LegoSNARK: Compose ZKPs Simply and Efficiently

Matteo Campanelli
Dario Fiore
Anaïs Querol

Instituto IMDEA Software

eprint: ia.cr/2019/142

API (soon): github.com/imdea-software/legosnark

Modular SNARKs

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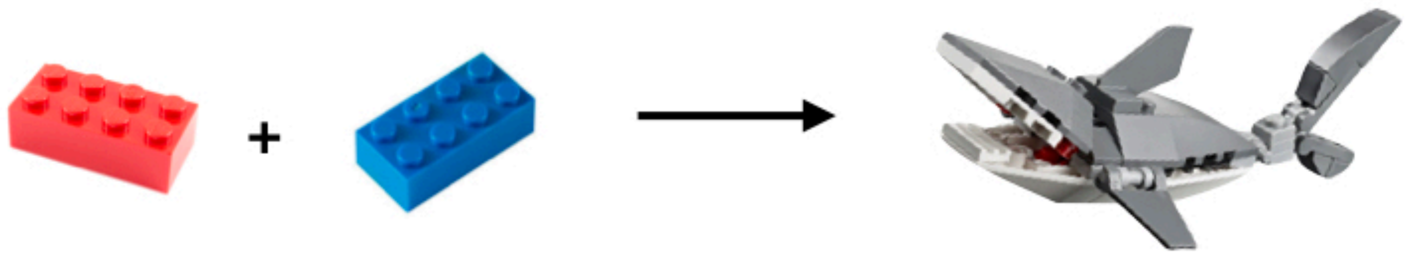
Modularity (roughly)**:**



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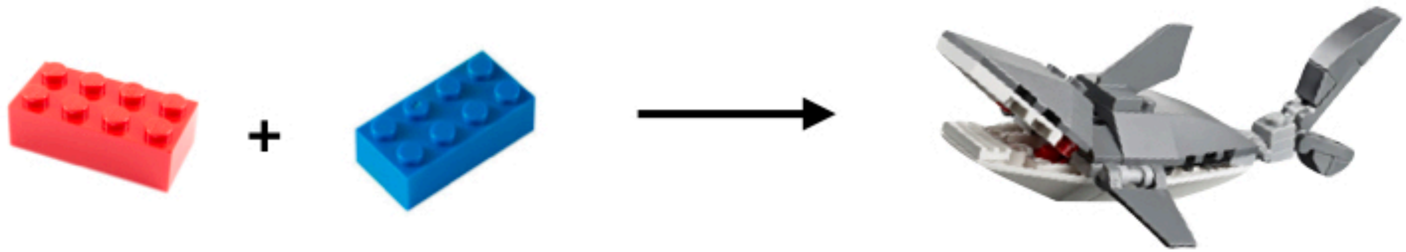

Our focus: Non-Interactive and Succinct arguments

Modularity:
“*Why?*” and "*What Exactly?*”

Through two Tales…

A Tale of Efficiency

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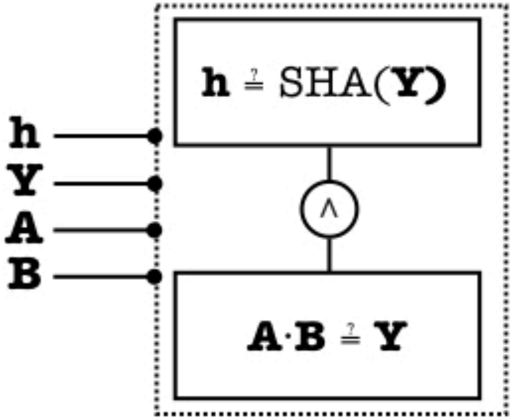

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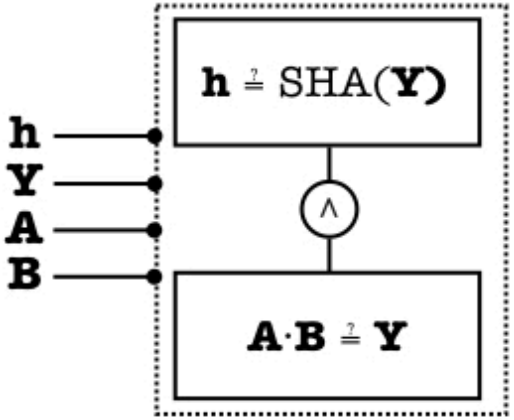

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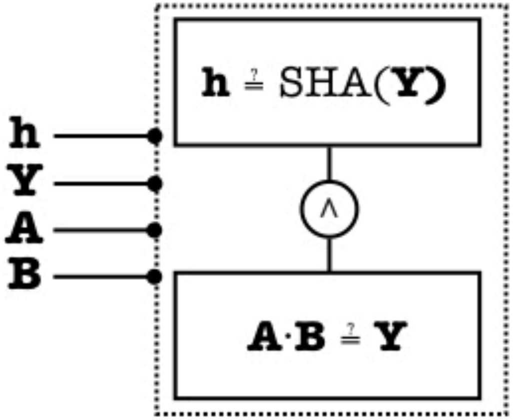

ZKP1

ZKP2

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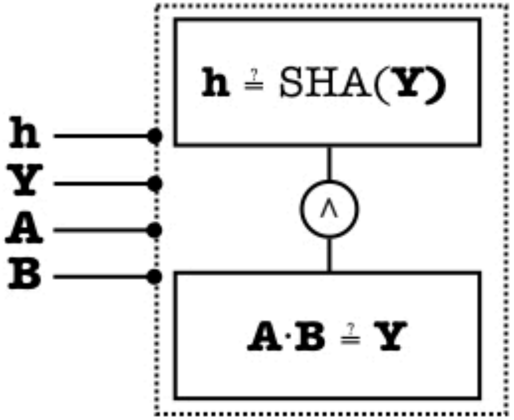

Bool

Algebra

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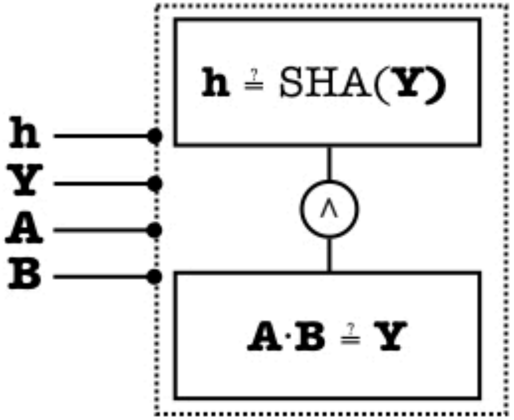

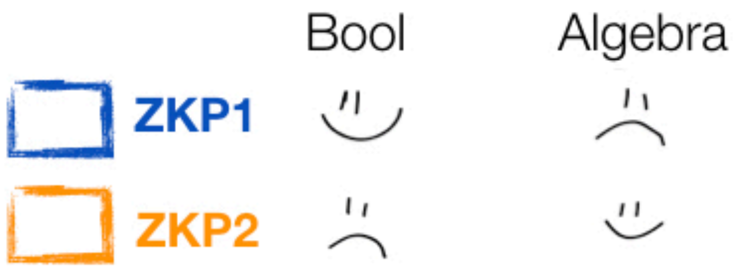

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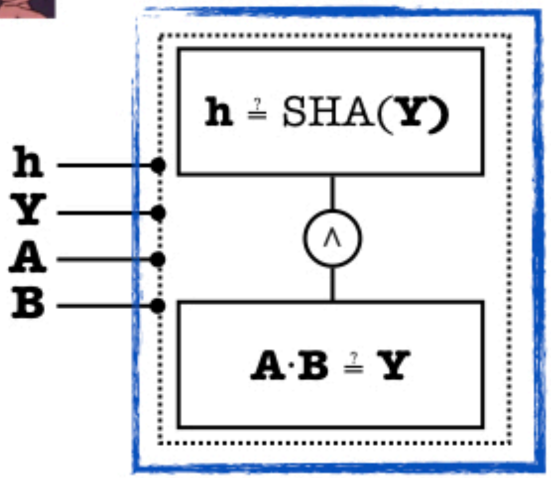

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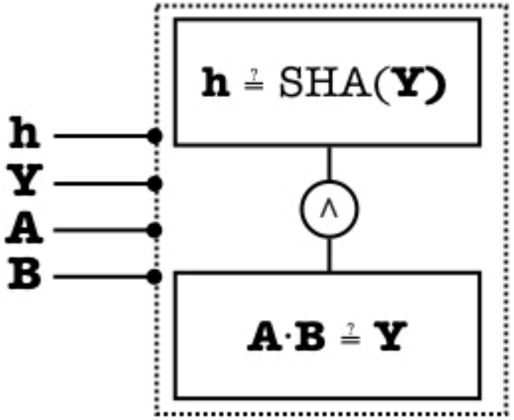

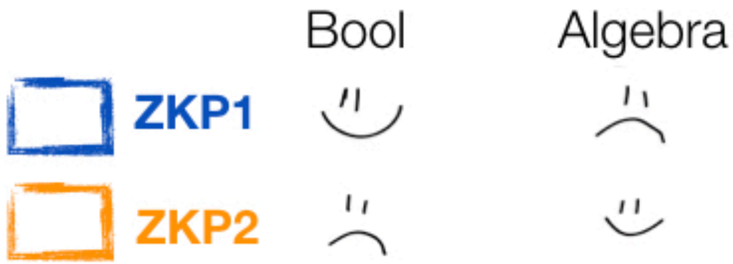

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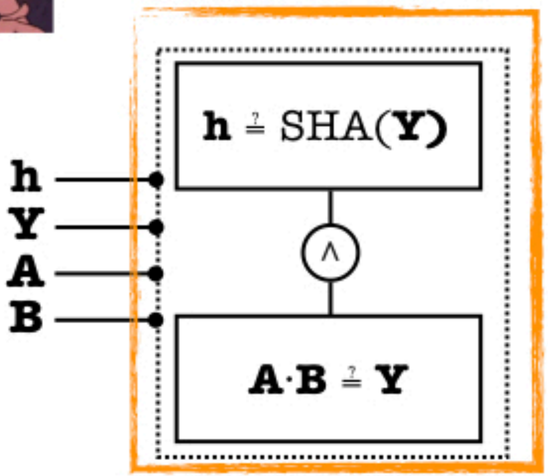

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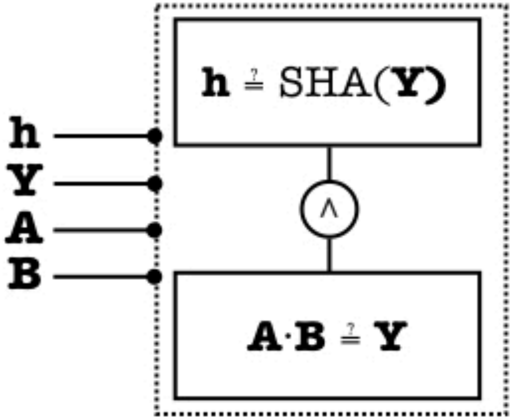

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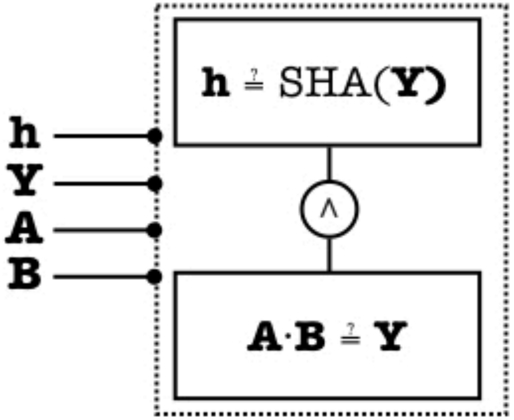

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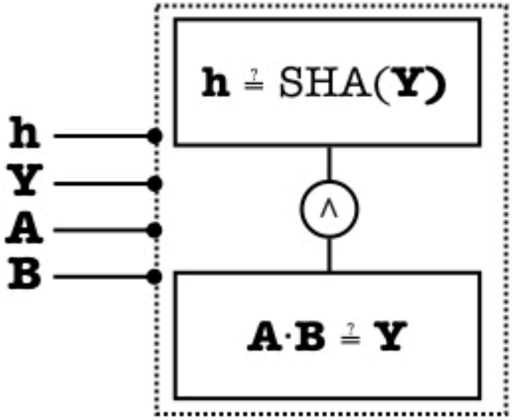

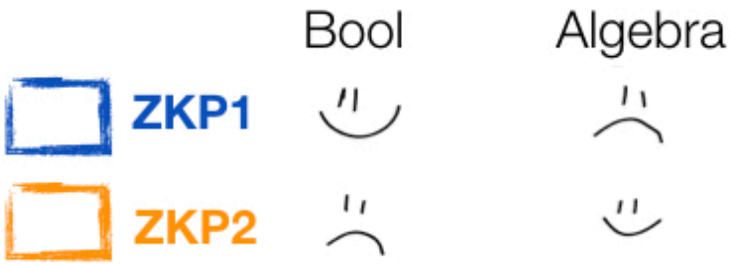

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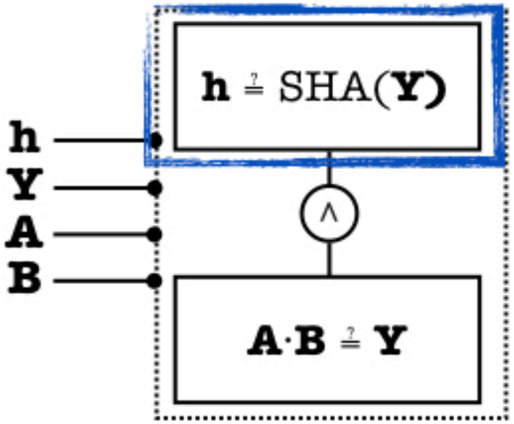

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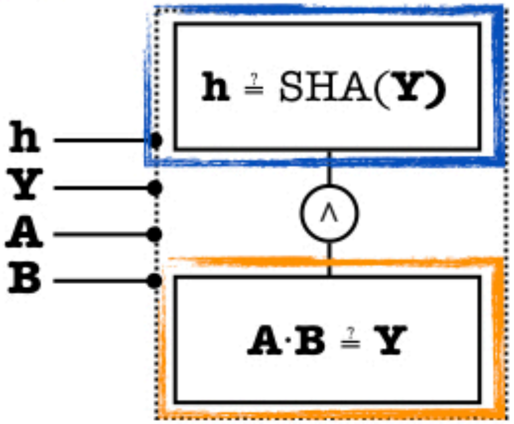

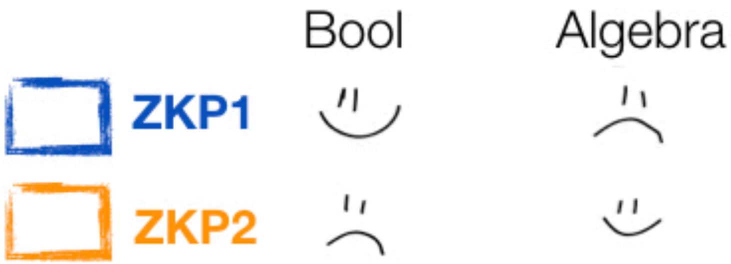

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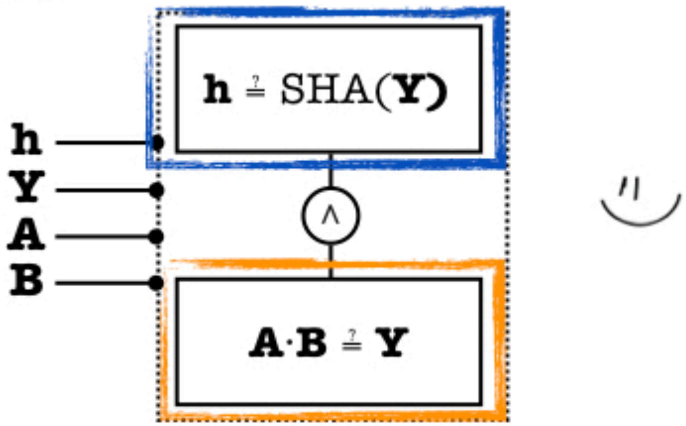

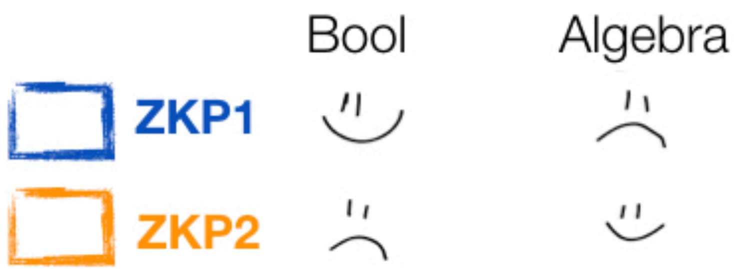

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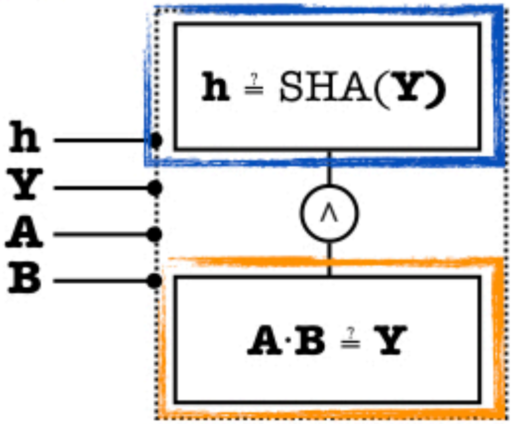

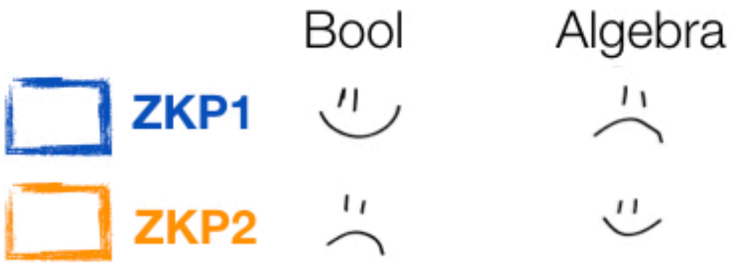

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“Splittable" relations are common
(e.g. select+aggregate in a DB, polynomial evaluation)

A Tale of Simplicity

There once were two bearded wizards…

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Digression: UNIX's simplicity

Do Not *Write* Programs; *Glue* Them Together.

UNIX shell commands are simple.

grep '*pattern*' *file*	Prints lines matching a pattern

head -n 5 *file*	prints first five lines from a file
tail *file*	prints last lines from a file

sort -u *file*	sorts and return unique lines
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Solution:

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cut -d ' ' -f 2 book.txt | sort | uniq -c | sort -rn | head -5
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Do Not *Write* SNARKs;
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UNIX Philosophy

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LegoSNARK Philosophy

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We need a “cryptographic pipeline”

(should preserve soundness, ZK, succinctness, etc.)

