

Function	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Snefru																												
MD2 (128-bit)[1]																												
MD4																												
MD5															[2]													
RIPEMD															[2]													
HAVAL-128[1]															[2]													
SHA-0																												
SHA-1																												[3]
RIPEMD-160																												
SHA-2 family																		[4]										
SHA-3 (Keccak)																												

Key | Didn't exist/not public | Under peer review | Considered strong | Minor weakness | Weakened | Broken | Collision found

And in the real world?

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Length Extension (e.g., SHA-1, SHA-2)

- Not a traditional property for cryptographic hashes
- From H(x) an adversary can produce H(x||y) without knowing x
- Example: Breaking authentication in Flickr

flickr

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Transcript Collisions [BL16]

- MITM session hijacking
- Downgrading attacks
- …

flickr

>_ SSH

IPsec

SSL SECURED

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Can we find these flaws **automatically** in the protocol design?

Automatic analysis & Hashes

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Existing Symbolic Model of Cryptography

- Automated security protocol analysis tools
- Assumes “perfect” hash functions (ROM)

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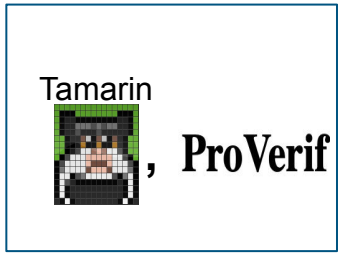
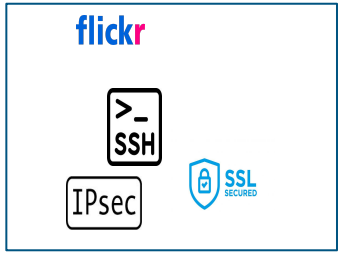
Our Work: Find better Models

- Model all known hash weaknesses
- Goal: discover vulnerabilities in protocols automatically





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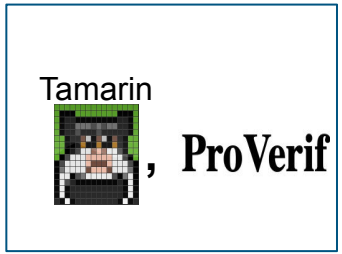
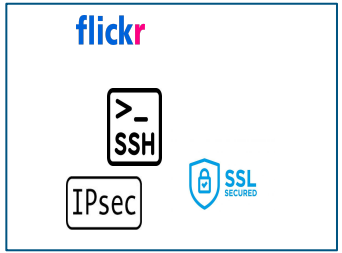
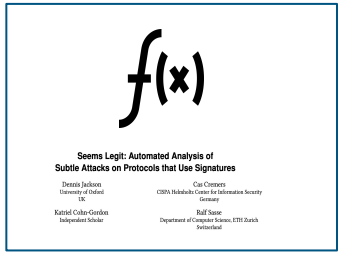
A Technical Detail: Non-Classical Modelling

Underspecified functions approach **[JCCS19]**

- Tool explores all possible functions that meet the requirements
- Trace restrictions limit the possible functions (e.g., forbid collisions)







Symbolic hash models

We classify our attack models into 4 dimensions

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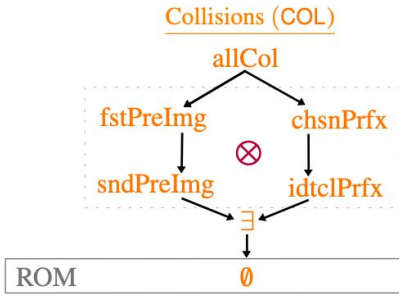
- Collisions



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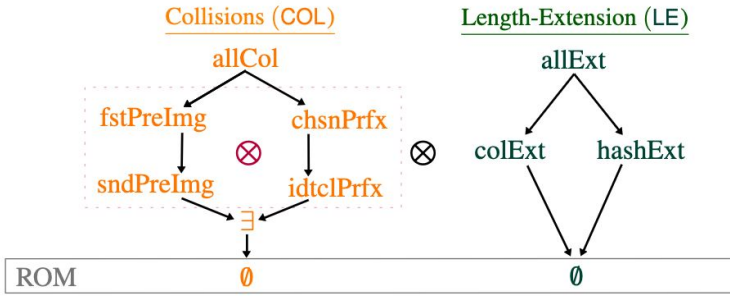
- Length Extensions



