zkSaaS

Zero-Knowledge SNARKs as a Service

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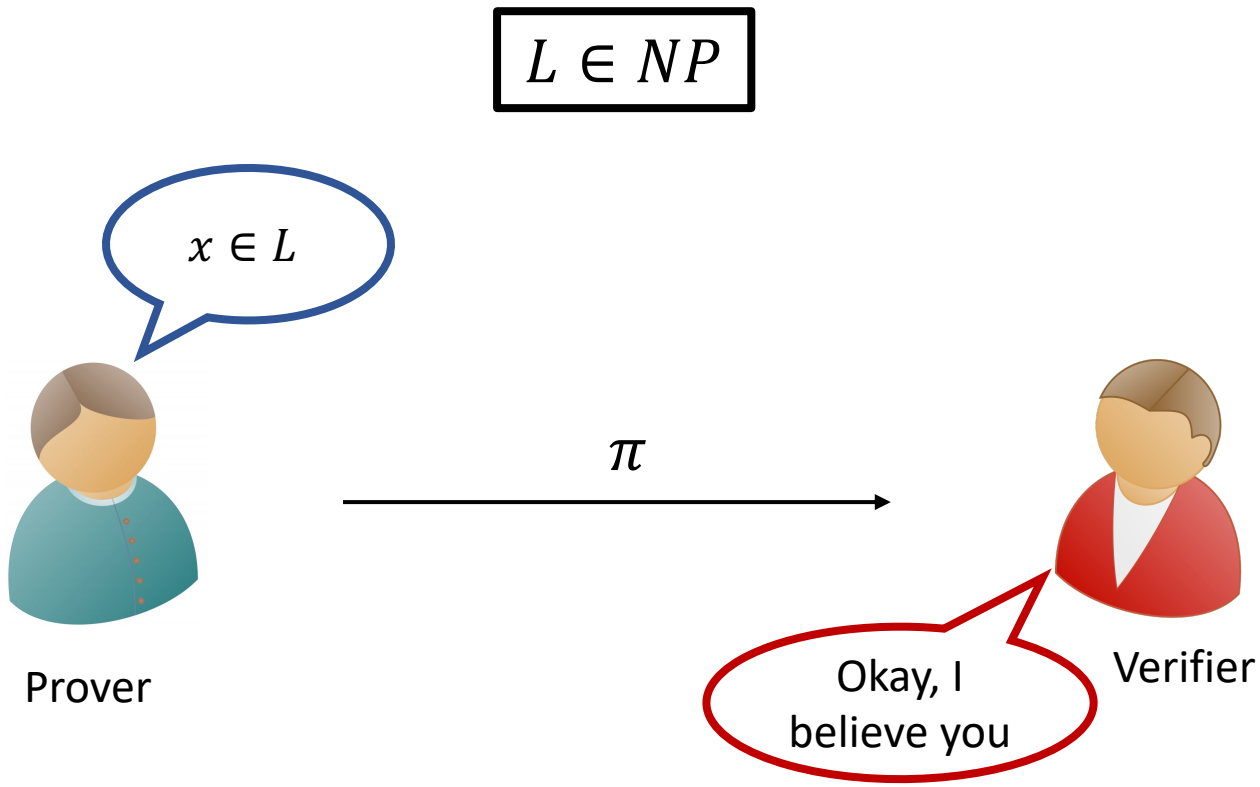
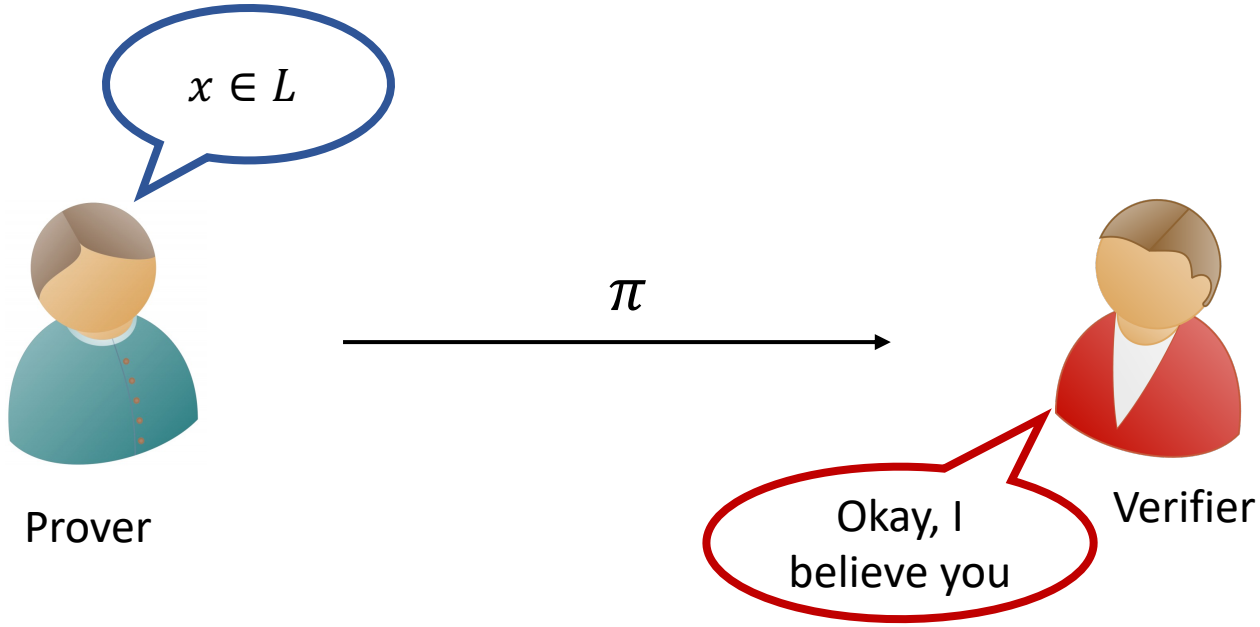
USENIX Security 2023