Our Pipeline:
Commit-and-Prove (CP)

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$$\mathbf{u} \longrightarrow \mathbf{u}^{✉}$$

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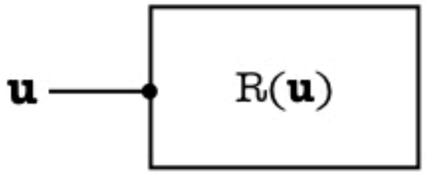

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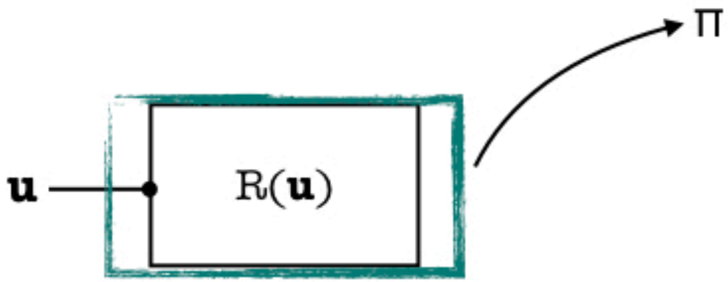

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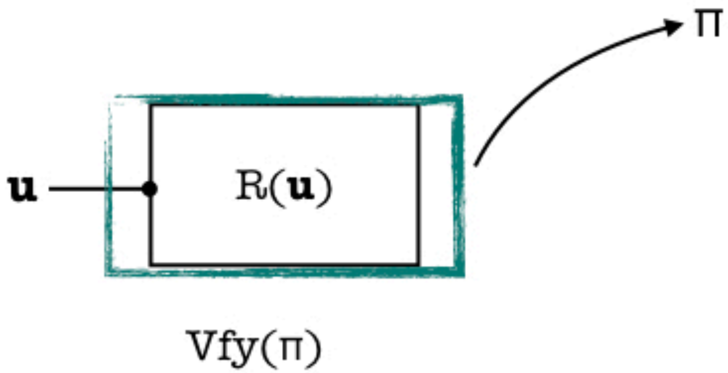

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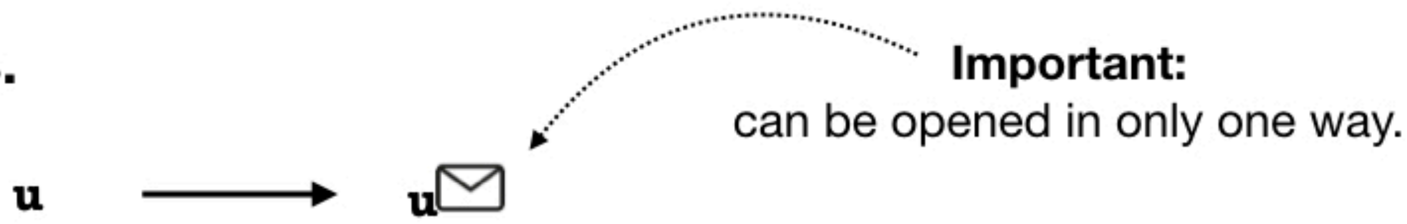

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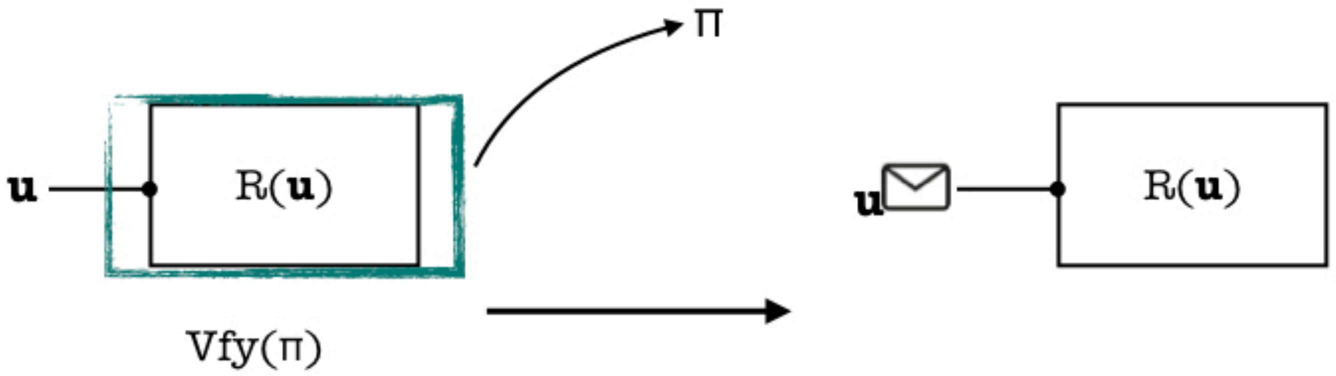

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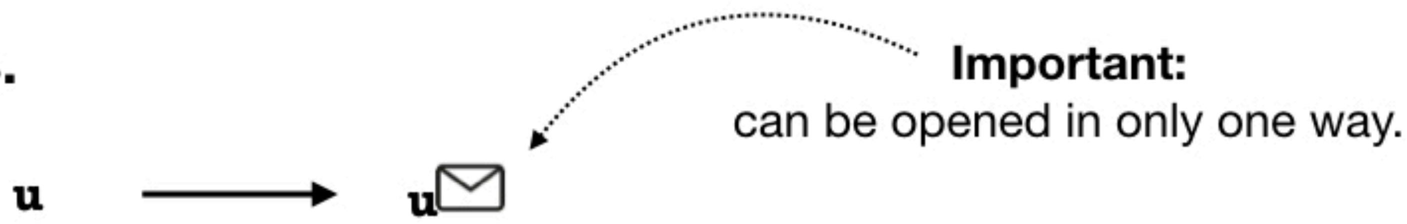

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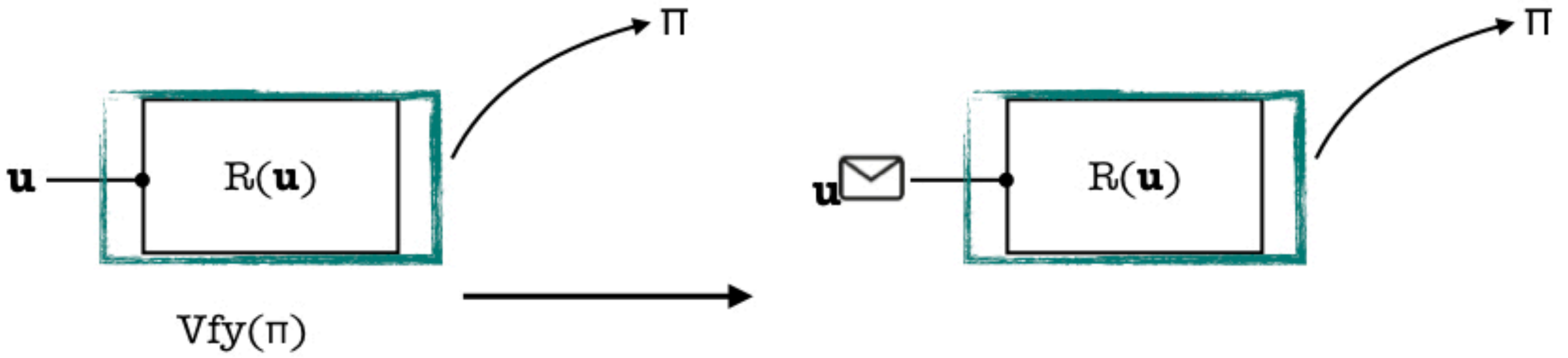

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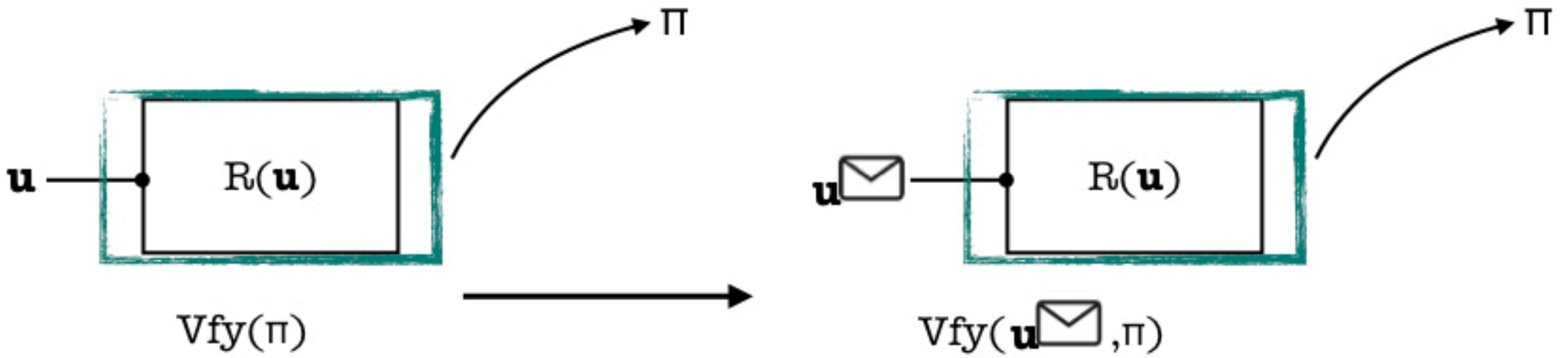

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Warm-up: What do we learn from verifying two CP-proofs on the same commitment?

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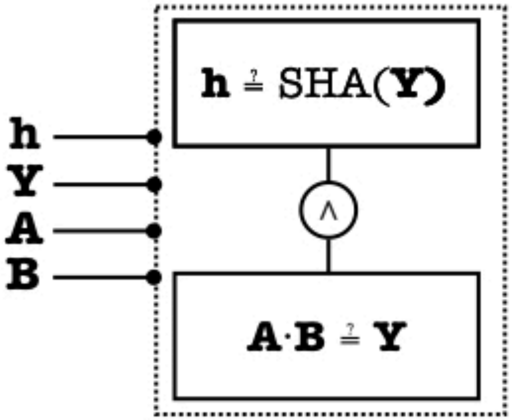

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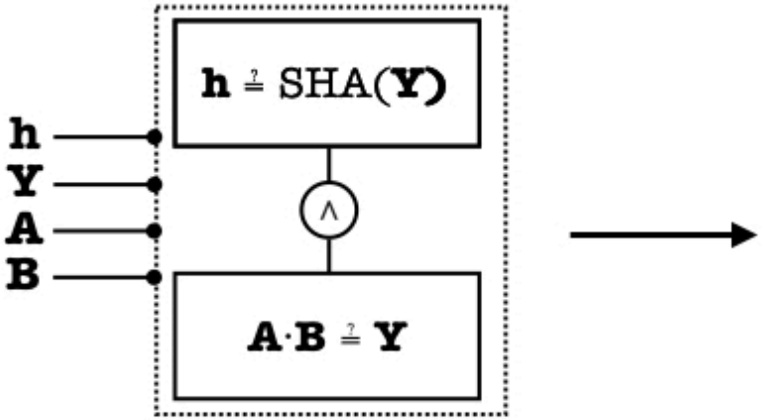

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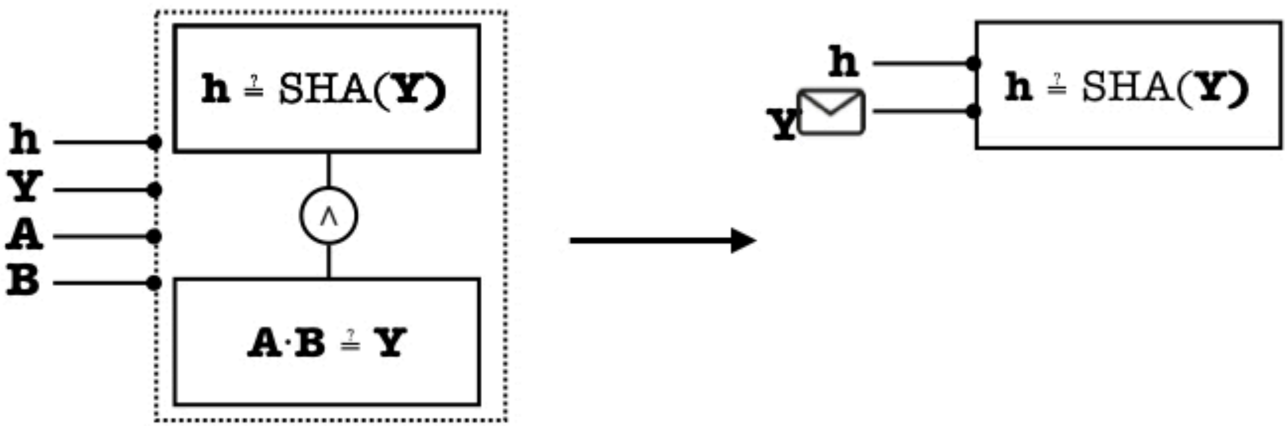

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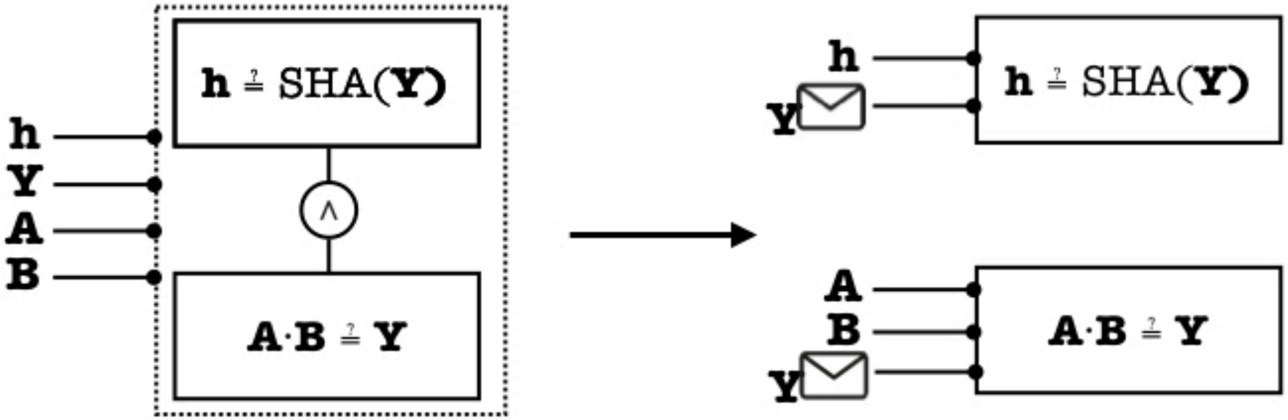

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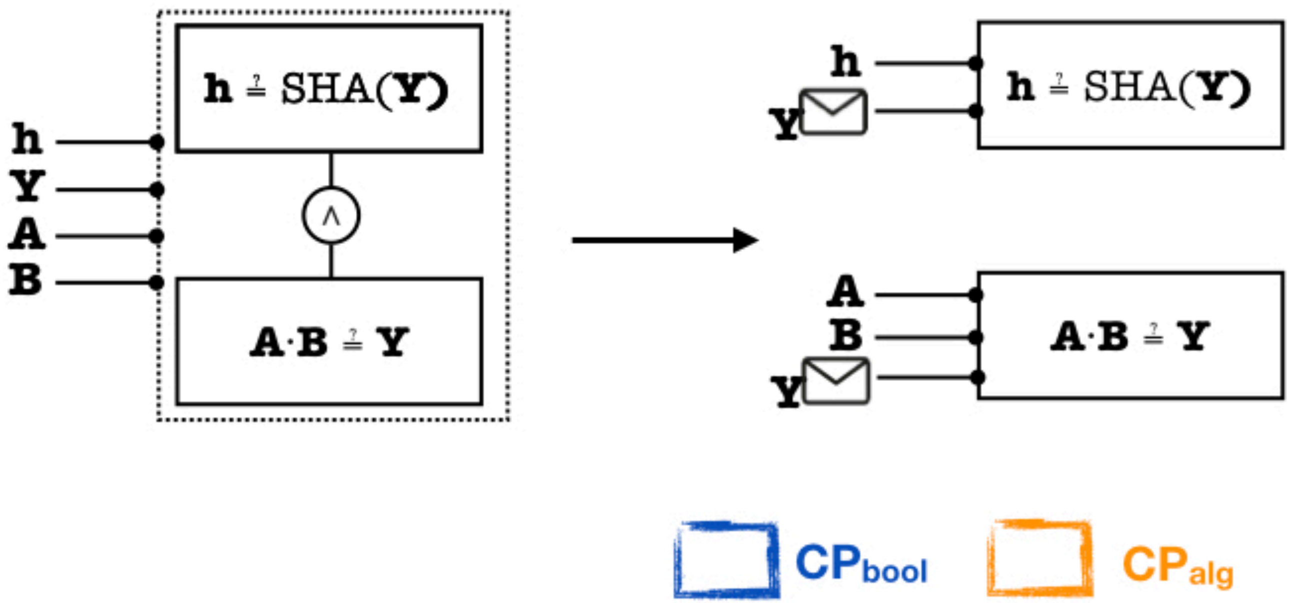

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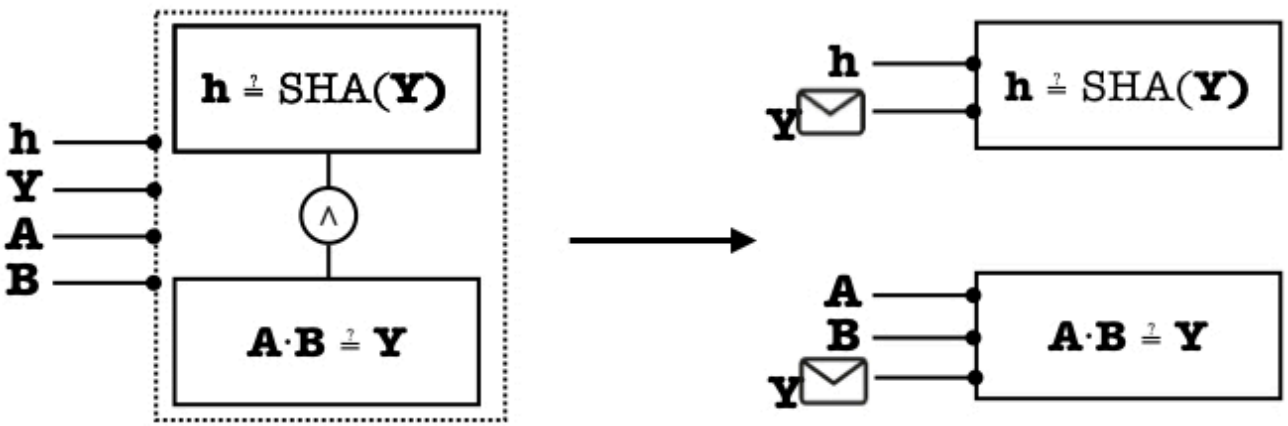

Verifier

CP_{bool} CP_{alg}

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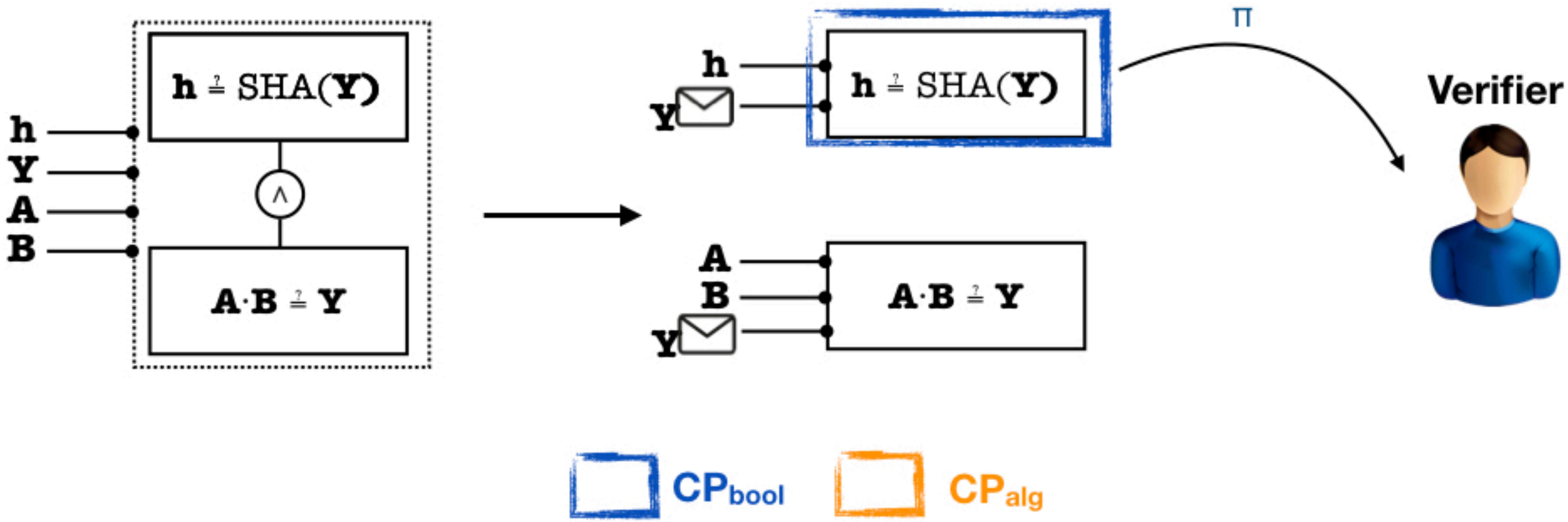