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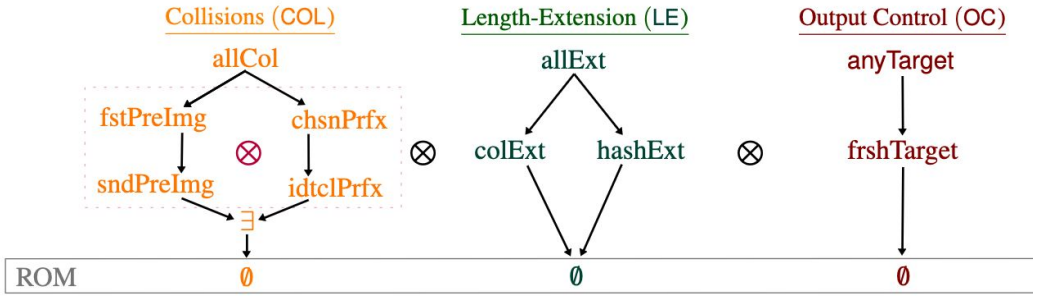
- Output Control



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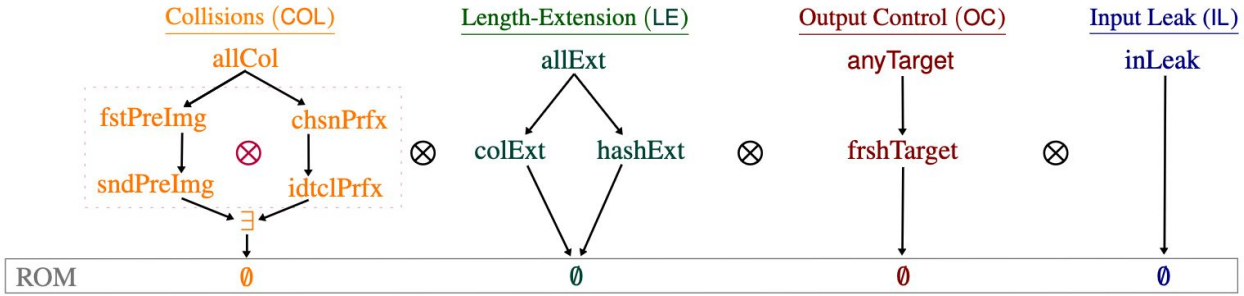

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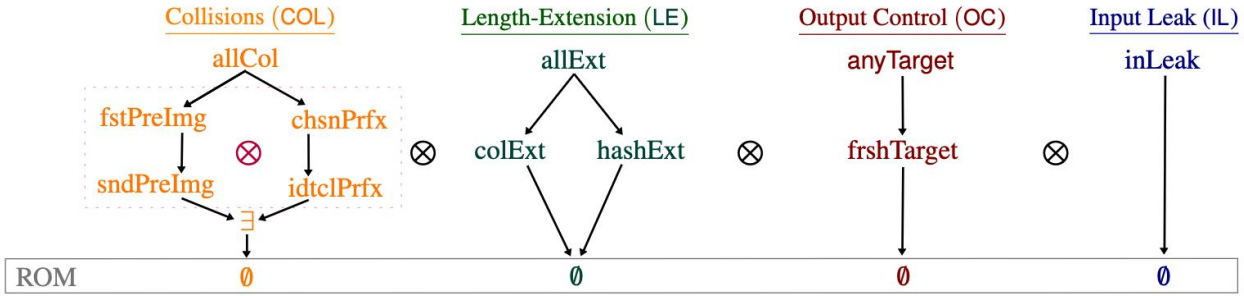

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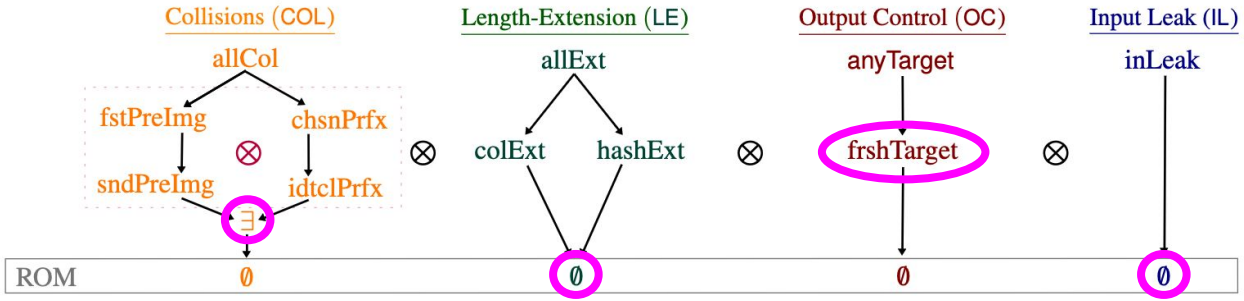