zk-SNARKs: Zero-Knowledge Succinct Non-Interactive Arguments of Knowledge



zk-SNARKs: Zero-Knowledge Succinct Non-Interactive Arguments of Knowledge

$L \in NP$



Anyone can verify

Zero knowledge

Verifier should not learn the secret witness

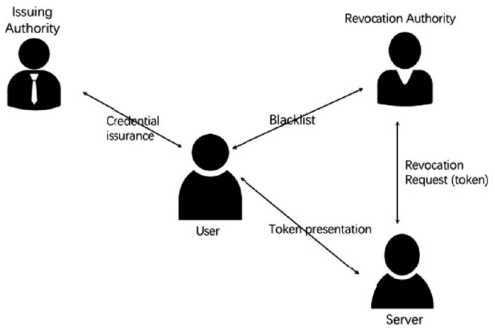
Soundness

Cheating prover cannot give accepting proof if $x \notin L$

Succinctness

Time to verify is smaller than time to compute

zk-SNARKs: Numerous Applications



Anonymous Credentials [Chaum82]

Verifiable Inference of Machine Learning [LKKO20]

Private Smart Contracts [BCGMMW20]

Proving existence of bugs in code [HK20]

Verifying authenticity of images in media [NT16]

Privacy Respecting Cryptocurrency [BCGGMTV14]

zk-SNARKs: Lots of Work on Improving Efficiency

Orion: Zero Knowledge Proof with Linear Prover Time

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On the Size of Pairing-based Non-interactive Arguments*

Jens Groth**

Public-Coin Zero-Knowledge Arguments with (almost) Minimal Time and Space Overheads

Alexander R. Block[1], Justin Holmgren[2], Alon Rosen[3], Ron D. Rothblum[4], and Pratik Soni[5]

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Gemini: Elastic SNARKs for Diverse Environments

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DIZK: A Distributed Zero Knowledge Proof System*

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New optimization techniques for $\mathcal{PlonK}$'s arithmetization

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HyperPlonk: Plonk with Linear-Time Prover and High-Degree Custom Gates