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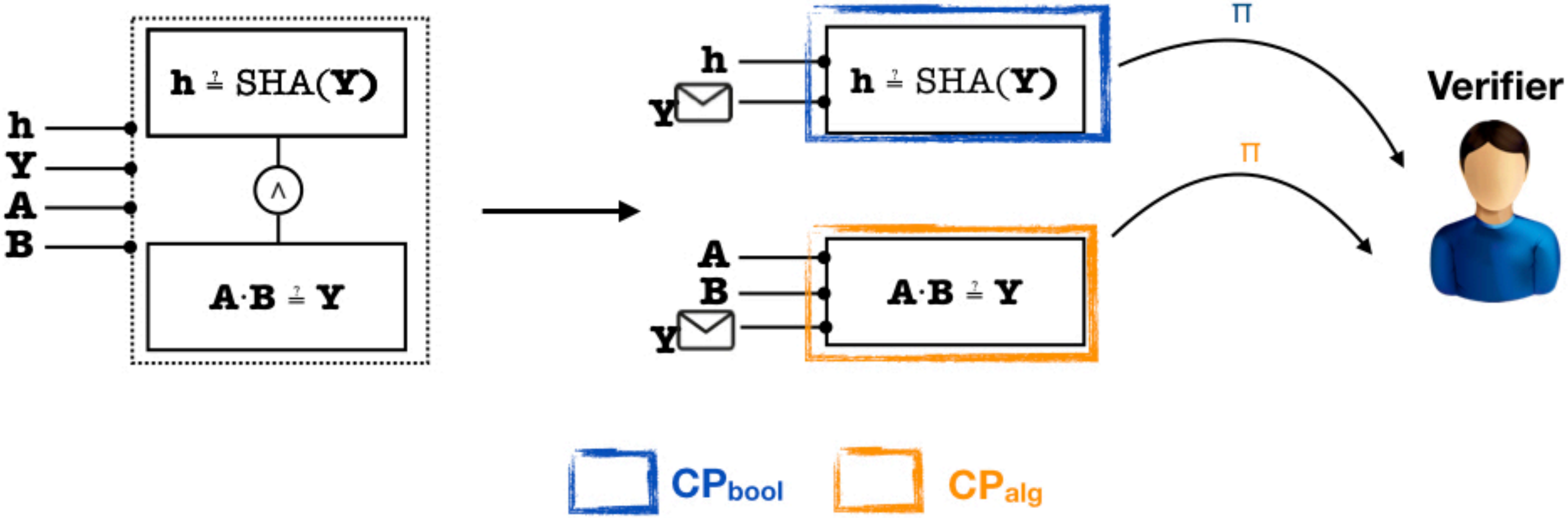

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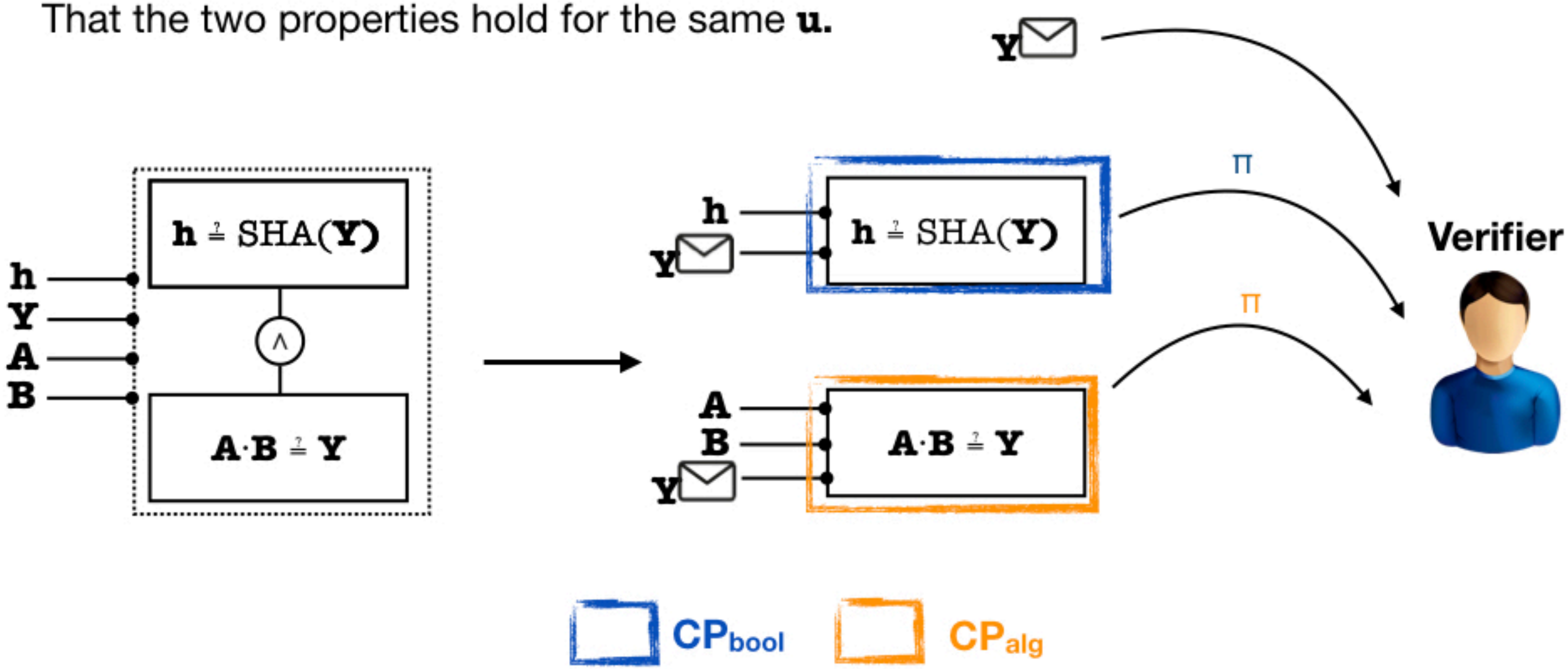

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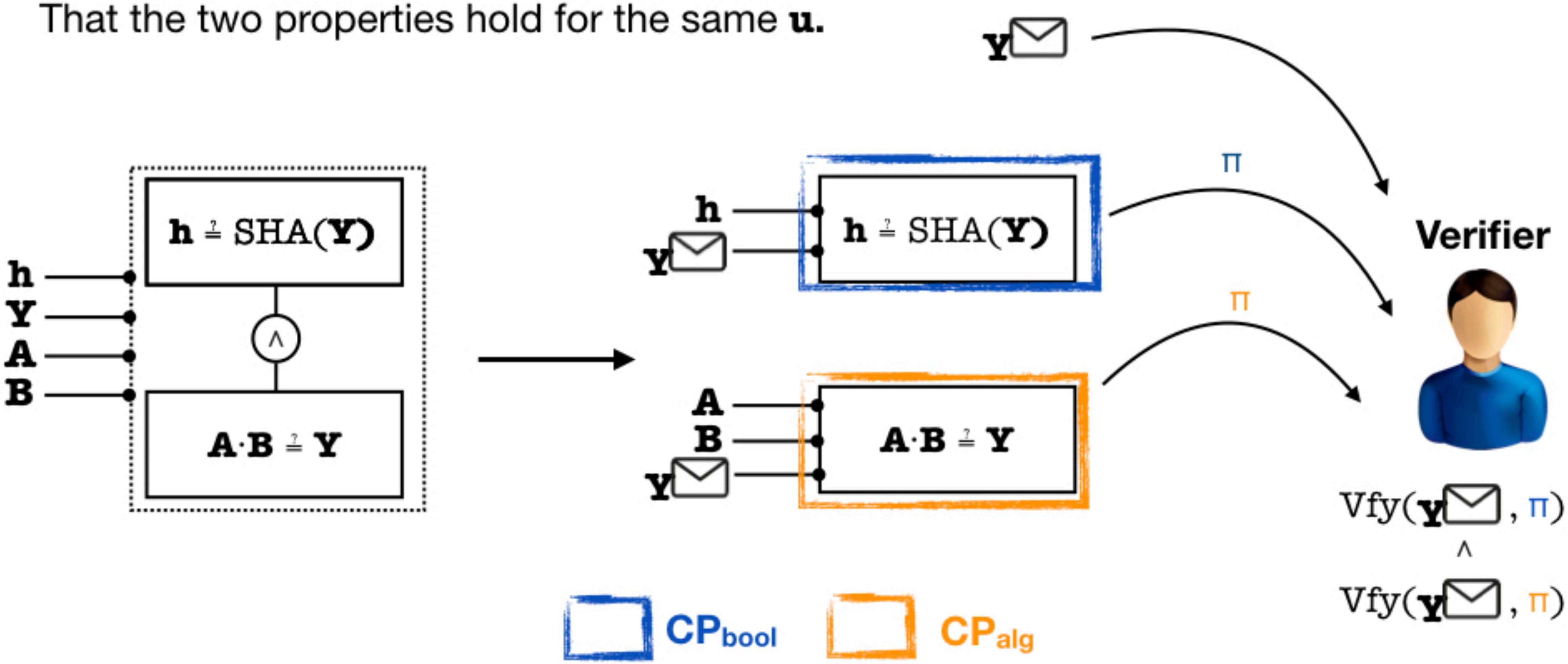

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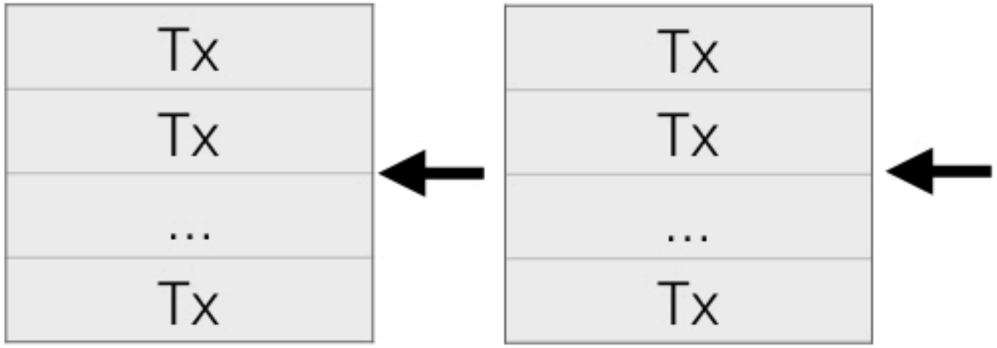

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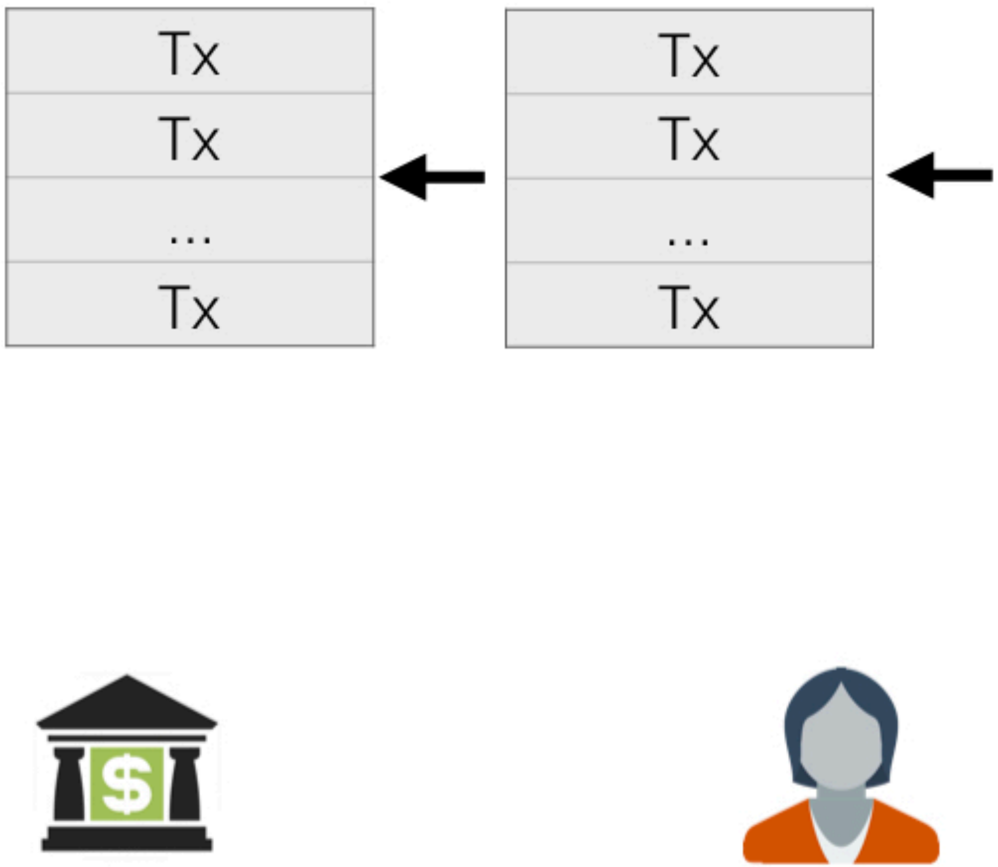

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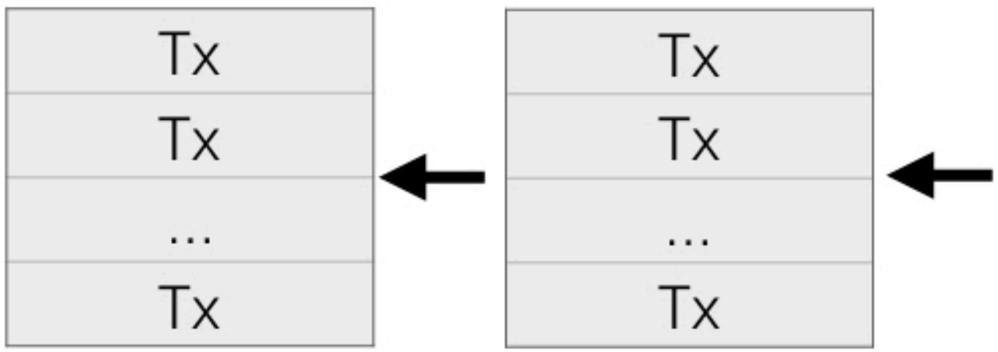

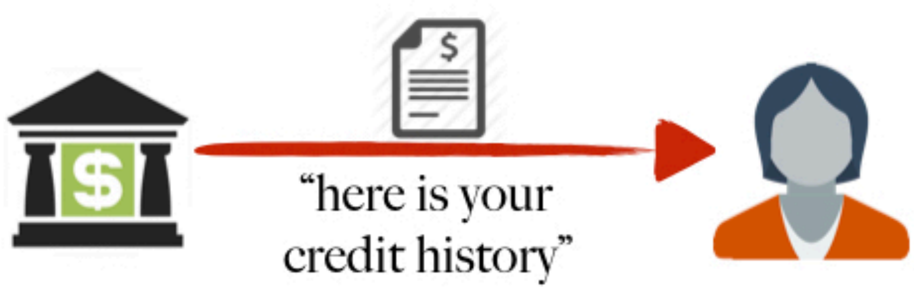

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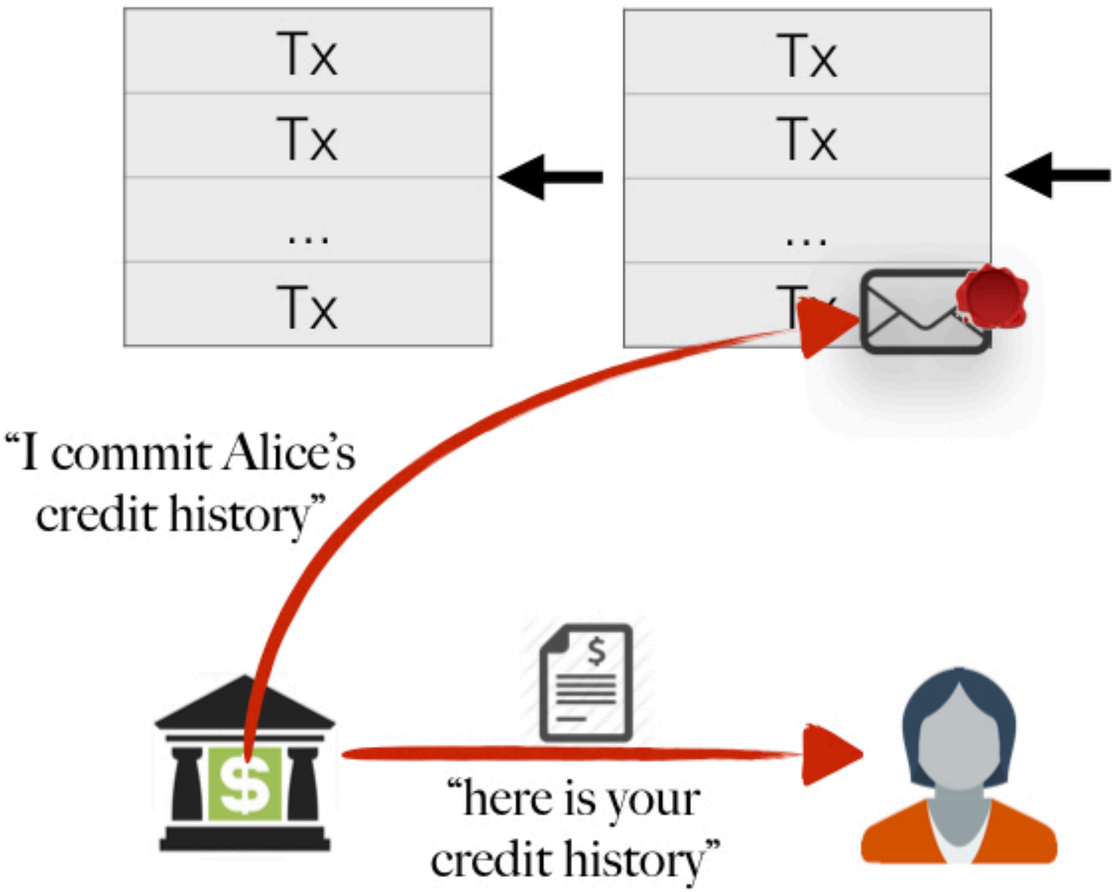