Finding a single collision between 2 random values

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, ProVerif

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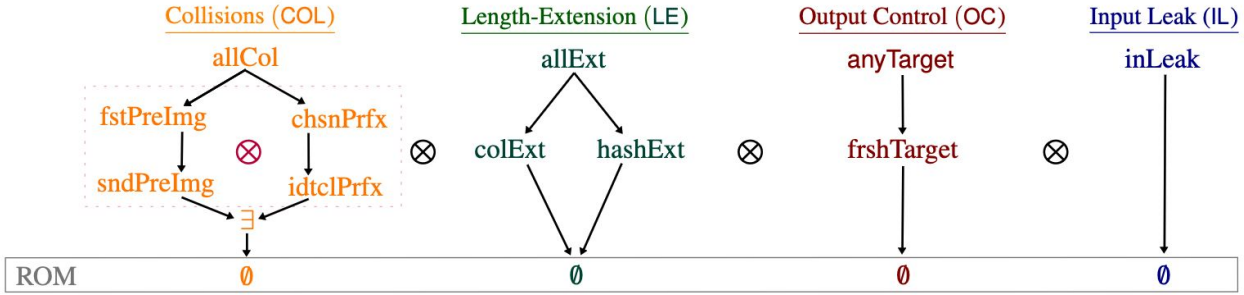

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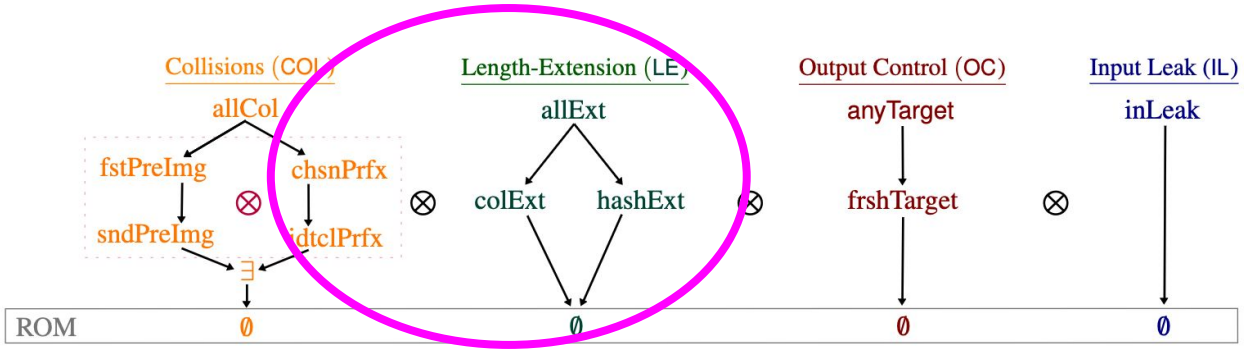

We need to extend the tools

Hashing lists and transcripts

Hashing lists and transcripts

Problems without associativity

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E.g., a list of 3 is expressed as a nested tuple

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- connected to underlying new maude feature

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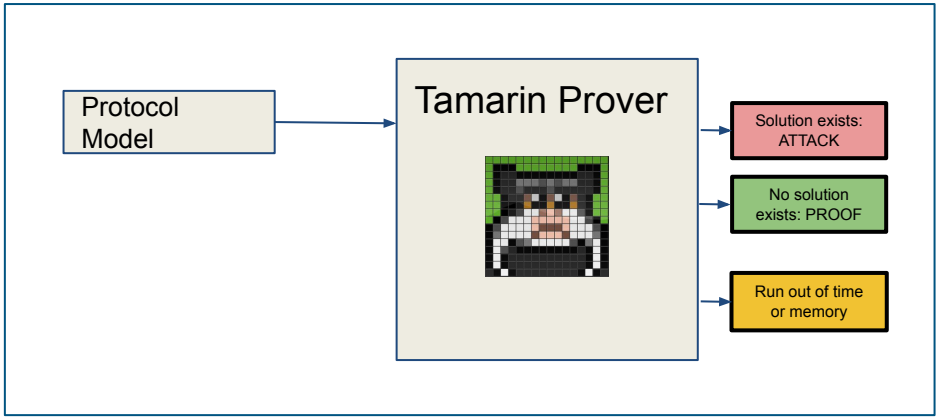
Proverif: Approximation