Dan Boneh
Zhenfei Zhang

Time to generate of zk-SNARKs >>> Time to check the relation directly

$\mathcal{PlonK}$: Permutations over Lagrange-bases for Oecumenical Noninteractive arguments of Knowledge

Ariel Gabizon*
Aztec

Zachary J. Williamson
Aztec

Oana Ciobotaru

Delegating Computations with (almost) Minimal Time and Space Overhead

Justin Holmgren*
Ron D. Rothblum†

September 13, 2018

Time- and Space-Efficient Arguments from Groups of Unknown Order*

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Justin Holmgren‡
Alon Rosen§
Ron D. Rothblum¶
Pratik Soni‖

September 21, 2021

Aurora: Transparent Succinct Arguments for R1CS

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May 8, 2019

Scalable, transparent, and post-quantum secure computational integrity

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Iddo Bentov†
Yinon Horesh*
Michael Riabzev*

March 6, 2018

MARLIN:
Preprocessing zkSNARKs with Universal and Updatable SRS

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Brakedown: Linear-time and post-quantum SNARKs for R1CS

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Jonathan Lee
Nanotronics Imaging

Srinath Setty
Microsoft Research

Justin Thaler
Georgetown University

Riad S. Wahby
Algorand and Carnegie Mellon University

Gru's Quest to be a Supervillain

Since Gru has a very long list of despicable achievements, computing a zk-SNARK will take a really long time