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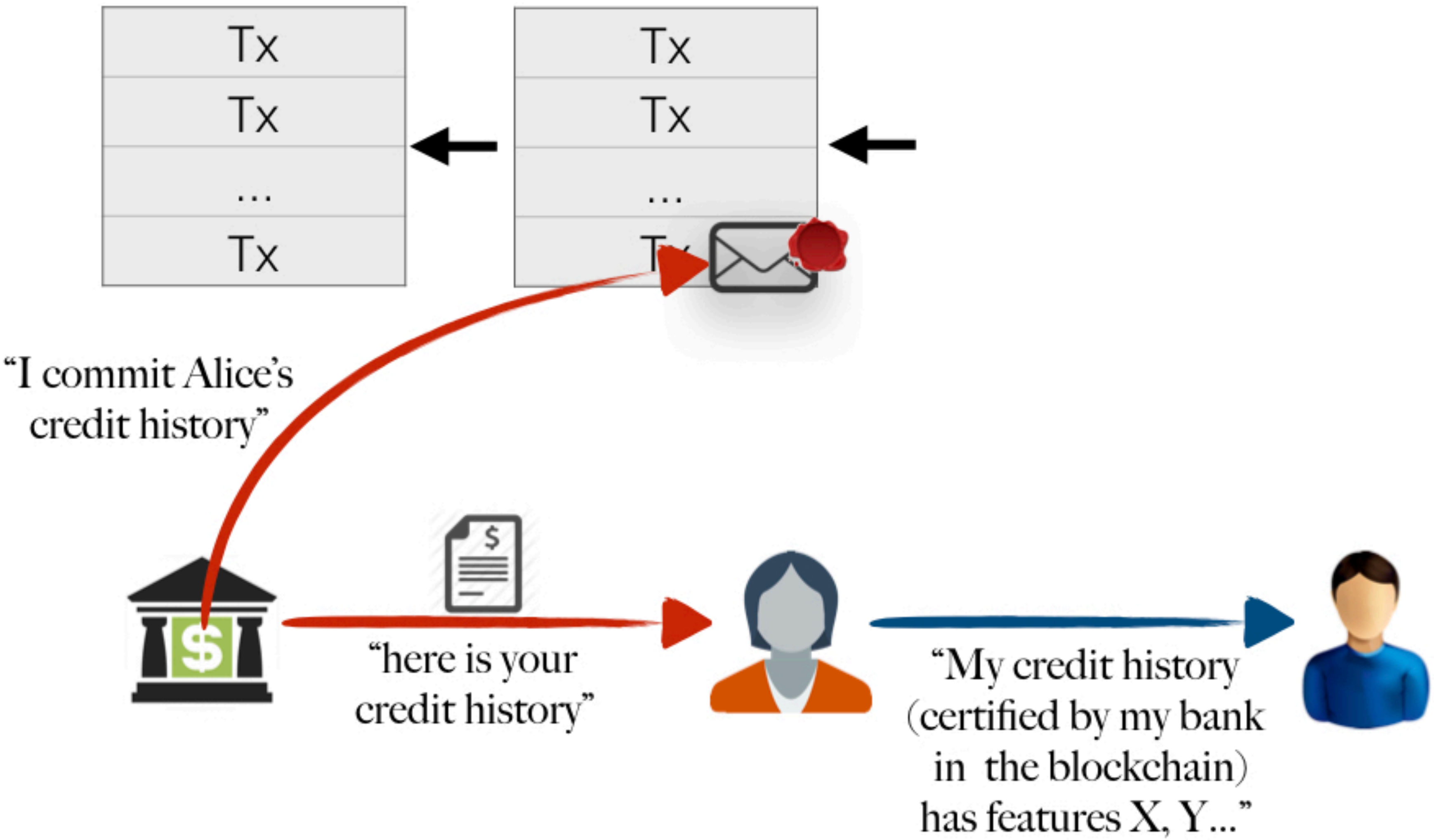

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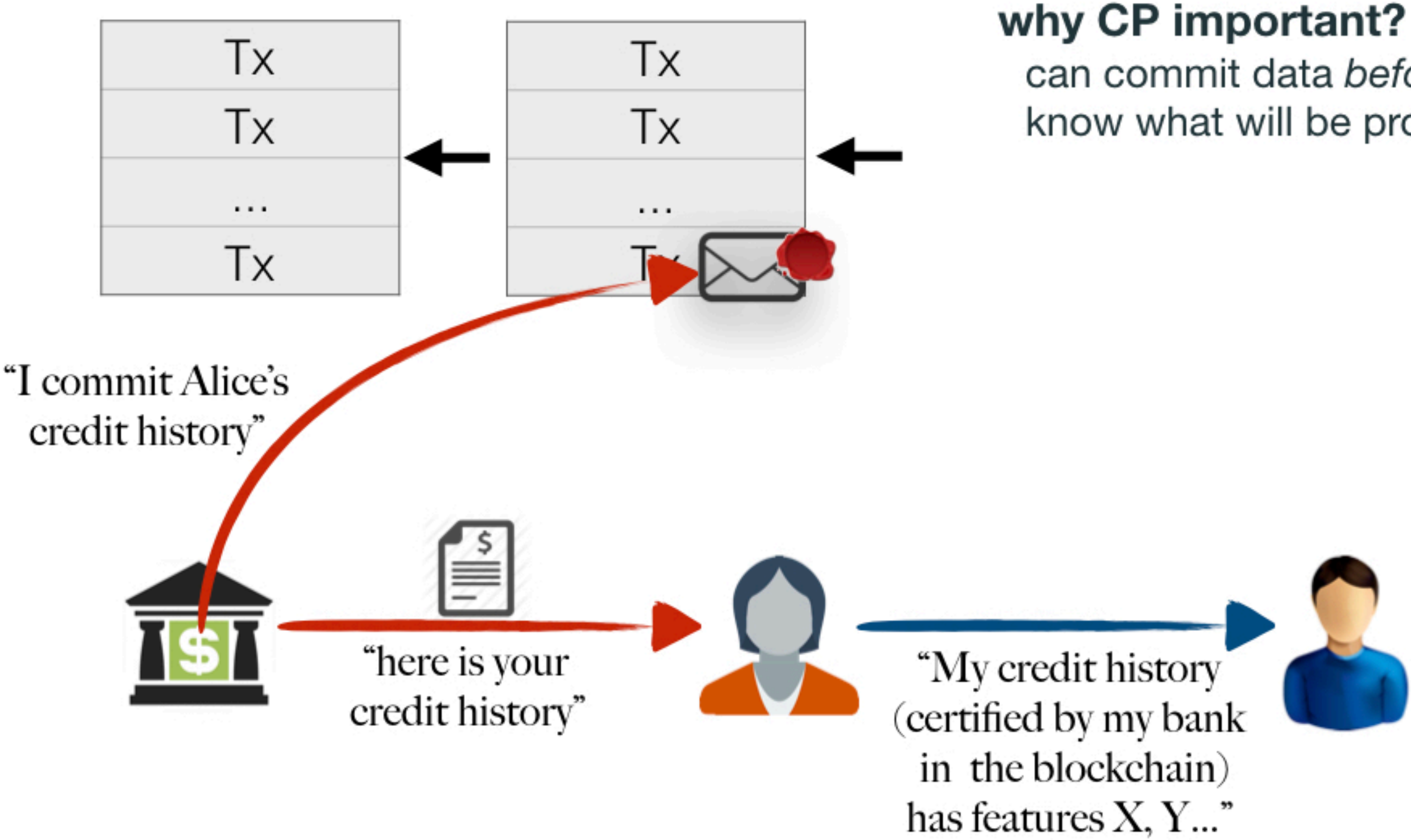
why CP important?

can commit data *before* we know what will be proved



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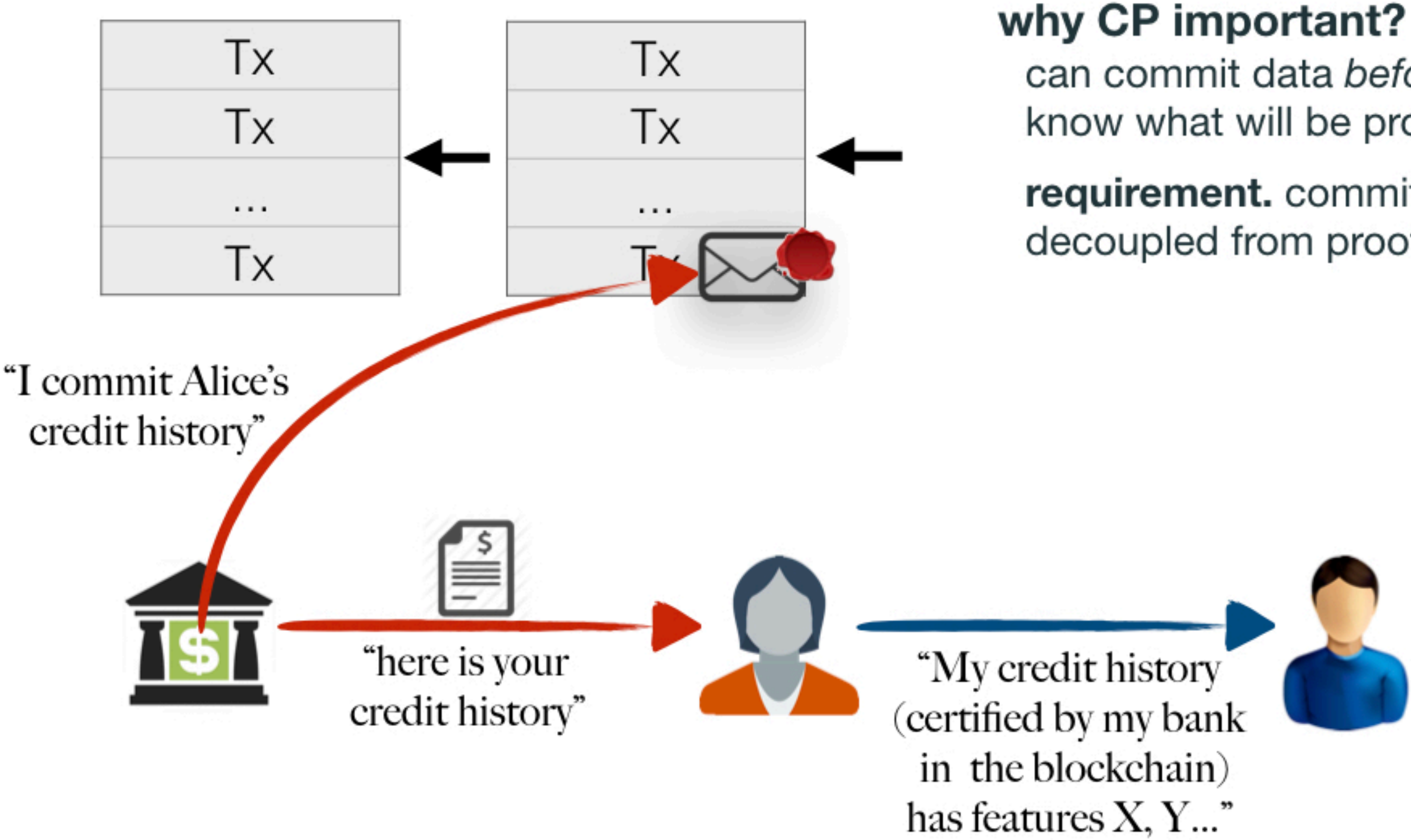

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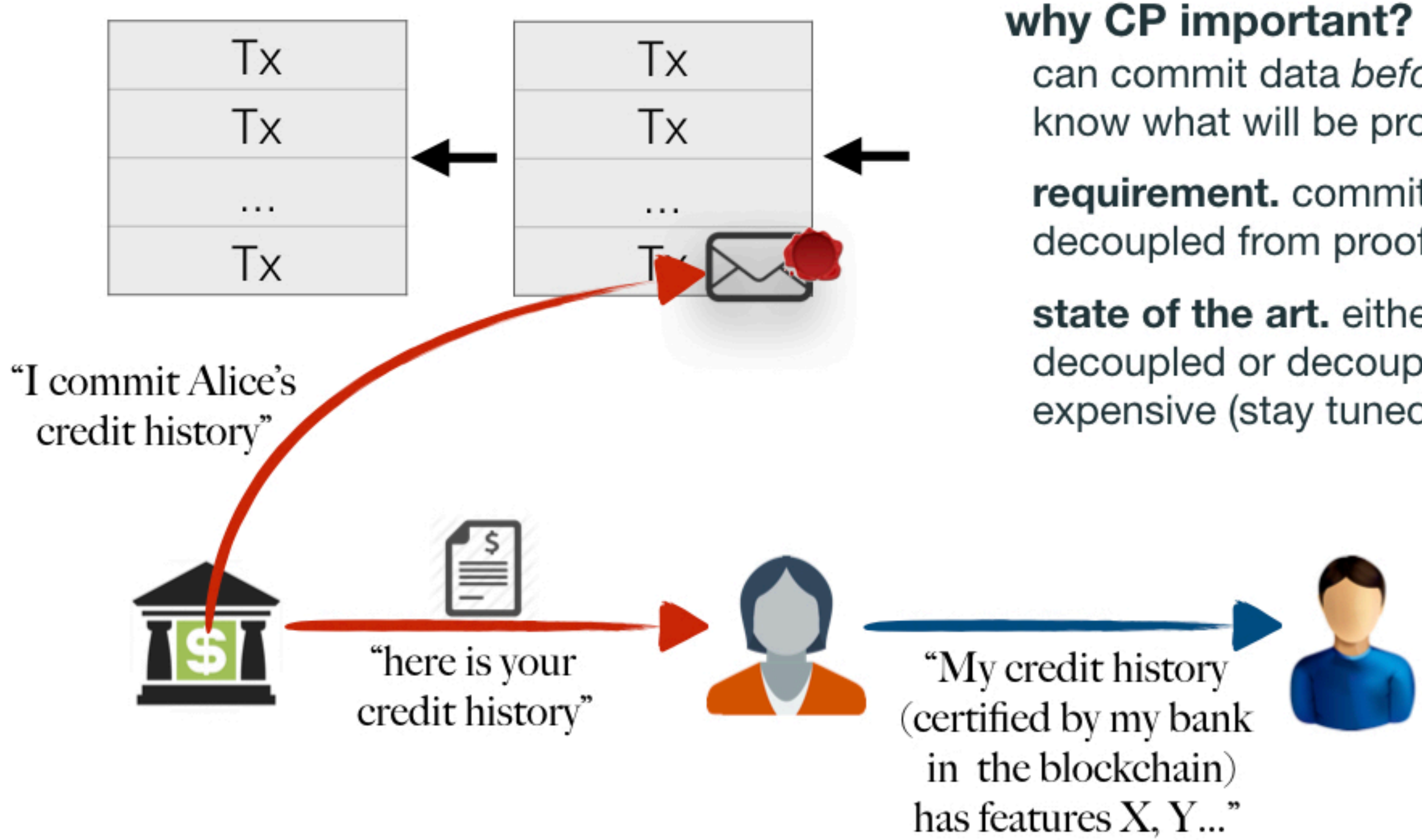

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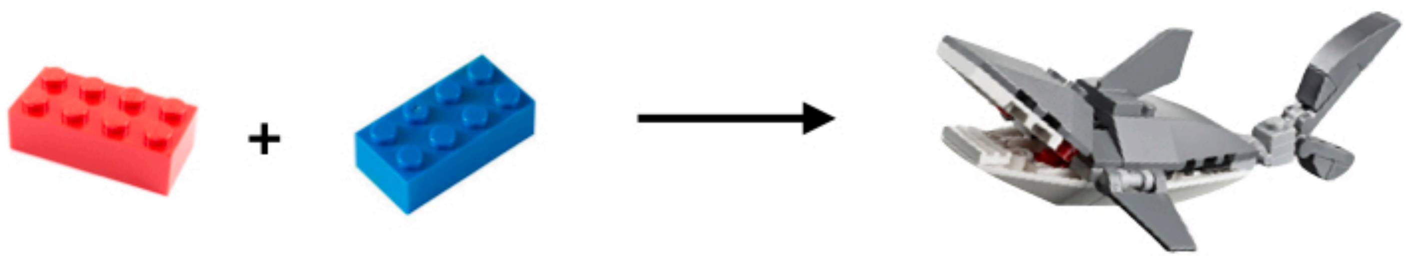
state of the art. either not decoupled or decoupling is expensive (stay tuned)

So Far



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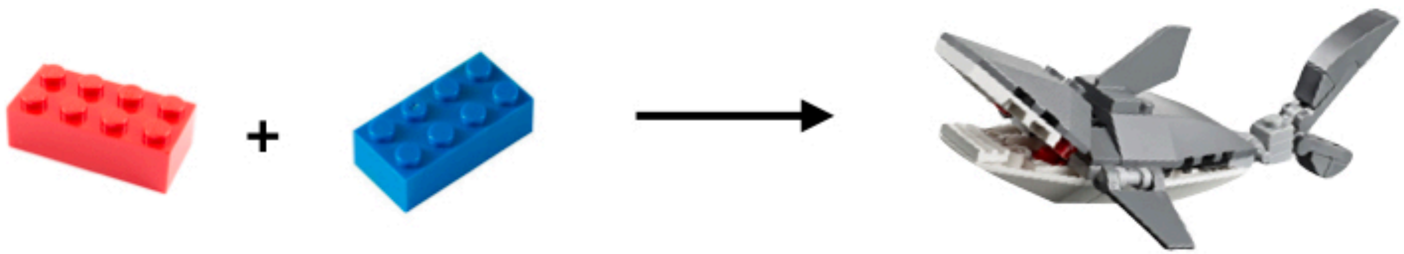
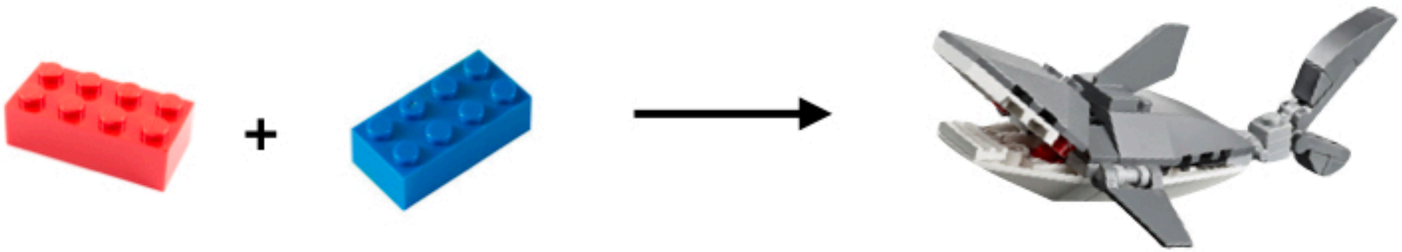
We want to make SNARKs **modular** for better **efficiency** and better **design**



So Far

We want to make SNARKs **modular** for better **efficiency** and better **design**

To compose SNARKs: make them use **commitments as a "glue"** (commit-and-prove, or CP, SNARKs)



This Talk

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Building CP gadgets and its challenges

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Applications and Efficiency of LegoSNARK

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Building CP gadgets
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Applications and Efficiency
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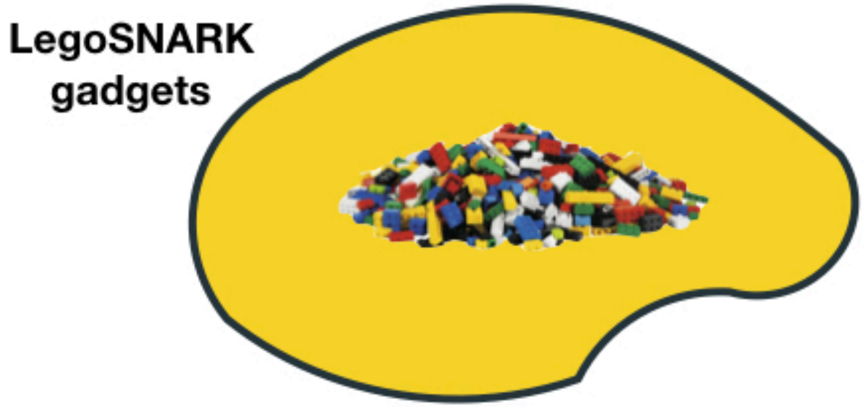
LegoSNARK in practice:
a C++ API