introduced recursive computation functions to define functions through general axiomatizations

Systematic Analysis (focus on Tamarin)



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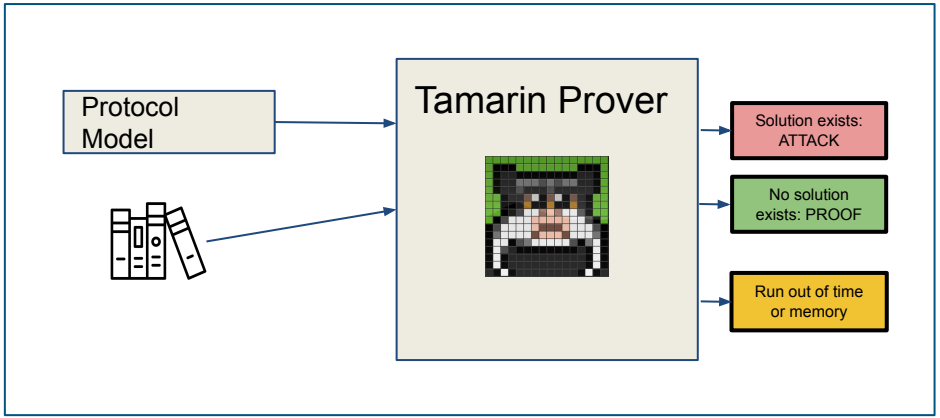

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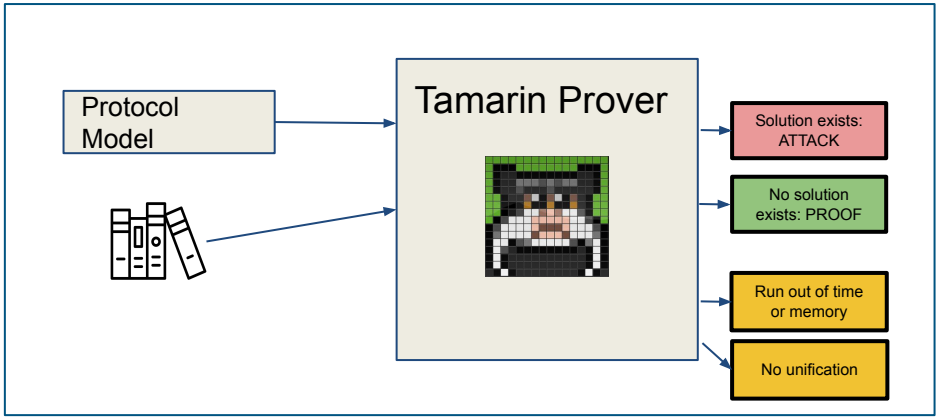
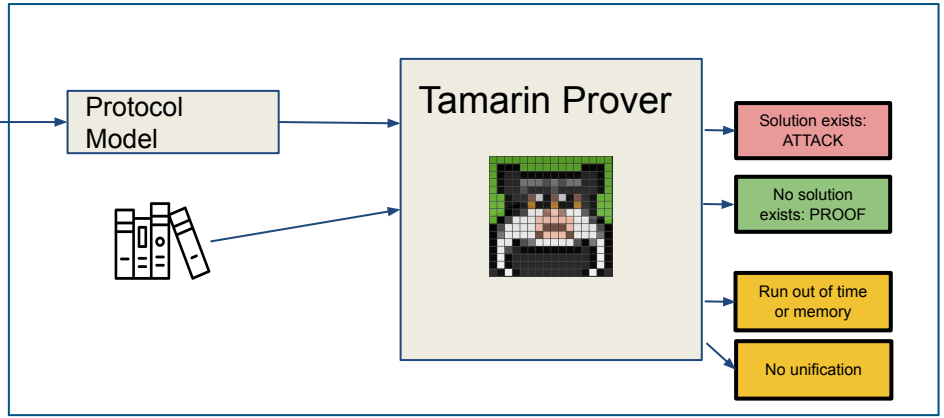