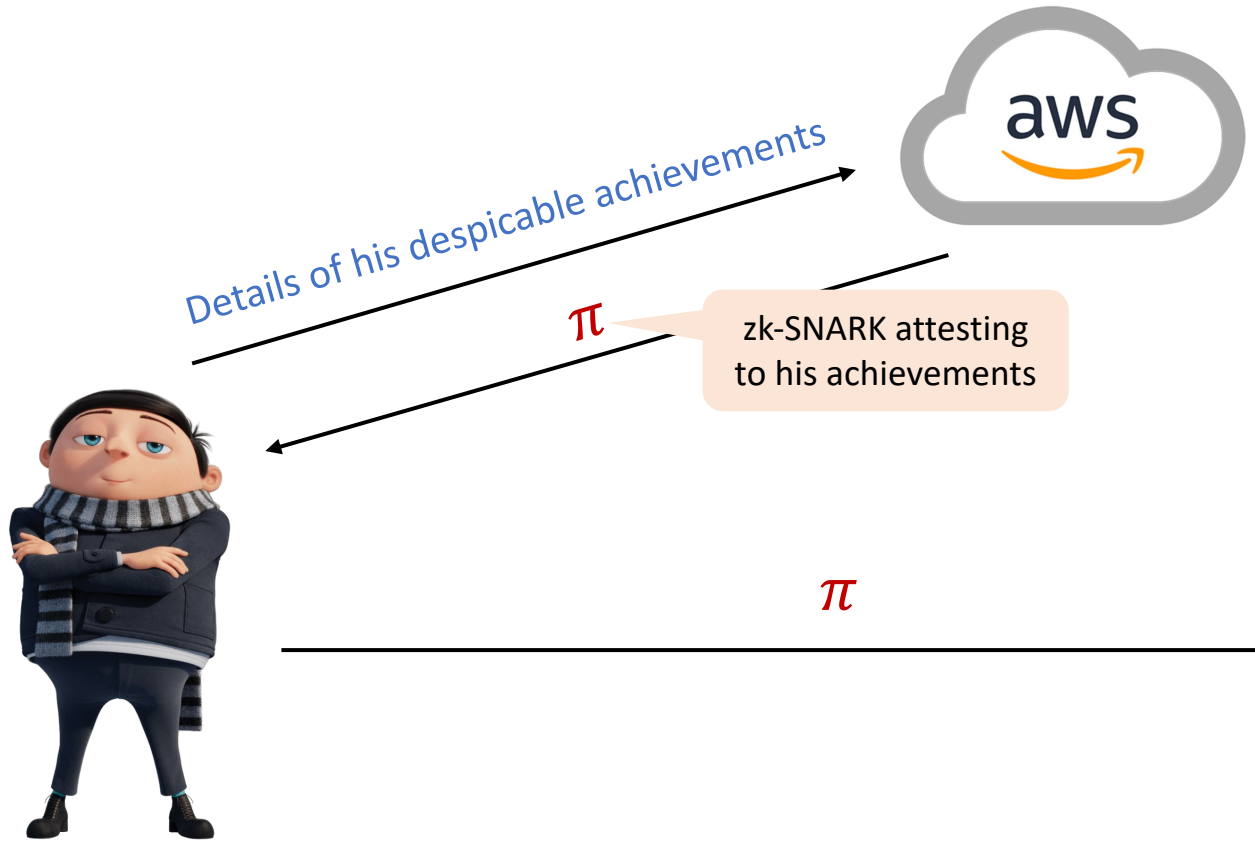
Prove this in zero-knowledge

I am a great villain and deserve to be part of Vicious 6

Gru: Rising Villain

Vicious 6: A prolific set of Supervillains

Can Gru Delegate zk-SNARK Computation?