Building a Pool of Gadgets

Building Gadgets

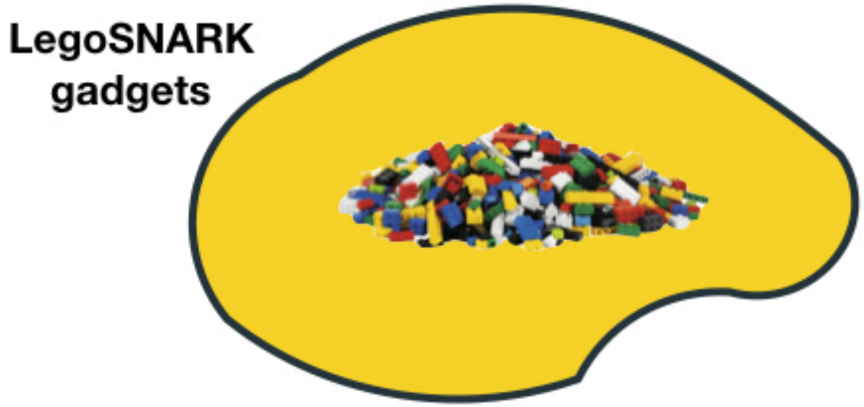


Building Gadgets

LegoSNARK
gadgets

1. **Import** existing zkSNARKs in the framework

Building Gadgets



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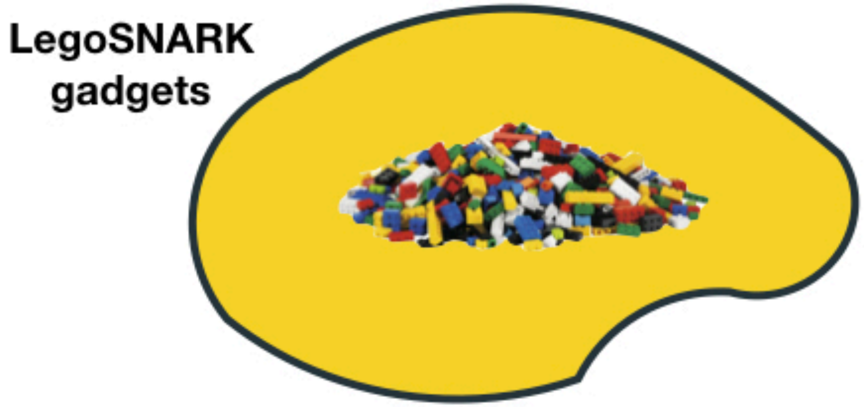

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2. **Construct** new CP-SNARKs

   exploit the power of specialization

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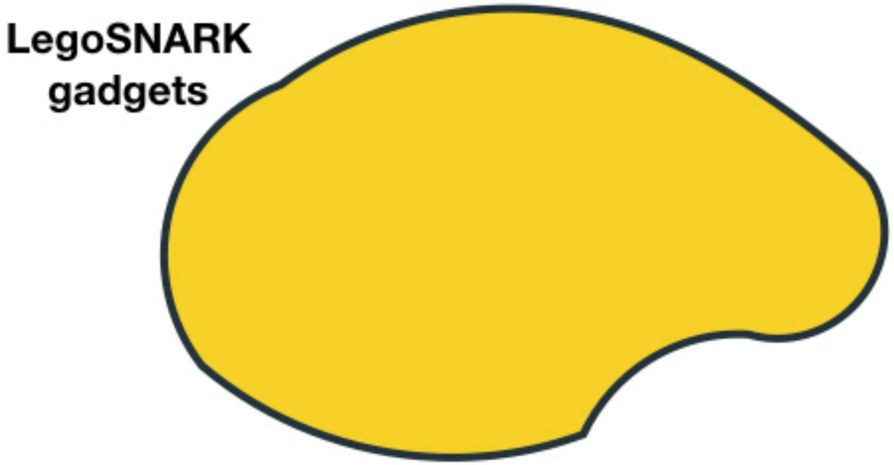

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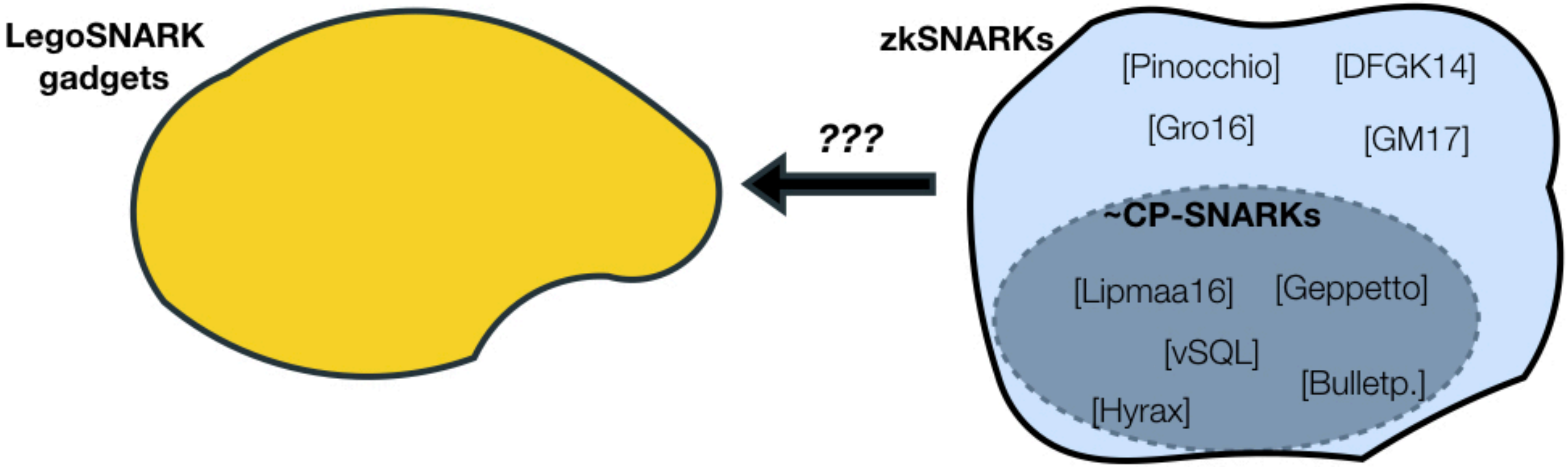

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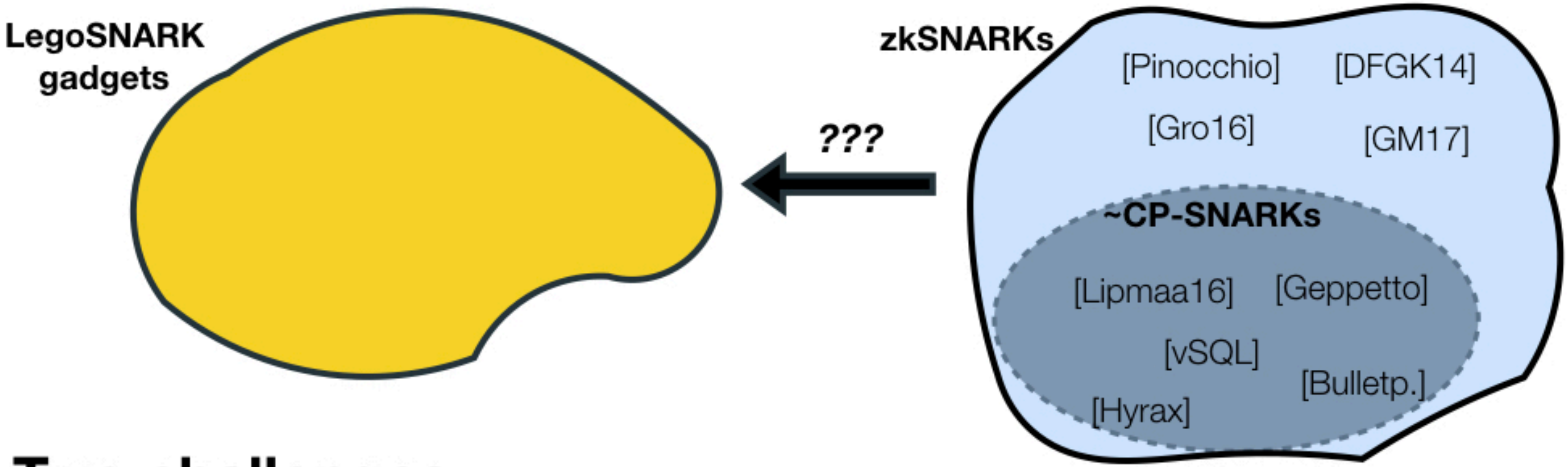

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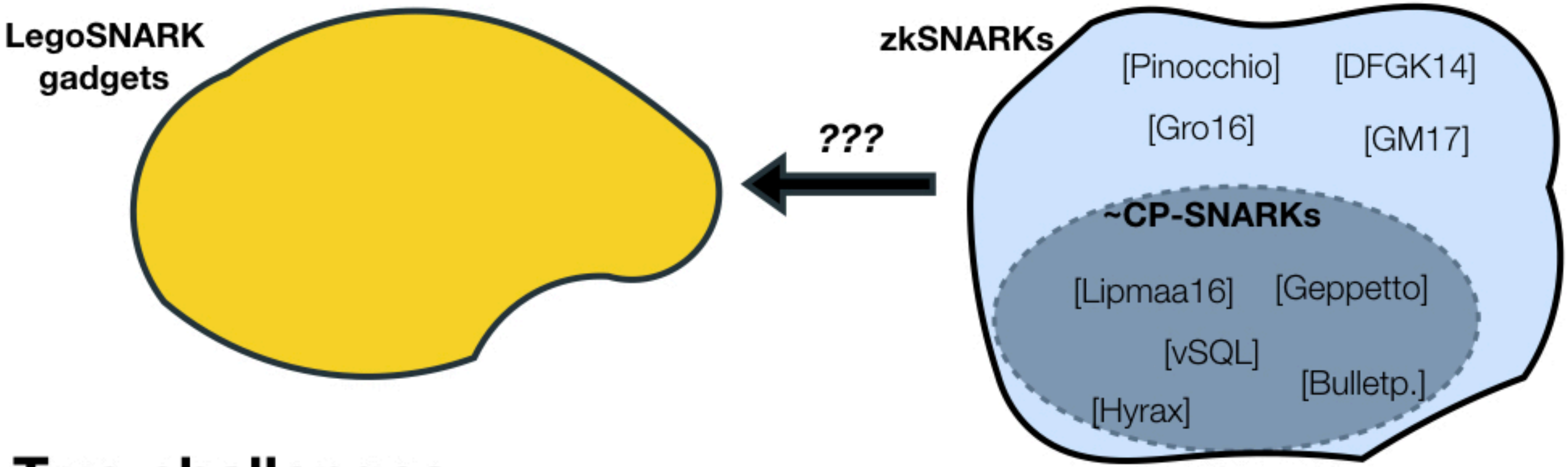

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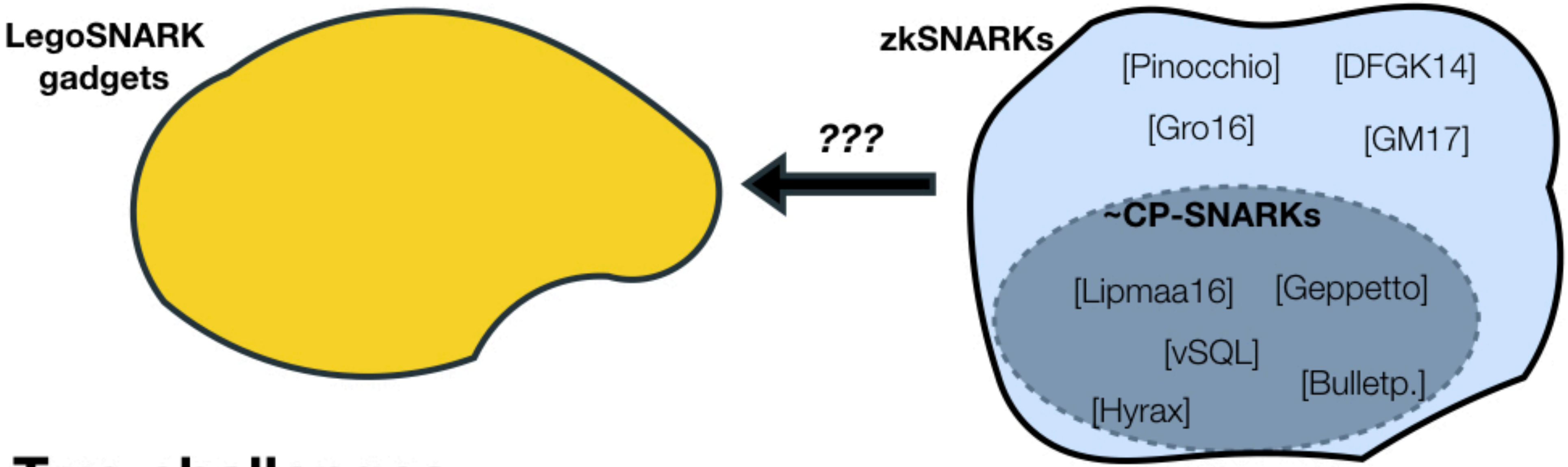

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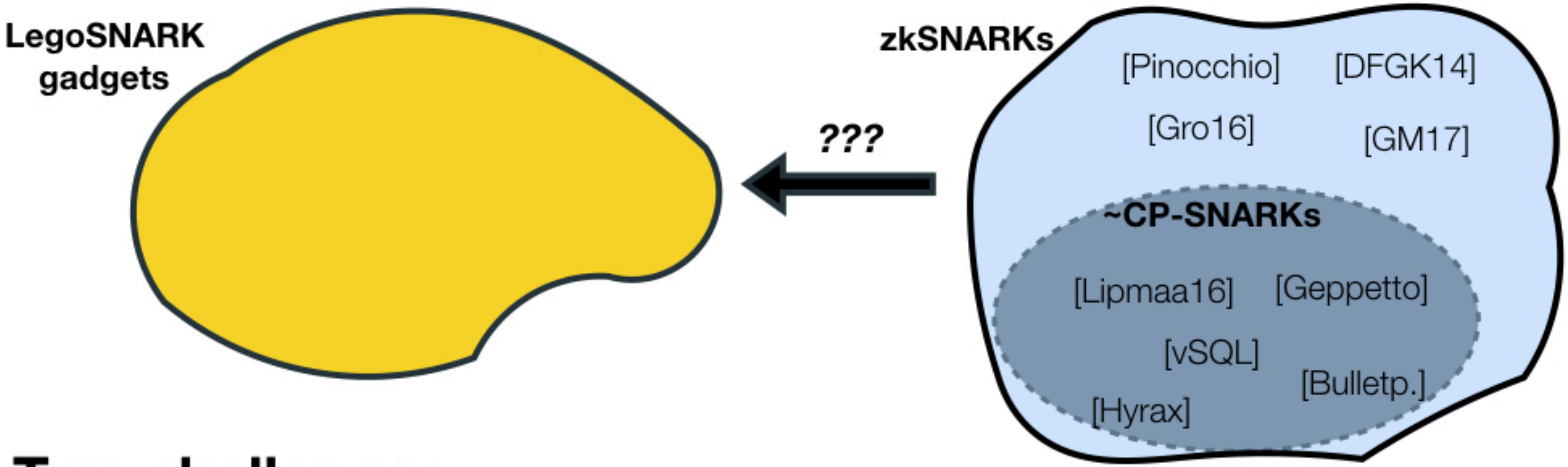

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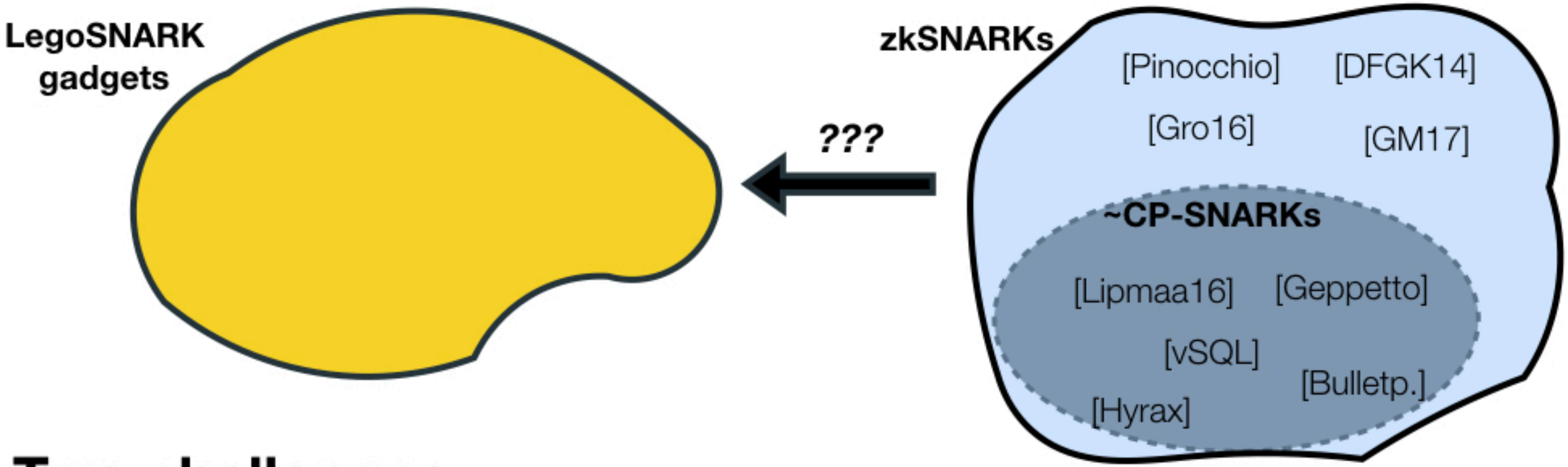

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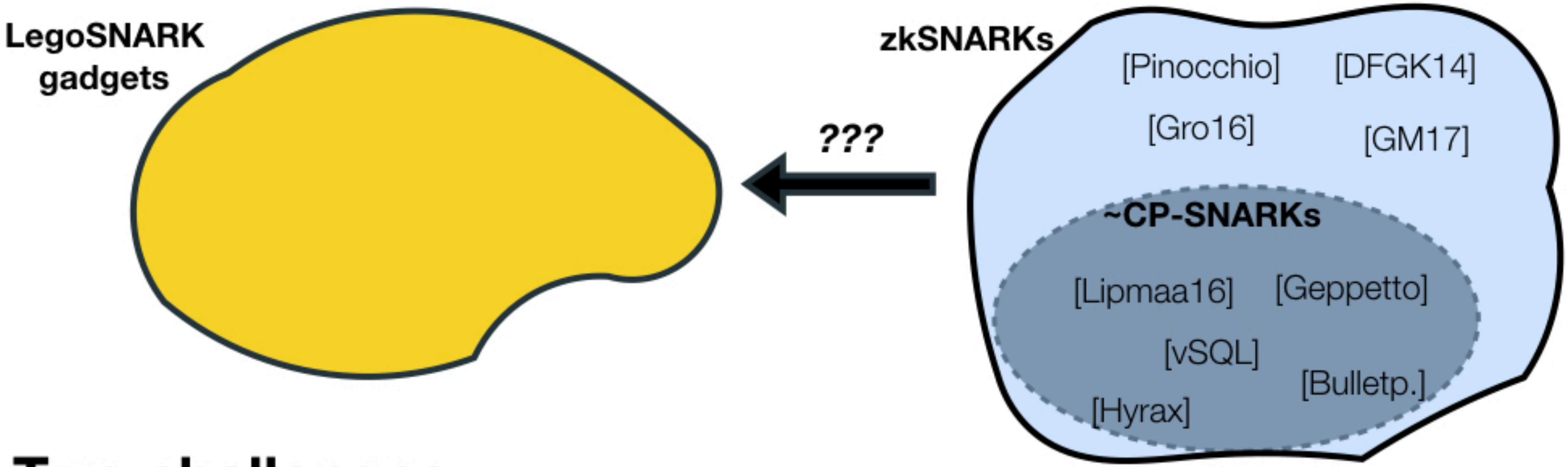