Systematic Analysis (focus on Tamarin)

Protocol Models

- Sigma
- SSH
- IKEv2
- Flickr



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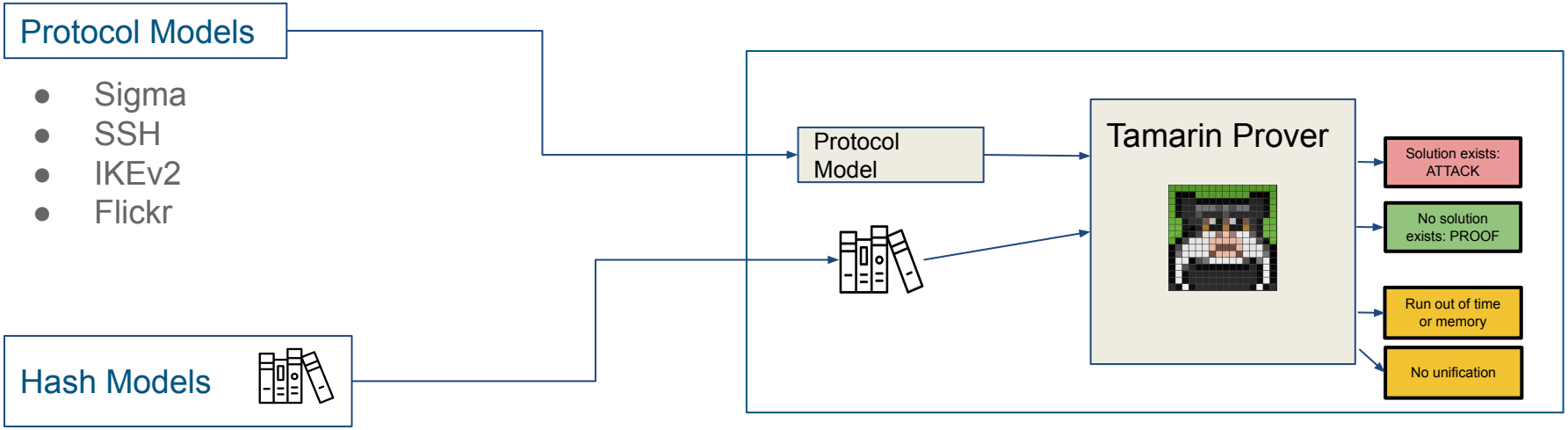

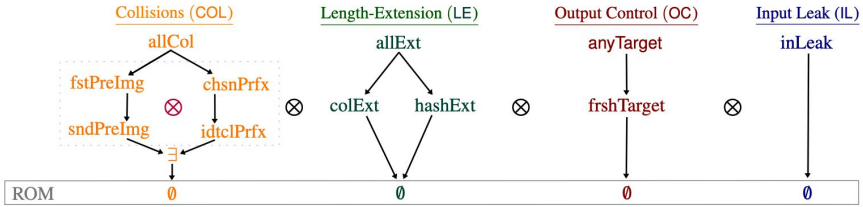

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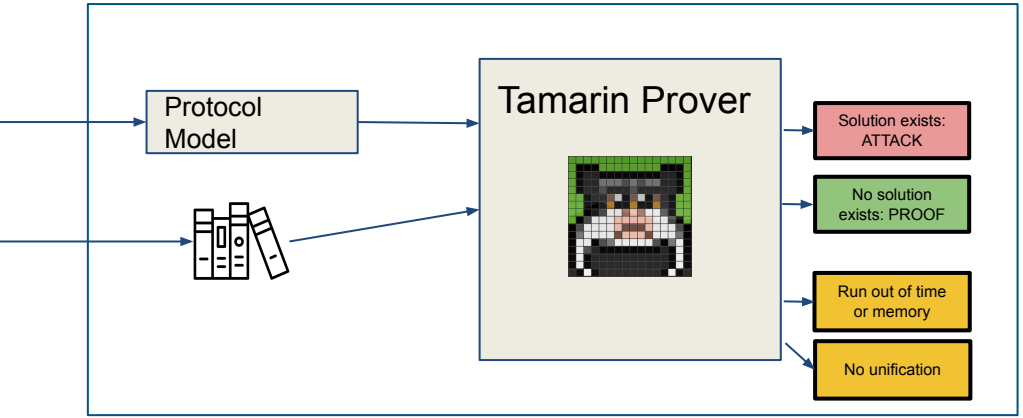
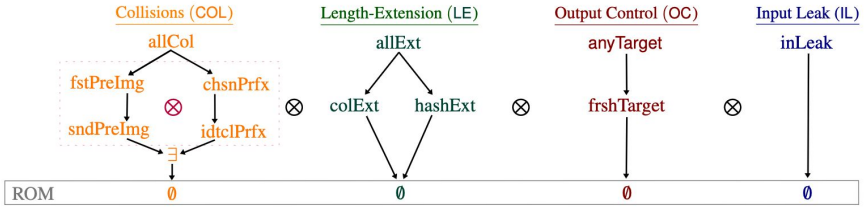


Automatically construct all combinations



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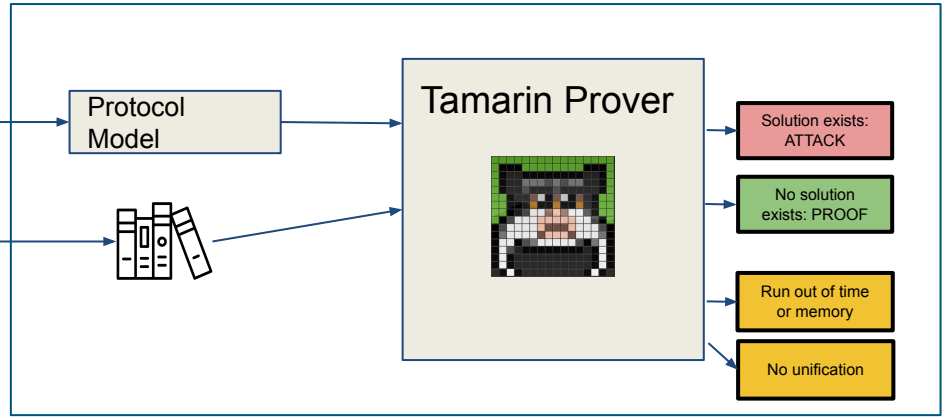

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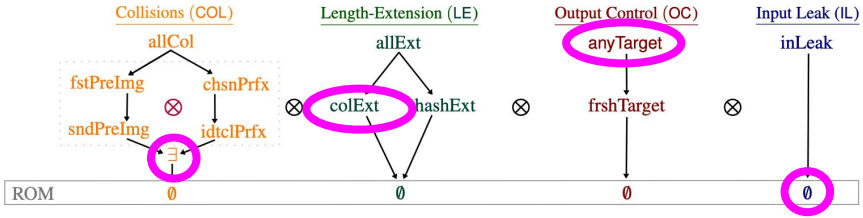

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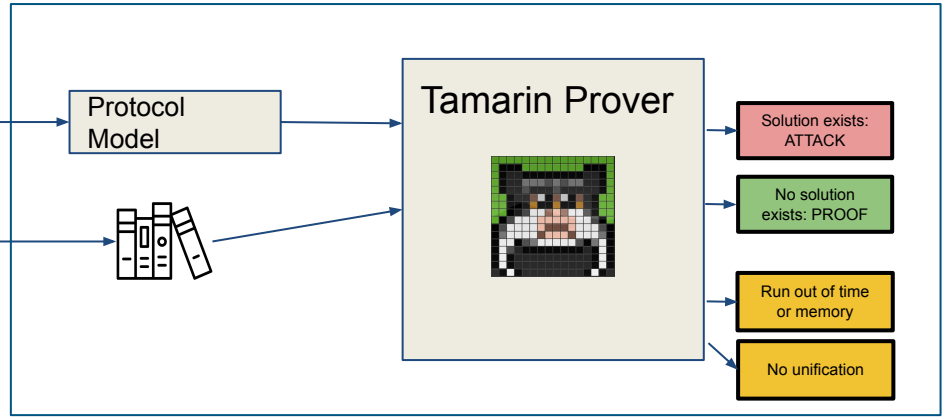