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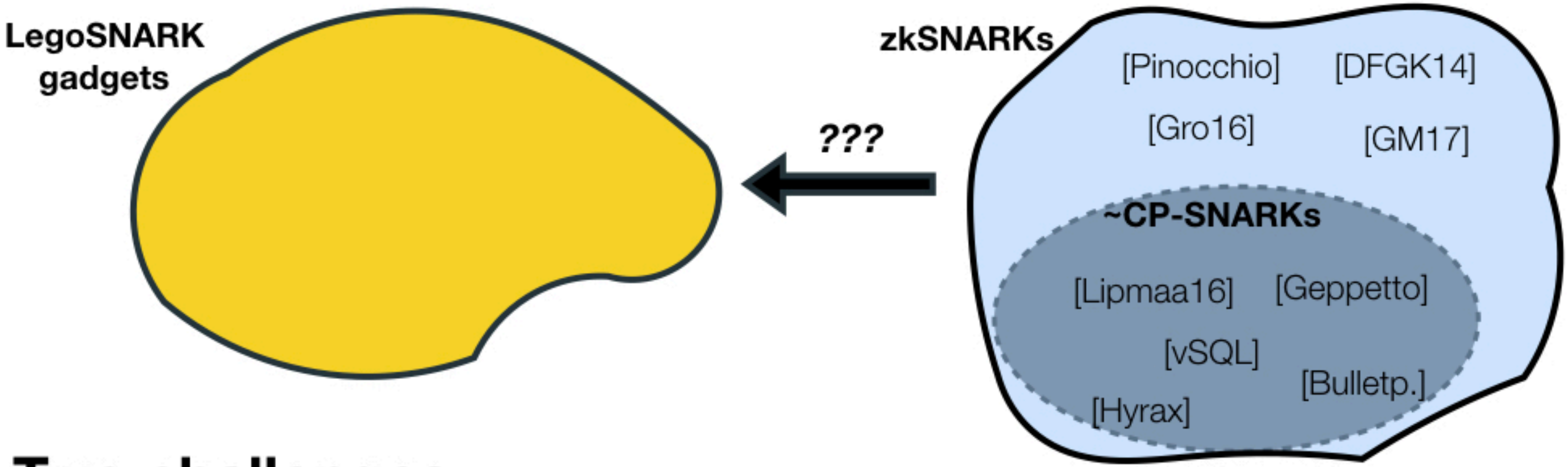

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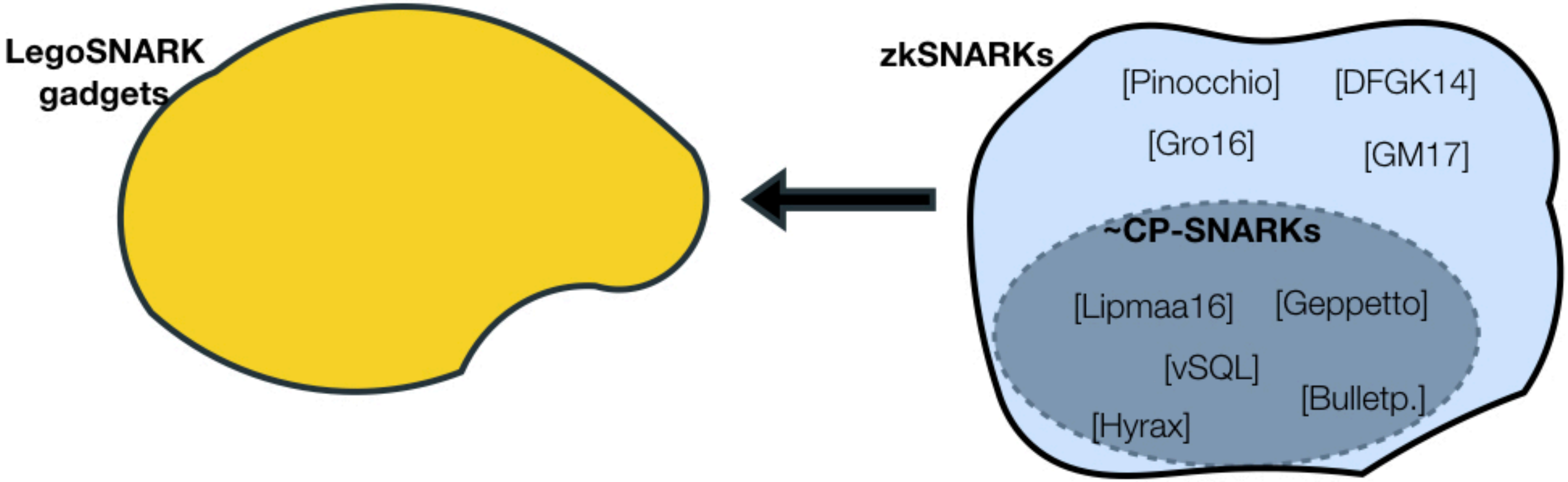

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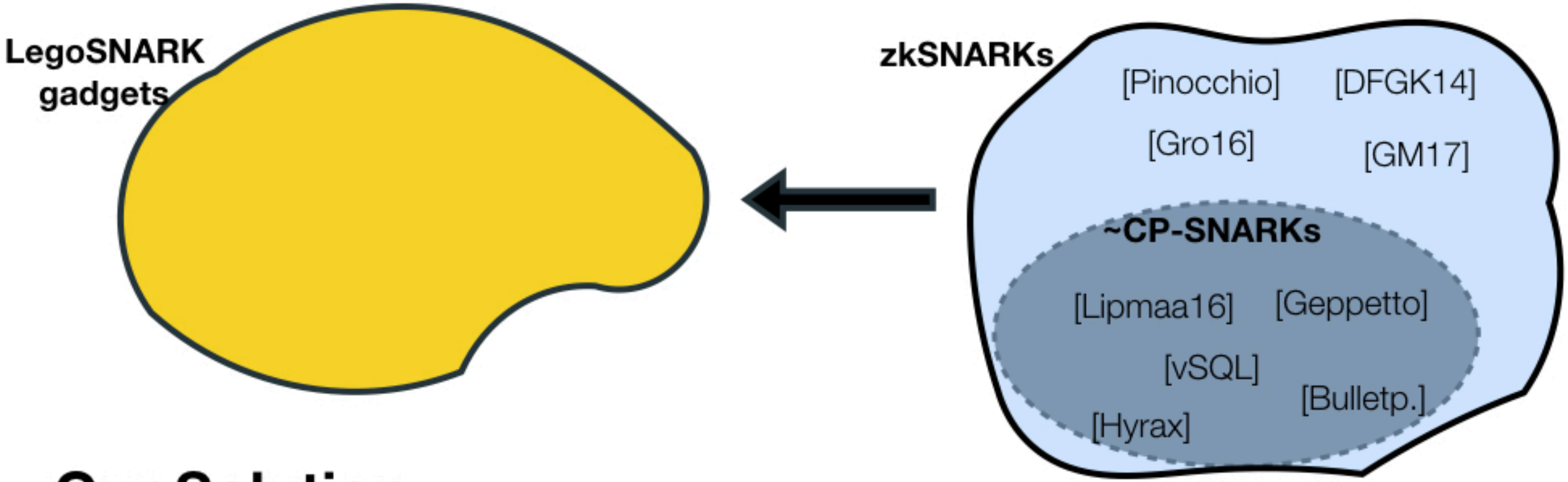

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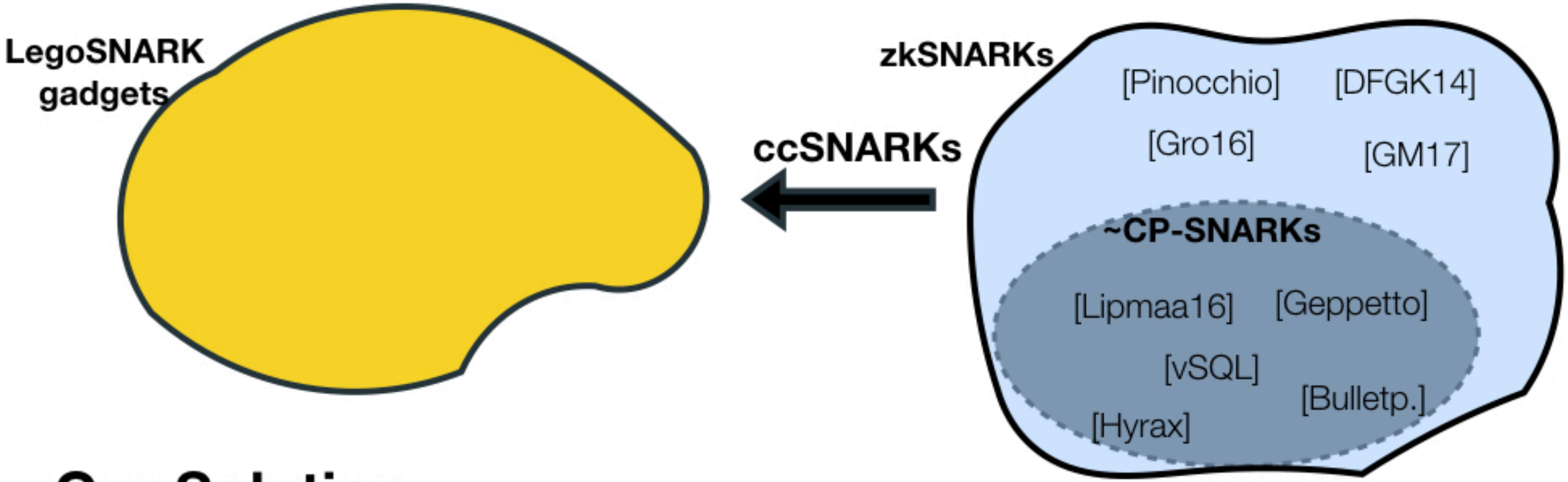

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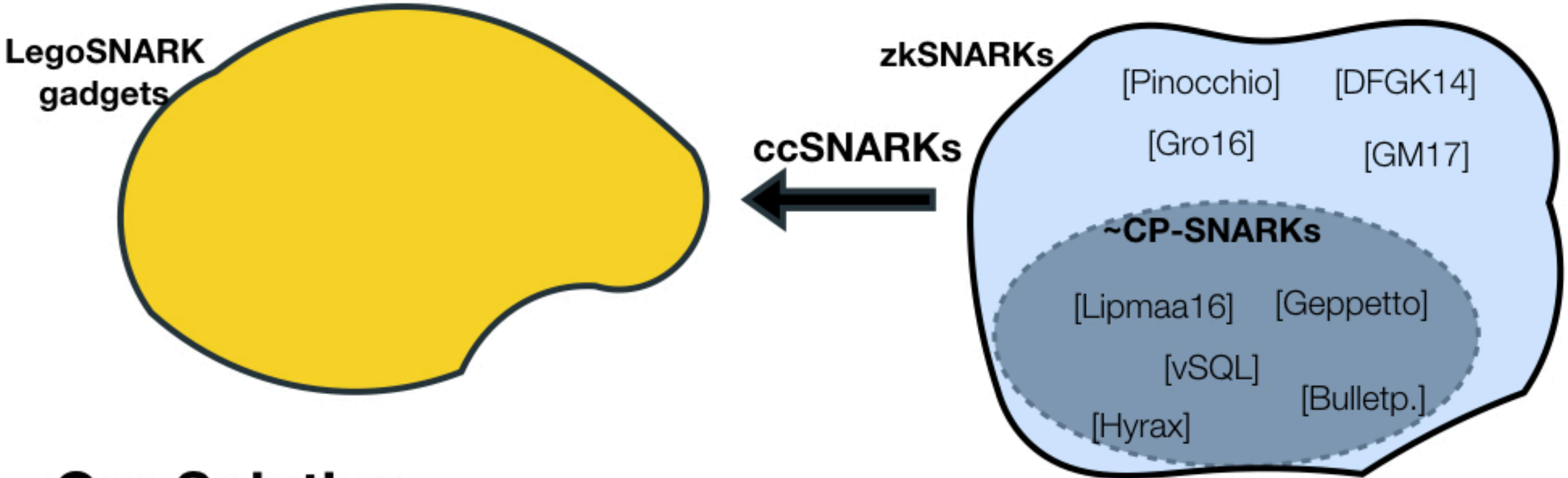

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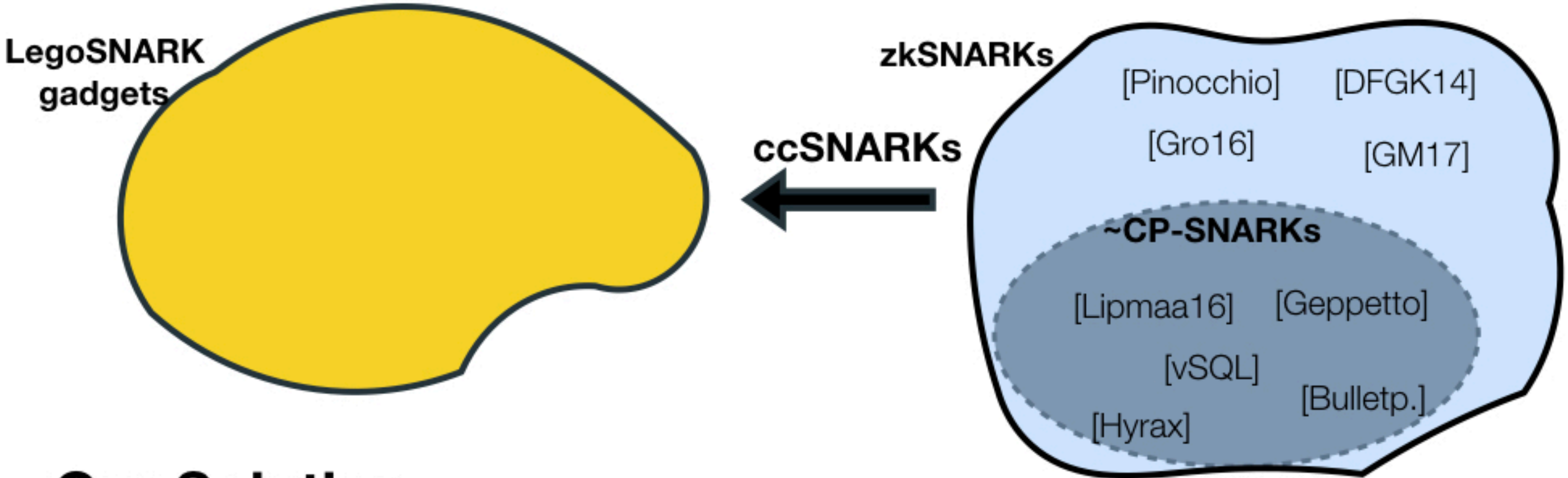

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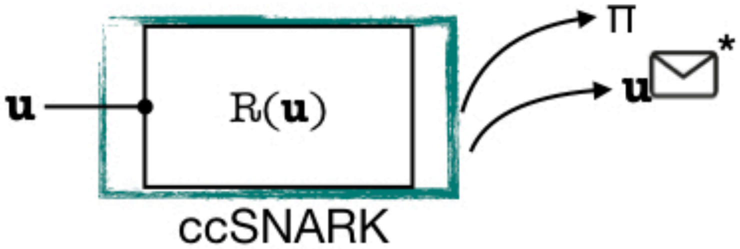

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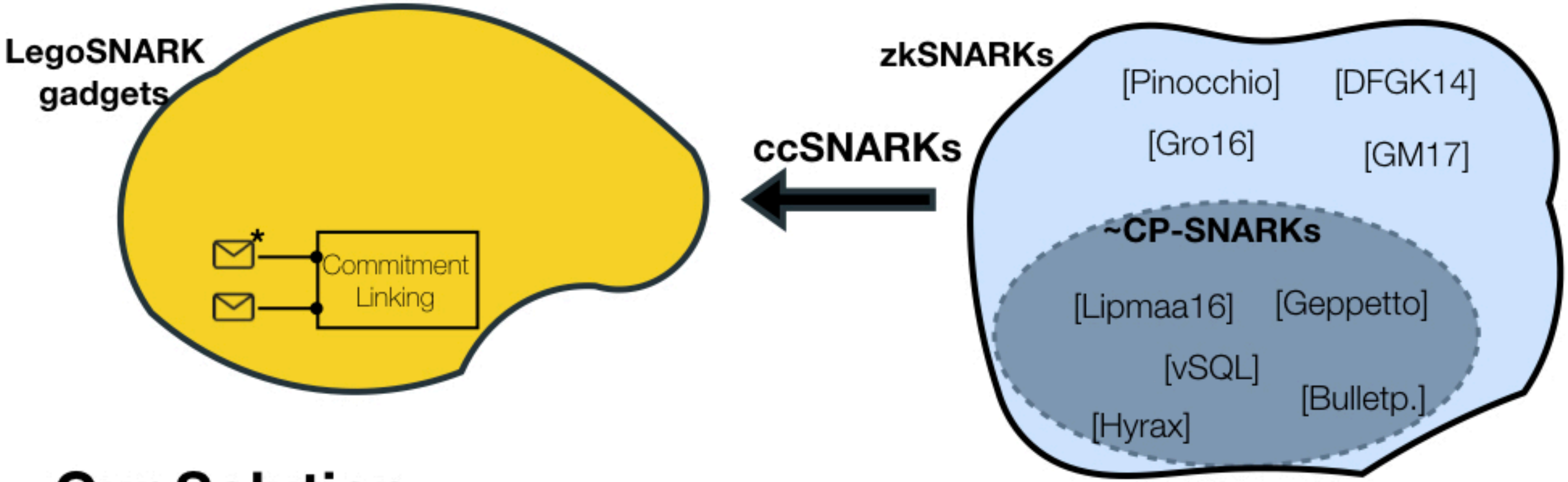

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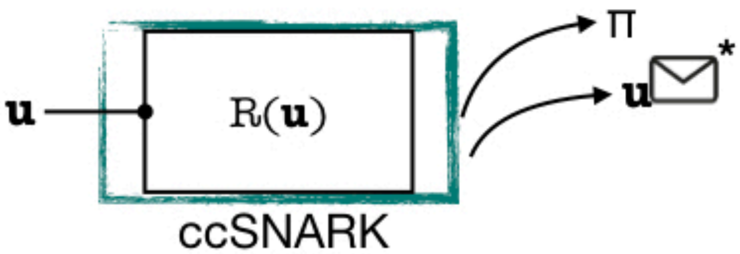

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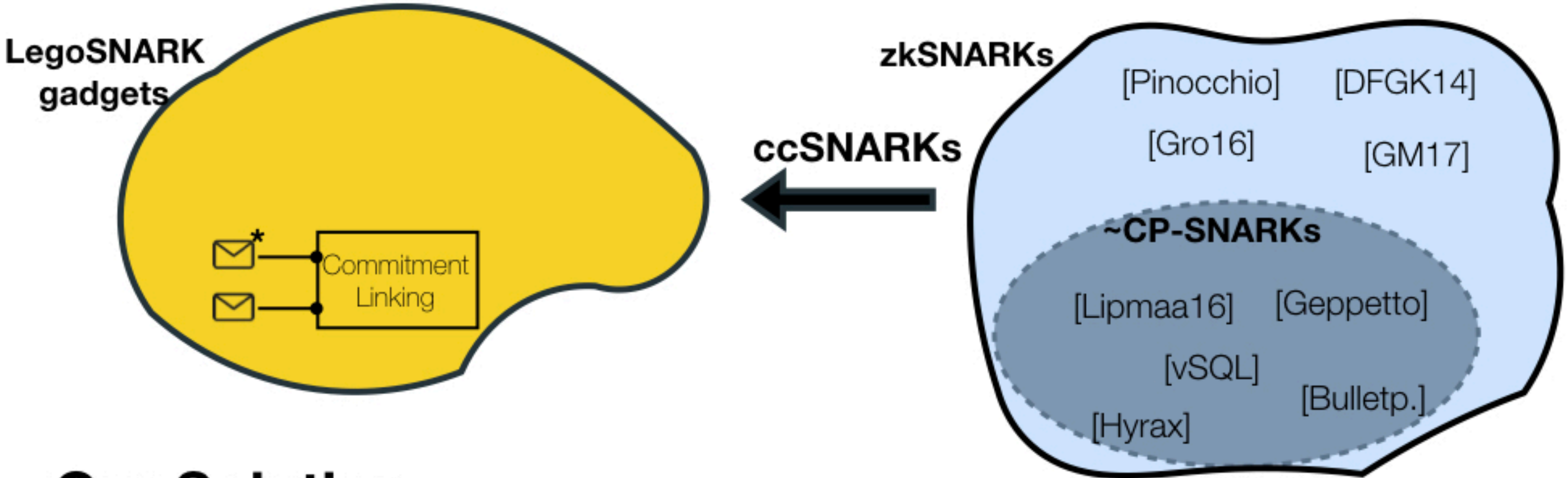

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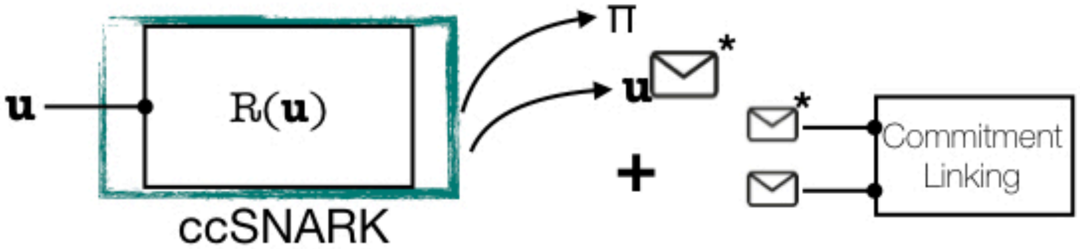

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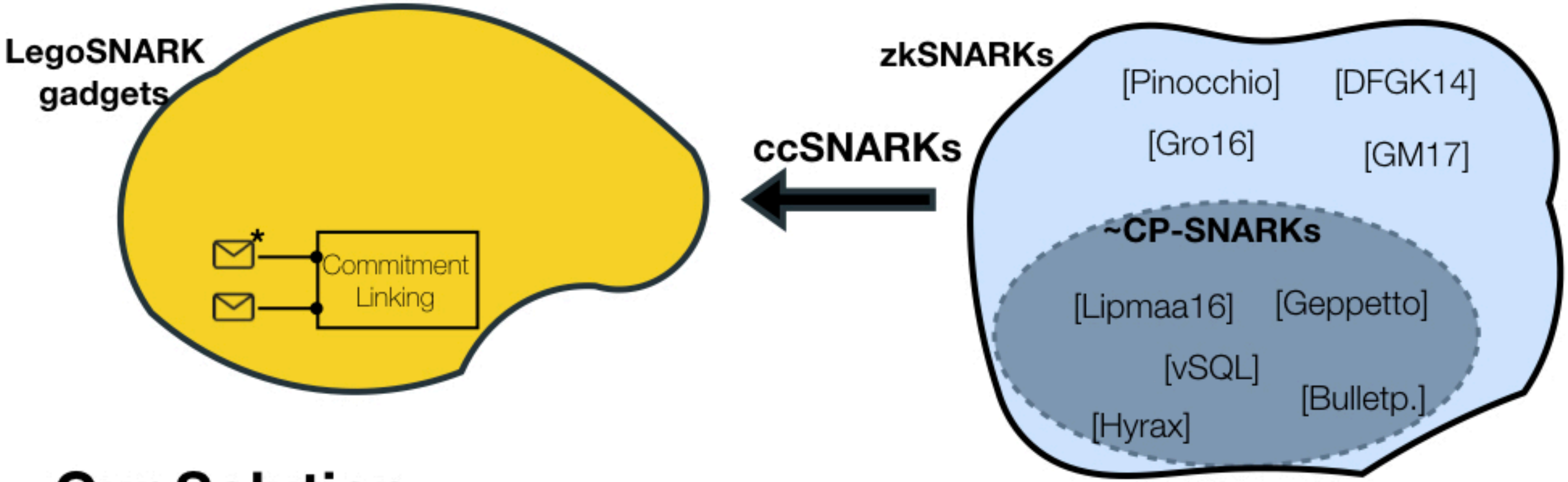

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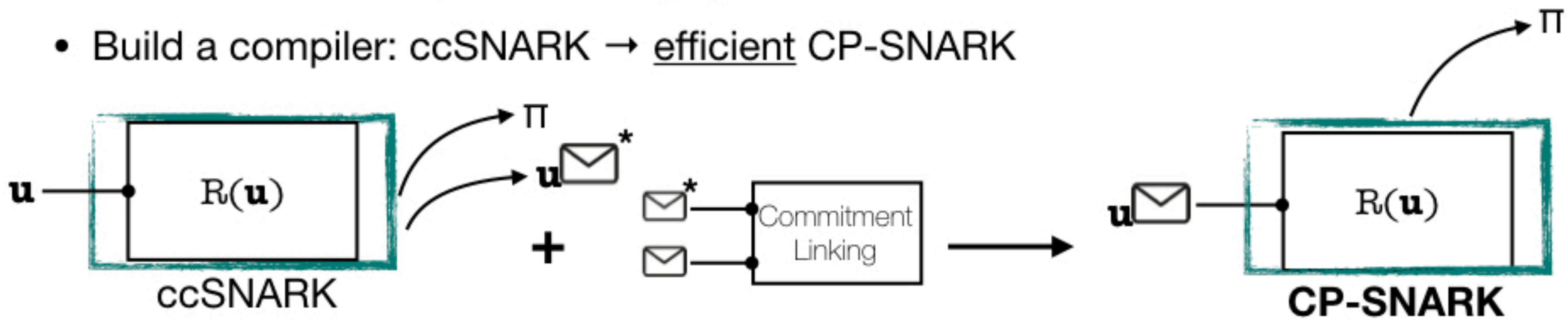

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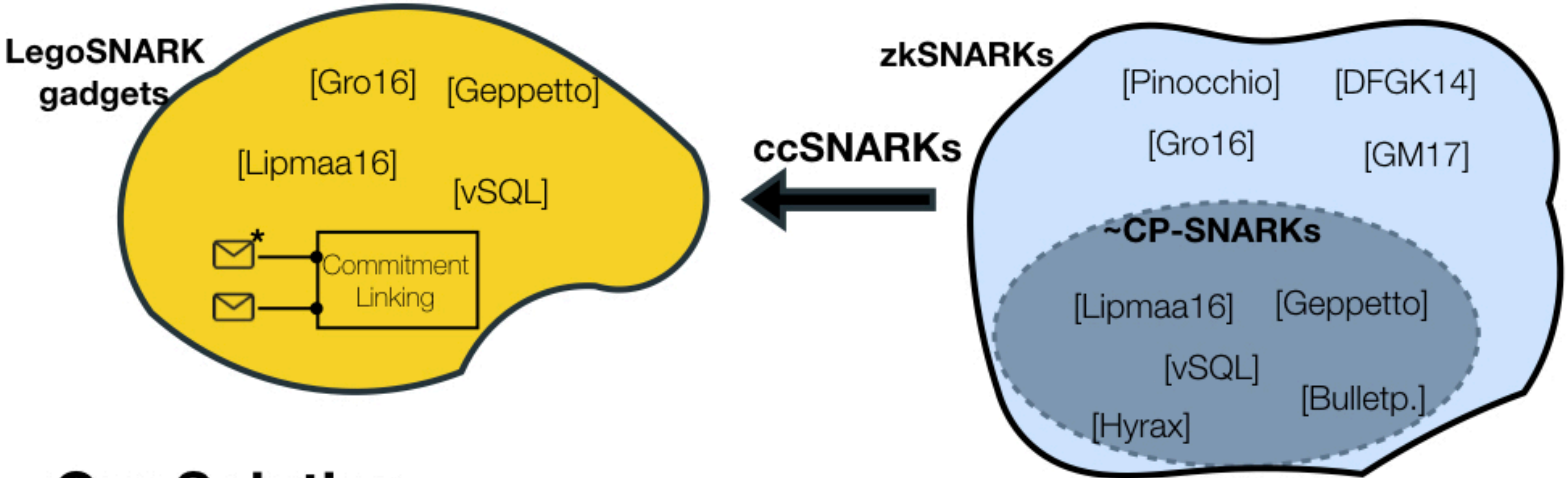

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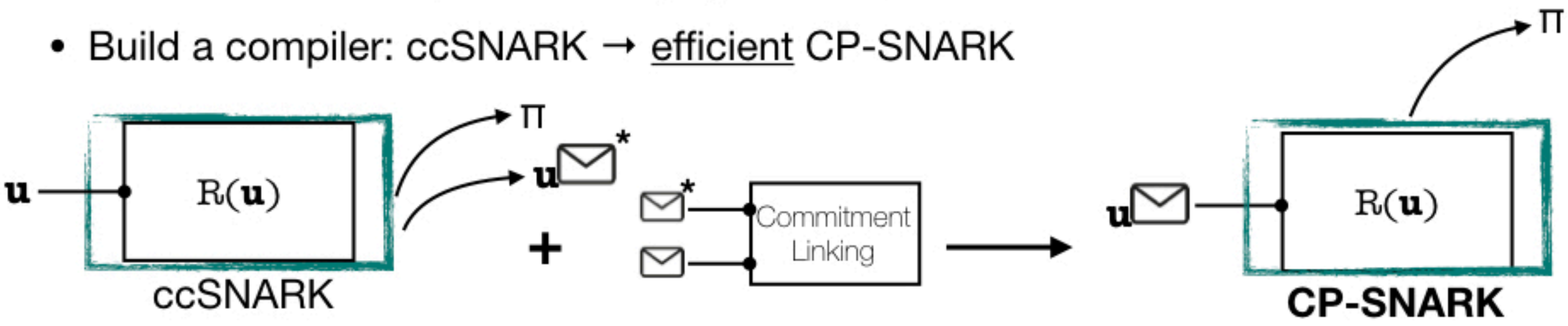

2. Specialized Proof Gadgets in LegoSNARK

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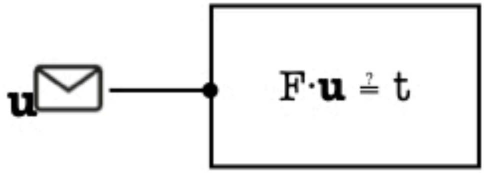

Linear Properties

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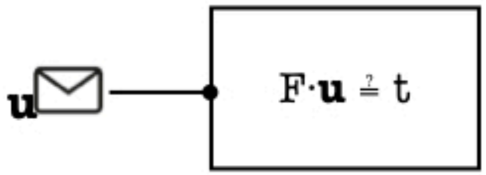

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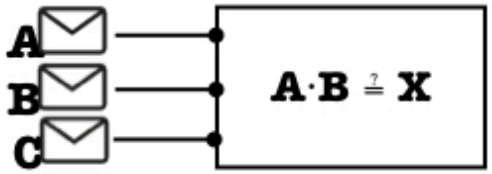

Matrix Multiplication

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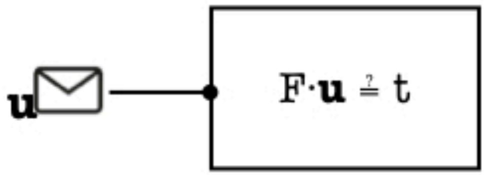

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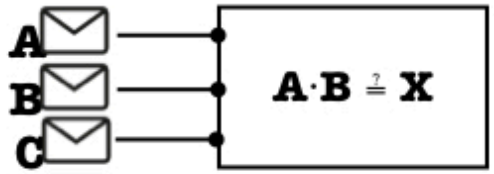

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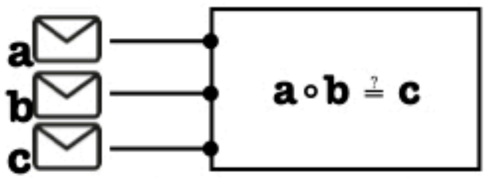

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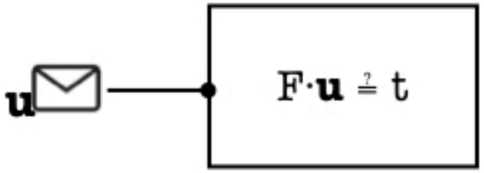

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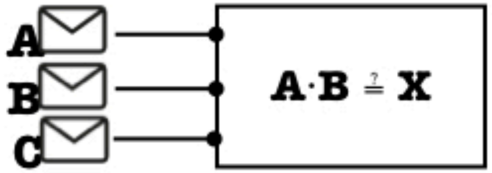

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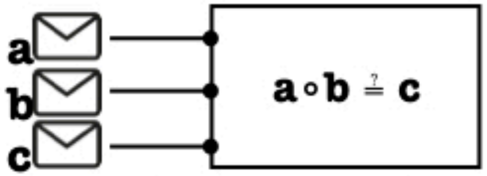

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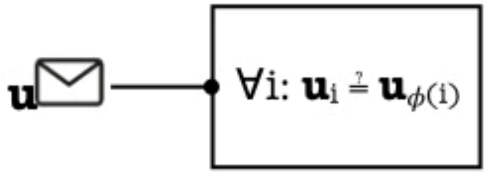

Self-Permutation

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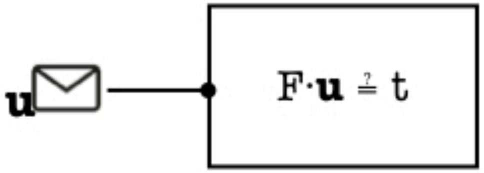

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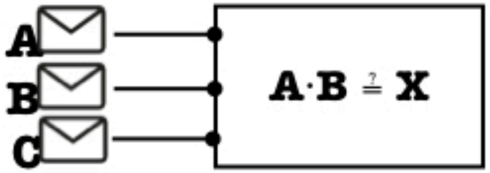

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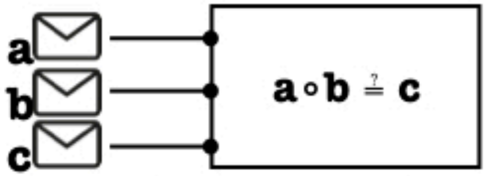

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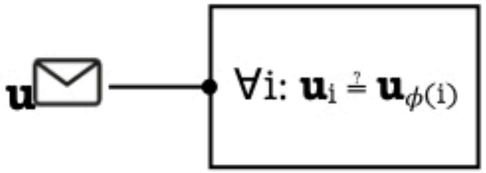

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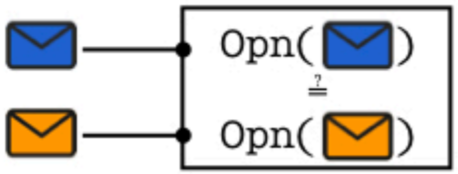

Commitment Linking

Is This Really Any Good?

Checking Modularity on its Promises

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- Can we build/glue new SNARKs for complex relations?

Checking Modularity on its Promises

- Can we build/glue new SNARKs for complex relations?
- Is any of this really efficient?

New General-purpose SNARKs

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General-Purpose Efficient CPSnark:

LegoGroth16: efficient CP version of Groth16
(5000x faster than trivially opening a commitment in Groth16)

New General-purpose SNARKs

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LegoGroth16: efficient CP version of Groth16

(5000x faster than trivially opening a commitment in Groth16)

<u>**One of the *first* (CP)Snark with universal SRS**</u>**:** [concurrent to [Sonic]]

LegoUAC

(O(N) SRS; O(N) proving; $O(\log^2(N))$ proof)

New General-purpose SNARKs

General-Purpose Efficient CPSnark:

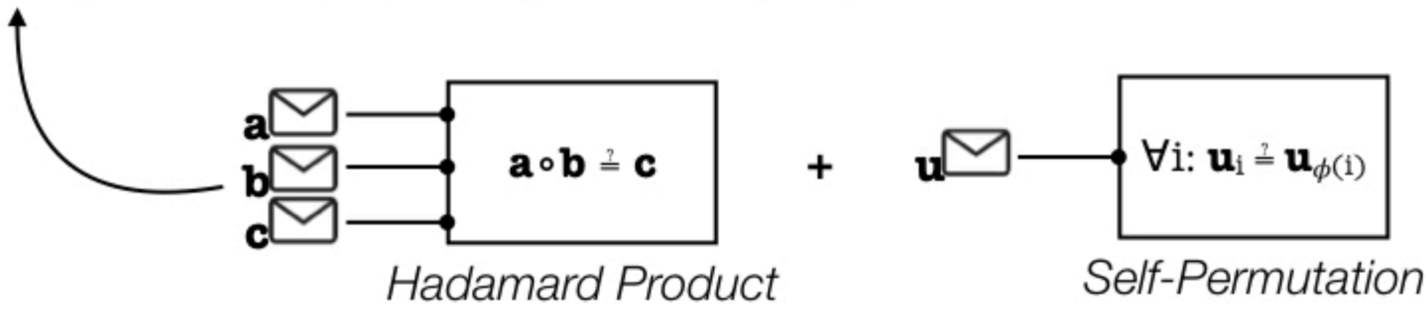
LegoGroth16: efficient CP version of Groth16

(5000x faster than trivially opening a commitment in Groth16)

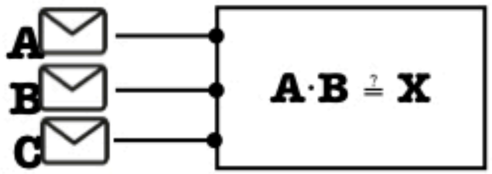
One of the *first* (CP)Snark with universal SRS: [concurrent to [Sonic]]

LegoUAC

(O(N) SRS; O(N) proving; O($\log^2$(N)) proof)

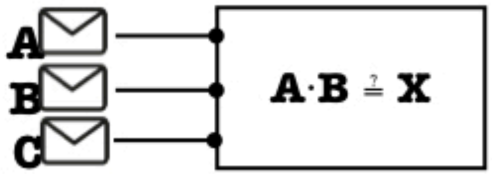


Gadgets with Optimal Proving Time: Matrix Multiplication



Gadgets with Optimal Proving Time: Matrix Multiplication

Our gadget vs Groth16:



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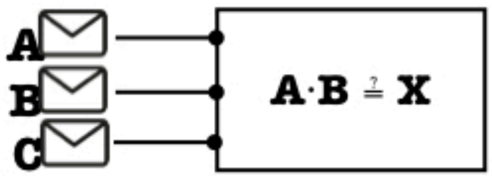

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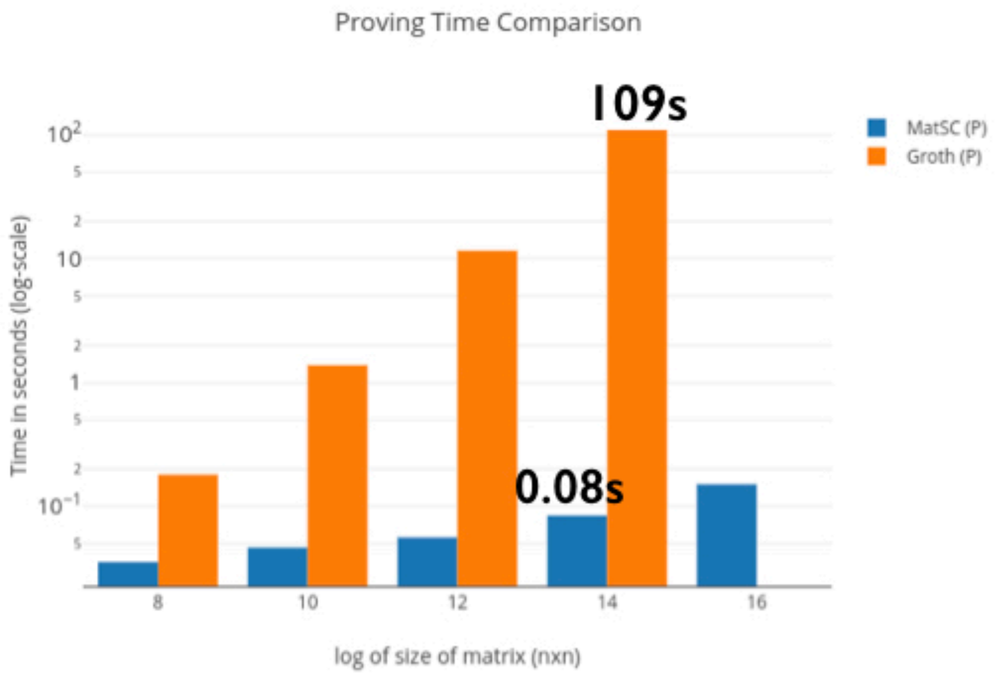