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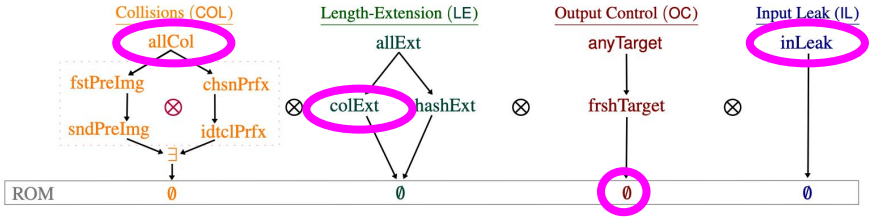

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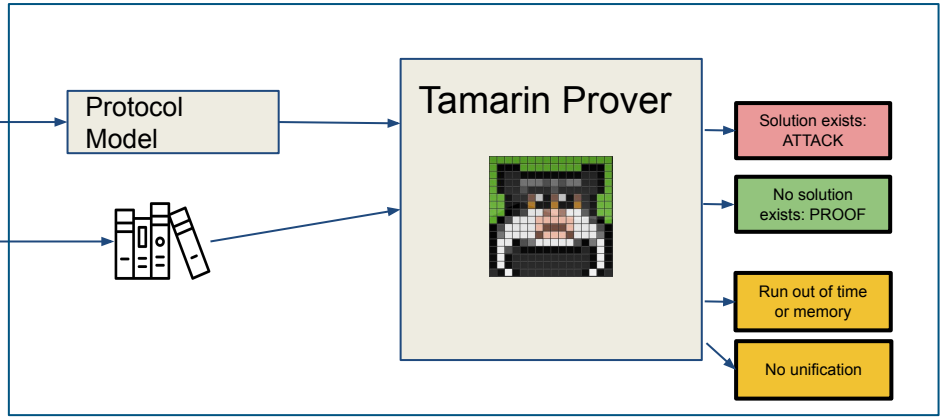

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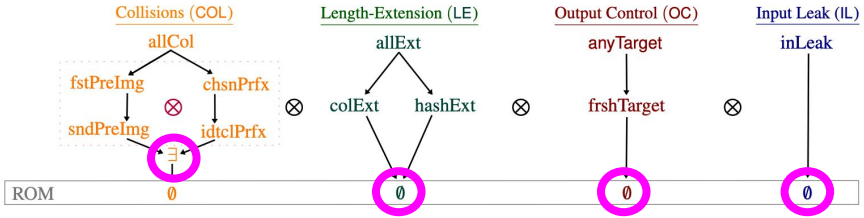

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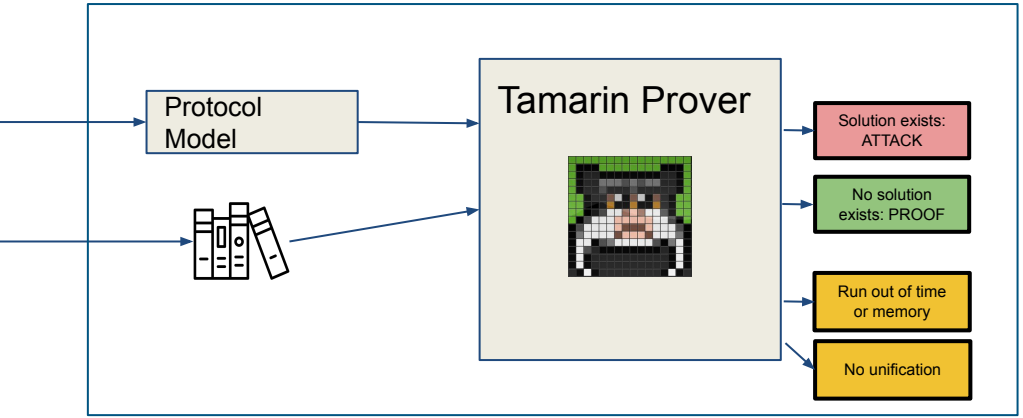