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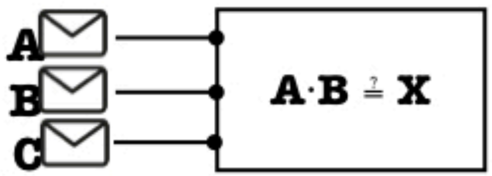
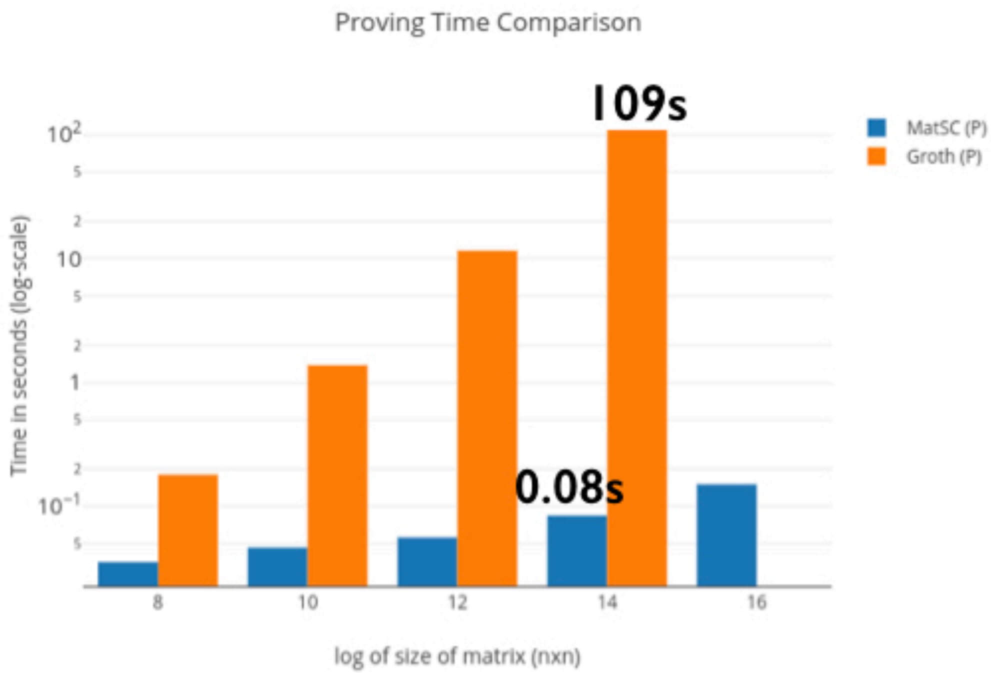


Our gadget vs Groth16:

n^2 **(optimal proving time)**

$n^3 \log(n)$



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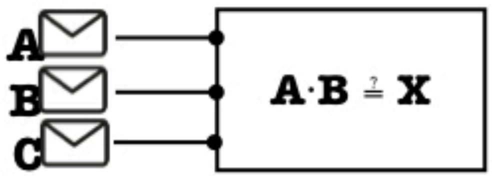

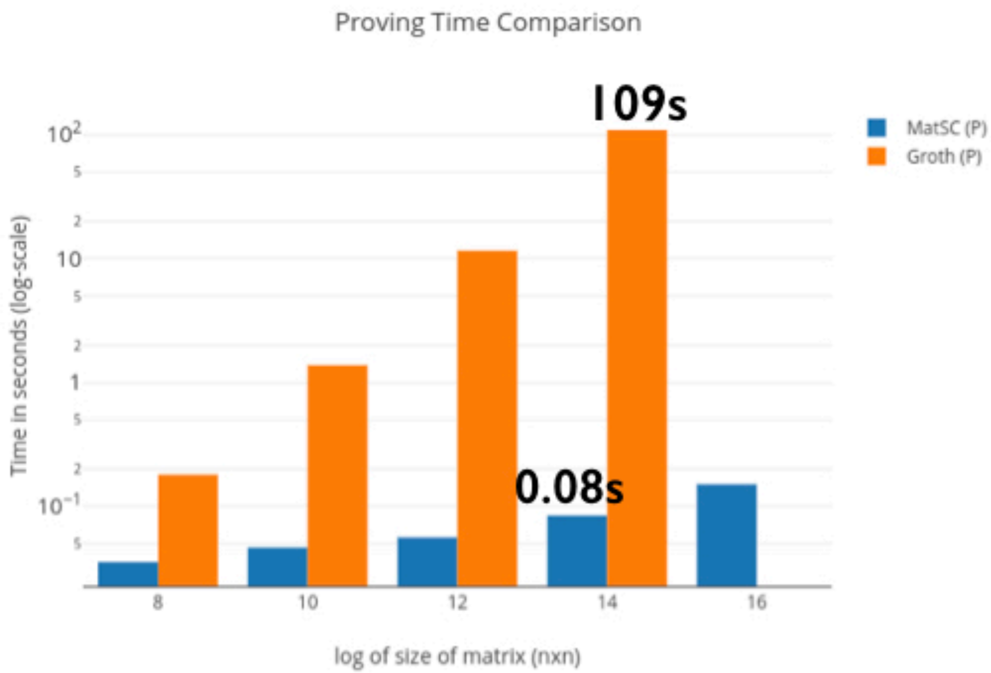

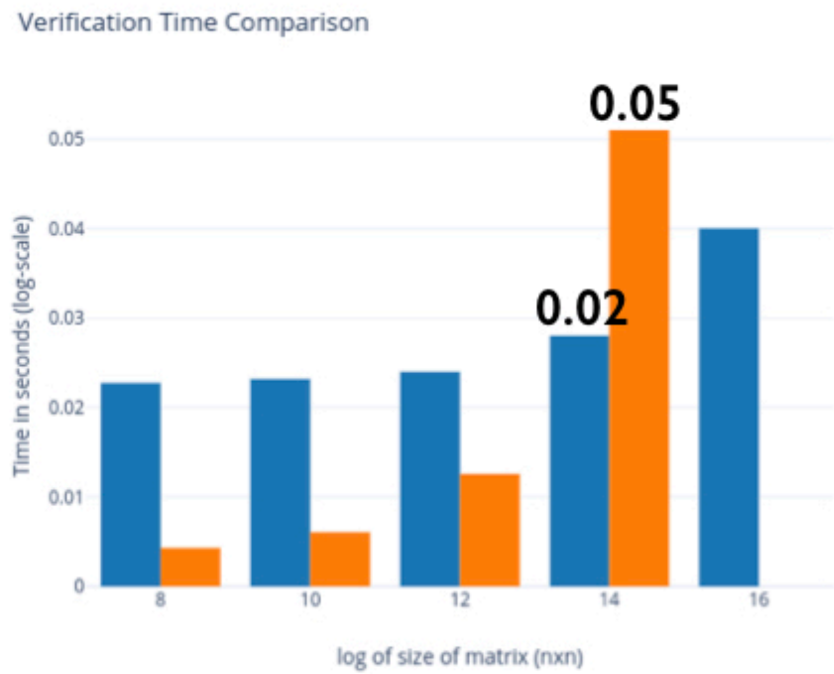

LegoSNARK in Practice

github.com/imdea-software/legosnark

Abstraction in SNARK APIs

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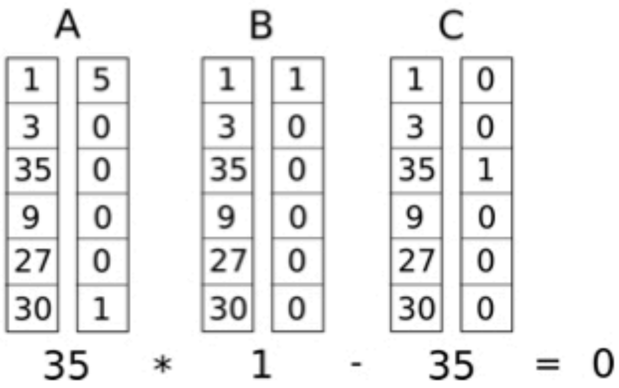
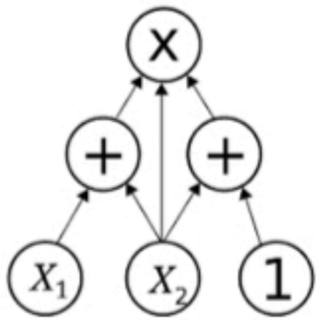
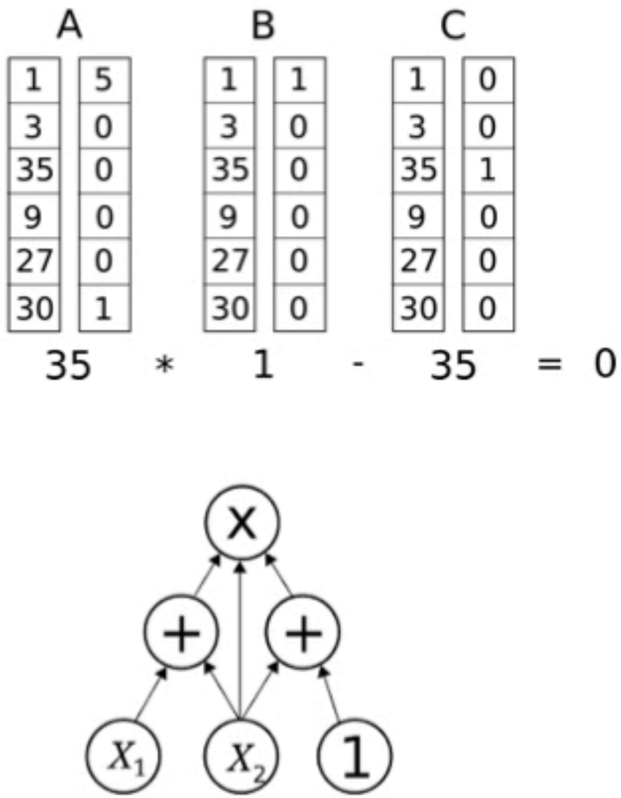




Standard Abstractions in SNARK Libraries

Abstraction in SNARK APIs



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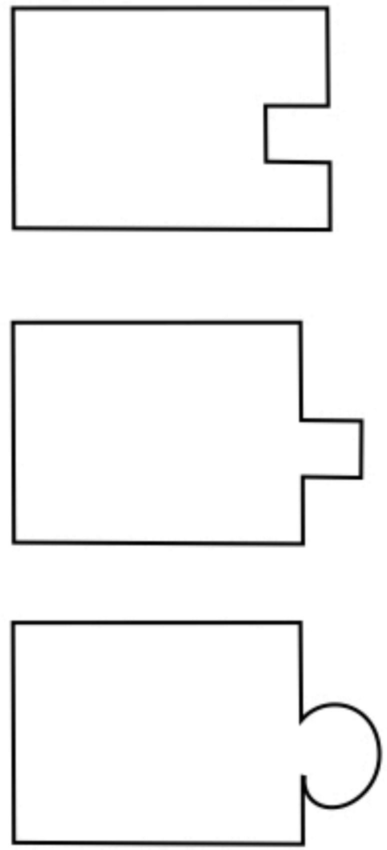

Abstractions in LegoSNARK

Goals of Our API

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Being an EDSL.

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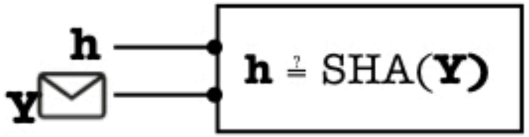
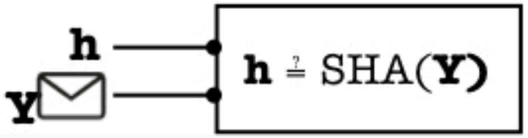
- Strong Typing! (non-trivial in C++)
- Super easy to compose gadgets and relations (exploiting automatic type deduction)
- Easy to define your own gadgets/relations

Defining Relations

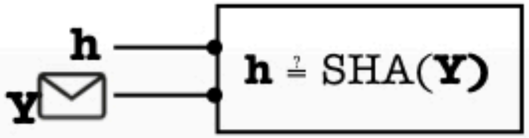


Defining Relations



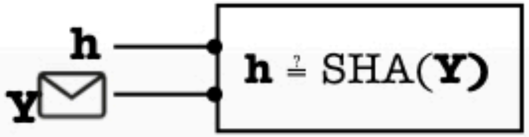

```
struct ShaSyntax
{
// [ ... ]
        decl("h"_s) .as<FldVec>() .public(), // h is a public input
        decl("Y"_s) .as<FldMatrix>() .committed() // Y is a committed input
// [ ... ]
};

// automatically defines ShaR::instance (next slide)
using ShaR = Rel<ShaSyntax>;
```

Compile-Time Checks in LegoSNARK




```
// Defining Instance of SHA relation
ShaR::instance sha_in;
sha_in["Y"_s] = someMatrix; // GOOD: right type
/*
sha_in["Y"_s] = someFieldElement; // WON'T COMPILE: wrong type
*/
```

Compile-Time Checks in LegoSNARK




```
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ShaR::instance sha_in;
sha_in["Y"_s] = someMatrix; // GOOD: right type
/*
sha_in["Y"_s] = someFieldElement; // WON'T COMPILE: wrong type
*/

SHAGadget sha_zkp;
// [ ... ]
sha_zkp.prv(sha_in); // WON'T COMPILE: variable "h" is not initialized

sha_in["h"_s] = someFieldVec;
sha_zkp.prv(sha_in); // GOOD: now it's initialized
```
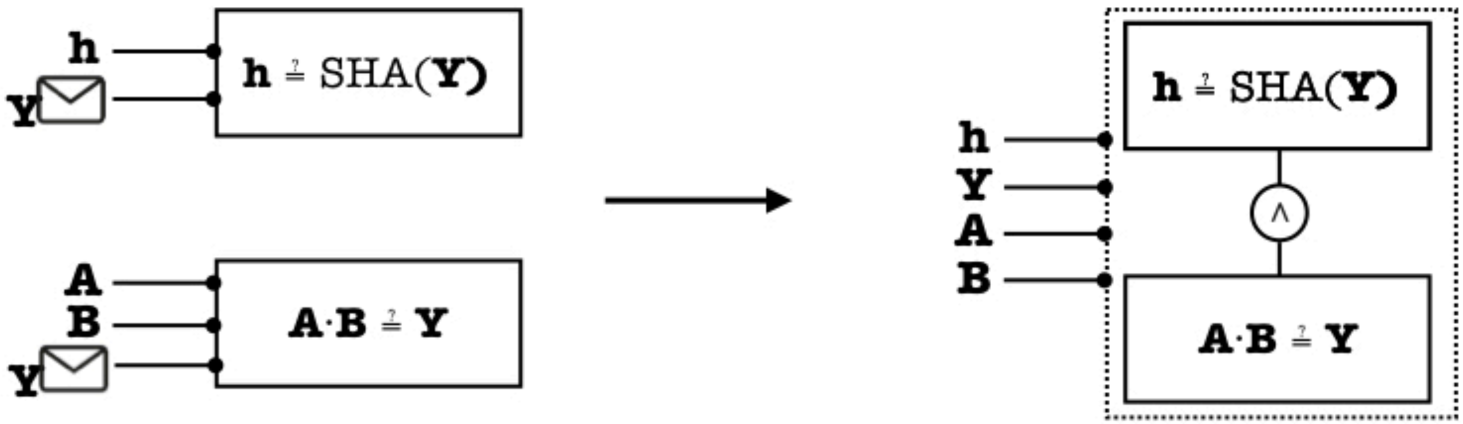
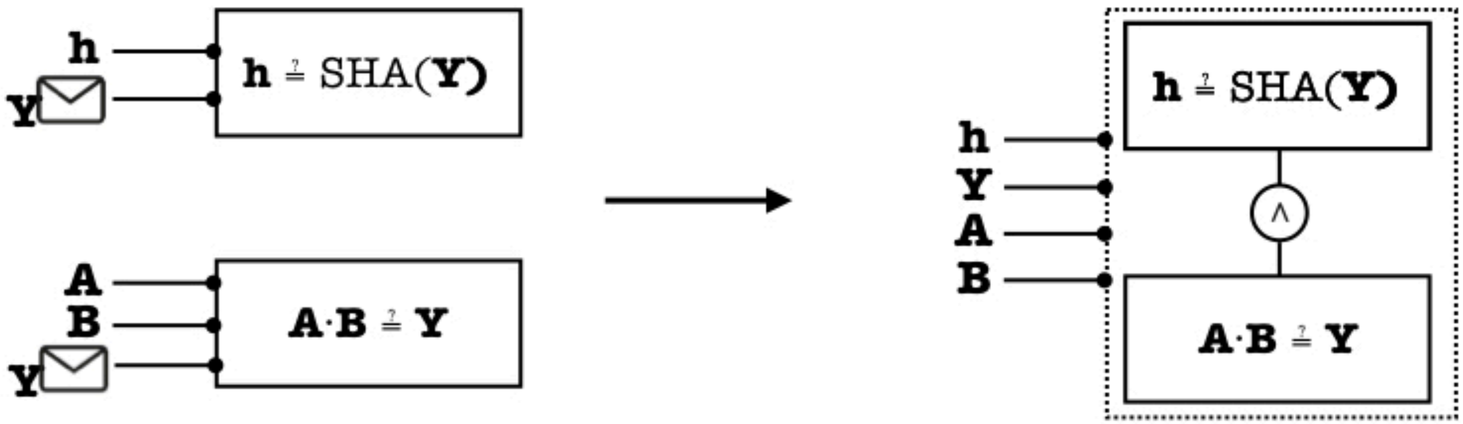

Composition



Composition




```
using ComposedGadget = Compose<MatMulGadget, SHAGadget>;
ComposedGadget cmp_gadg;

// ...
auto matrix_sha_in = sha_in || mat_mult_in; // automatically checks compatibility
cmp_gadg.prv(matrix_sha_in);
```

Wrapping up

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Modular Approach to SNARK Design

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Efficiency + Ease of Design

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Recent Extension:

Accumulate-and-Prove ia.cr/2019/1255

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Thanks!

specialized LegoSNARK gadgets

Relation	commit. scheme	CP scheme	time Prove	time Ver	space crs	space π	assumpt.	uni	upd
Pedersen commitments open to the same vector $R_{link}(\mathbf{c'}, \mathbf{u}, \mathbf{o'}) := \mathbf{c'} \stackrel{?}{=} \mathrm{Ped}(\mathbf{u}, \mathbf{o'})$ $n=\lvert\mathbf{u}\rvert$	Pedersen*	CP_{link}	*n*	*1*	*n*	*1*	AGM		
Linear properties $R_{F,c}(\mathbf{u}) := \mathbf{F} \cdot \mathbf{u} \stackrel{?}{=} \mathbf{c}$ $\mathbf{F}$ $m \times n$	Pedersen*	CP_{lin}	*n*	*1*	*n*	*1*	AGM		
	PolyCom	CP'_{lin}	$\lvert F\rvert+m+n$	$\log m \cdot n$	$m \cdot n$	$\log m \cdot n$	q-SDH, KoE, ROM		
Matrix multiplication $R_{mm}(\mathbf{X}, \mathbf{A}, \mathbf{B}) := \mathbf{X} \stackrel{?}{=} \mathbf{A} \cdot \mathbf{B}$ $n \times n$	PolyCom	CP_{mmul}	n^2	$n^2+\log n$	n^2	$\log n$	q-SDH, KoE, ROM		
Hadamard product $R_{had}(\mathbf{a}, \mathbf{b}, \mathbf{c}) := \mathbf{c} \stackrel{?}{=} \mathbf{a} \circ \mathbf{b}$ $n=\lvert\mathbf{u}\rvert$	PolyCom	CP_{had}	*n*	$\log n$	*n*	$\log n$	q-SDH, KoE, ROM		
Self permutation $R_{\phi}(\mathbf{u}) := \forall i: u_i \stackrel{?}{=} u_{\phi(i)}$ $n=\lvert\mathbf{u}\rvert$	PolyCom	CP_{sfprm}	*n*	$\log n$	*n*	$\log n$	q-SDH, KoE, ROM		

Pedersen* = any Pedersen-like commitment. **PolyCom** from [zk-vSQL]

AGM='Algebraic Group Model'. **uni**versal crs (yes, no). **upd**atable crs (yes, to be proven)

Thanks!