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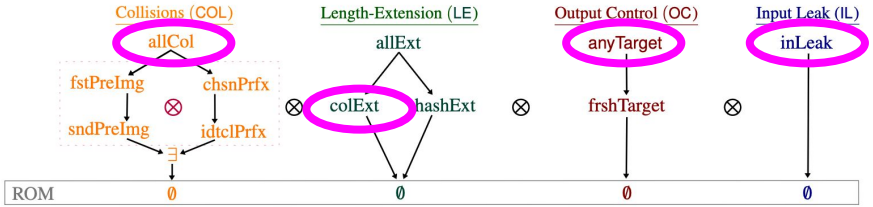

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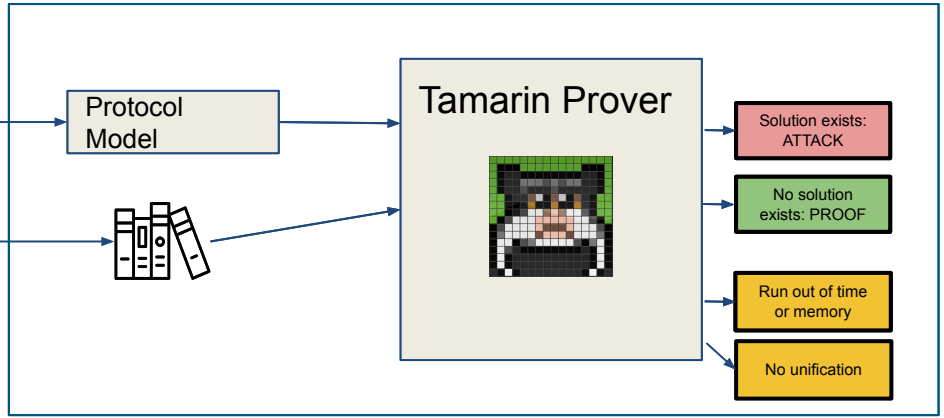

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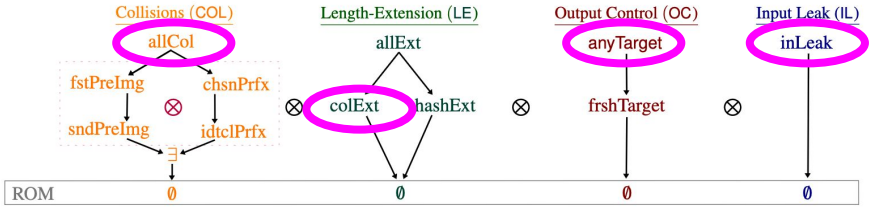

Tamarin, ProVerif

Implementations: https://github.com/charlie-j/symbolic-hash-models

Attacks automatically found

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Protocol	Main attack requirements	New?	Broken Property	Time(s)
Sigma	chsnPrfx,colExt	✗	Secrecy, Agreement	28
	chsnPrfx,colExt	✗ ~	Secrecy, Agreement	manual
	chsnPrfx	✓	Secrecy, Agreement	55
SSH	idtclPrfx,colExt	✗	Agreement	28
	sndPreImg,colExt	✓	Agreement	41
IKEv2	idtclPrfx,colExt	✗	Authentication	20
	∃ ,colExt	✓	Agreement	9
Flickr	hashExt	✗	Authentication	9

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	sndPreImg,colExt	✓	Agreement	41
IKEv2	idtclPrfx,colExt	✗	Authentication	20
	∃ ,colExt	✓	Agreement	9
Flickr	hashExt	✗	Authentication	9

Hash Gone Bad:

Automated discovery of protocol attacks that exploit hash function weaknesses

First automated methodology to find a large class of attacks

- Built new symbolic models for hash functions
- We extended both ProVerif and Tamarin
- Applied to several case studies, automatically finding attacks

Thanks for the Distinguished Paper Award!

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Artifact: https://github.com/charlie-j/symbolic-hash-models

Paper: https://www.usenix.org/conference/usenixsecurity23/presentation/cheval

References

[BL16] Bhargavan, K., & Leurent, G. (2016, February). Transcript collision attacks: Breaking authentication in TLS, IKE, and SSH. In *Network and Distributed System Security Symposium--NDSS 2016*.

[JCCS19] Jackson, D., Cremers, C., Cohn-Gordon, K., & Sasse, R. (2019, November). Seems legit: Automated analysis of subtle attacks on protocols that use signatures. In *Proceedings of the 2019 ACM SIGSAC Conference on Computer and Communications Security* (pp. 2165-2180).