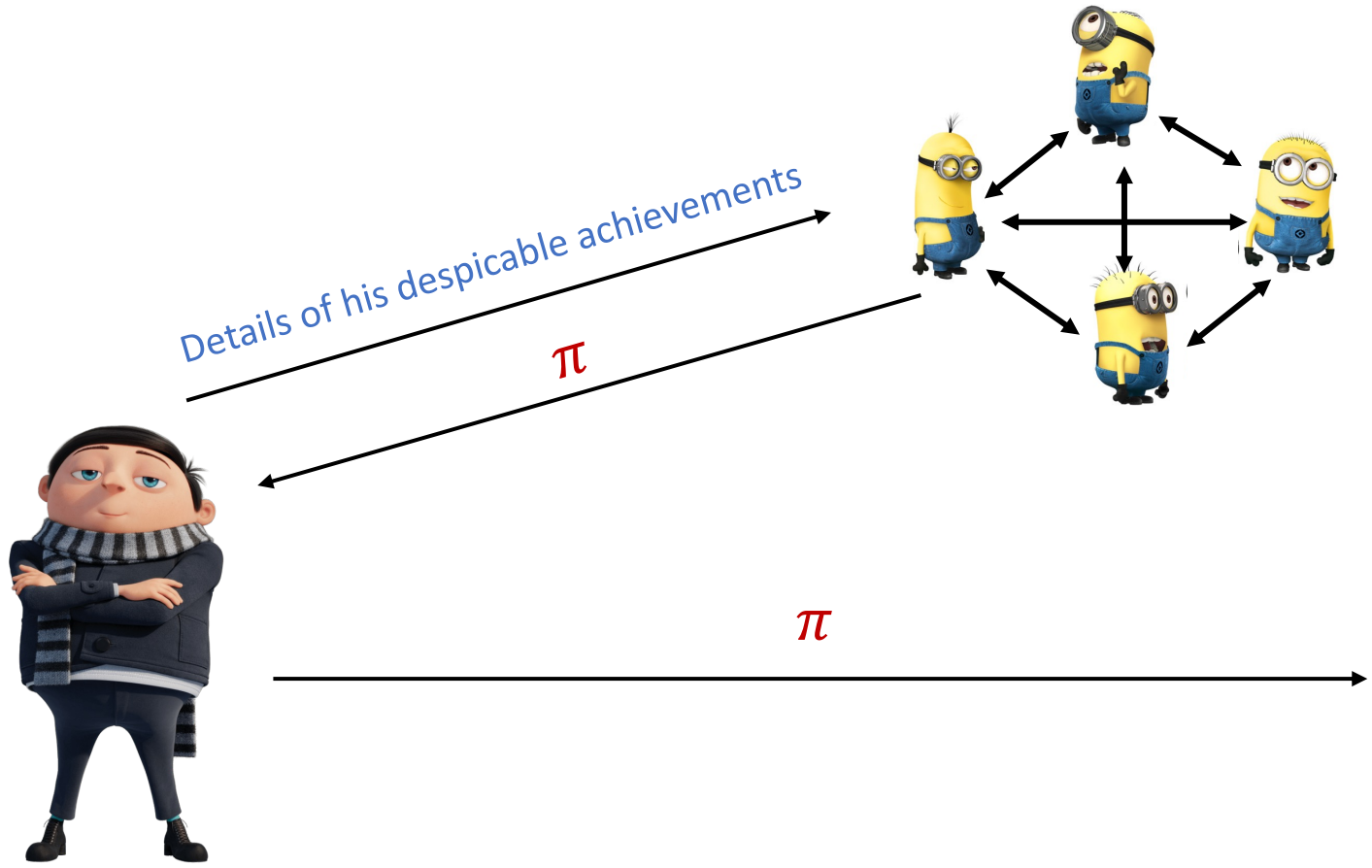


Violates Privacy!!: Requires leaking the entire witness to AWS

Gru: Rising Villain

Vicious 6: A prolific set of Supervillains

Can Gru Delegate zk-SNARK Computation?



Delegate to a group of minions who run an MPC to compute the zk-SNARK

Each minion only gets a share of the witness

Gru: Rising Villain

Vicious 6: A prolific set of Supervillains

Can Gru Delegate zk-SNARK Computation?

Delegate to a group of minions who run an MPC to compute the zk-SNARK

Each minion only gets a share of the witness

Details of his despicable achievements

π

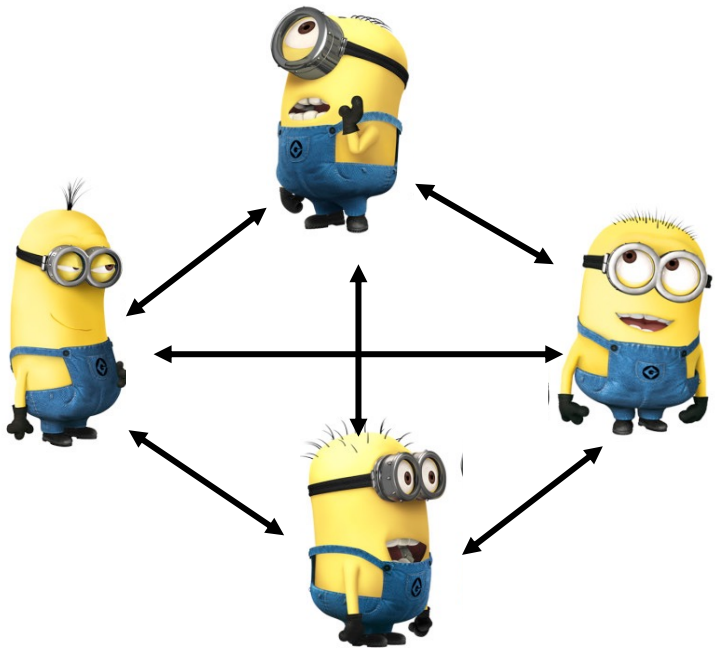
Collaborative zk-SNARKs [OB22]

π

Gru: Rising Villain

Vicious 6: A prolific set of Supervillains

Collaborative zk-SNARKs [OB22]



Efficient MPC for computing zk-SNARKs

Privacy

Each party does work proportional to a single prover

Wasteful

[WZCAS18] leverage parallelism to distribute work across machines in a compute cluster to get faster proof generation

Not Privacy Preserving

Our Goal

Better utilization of resources of the parties in collaborative zk-SNARKs, for faster proof generation, in a privacy-preserving manner

Our Results: zkSaaS

Framework	For privacy preserving delegation of zk-SNARK computation. Each servers is expected to run for a shorter duration than a single local prover.
Design	Design zkSaaS for Groth16 [Gro16], Marlin [CHMMVW20] and Plonk [GWC19].
Implementation	Implement a prototype of zkSaaS for Groth16, Plonk and get $\approx$ 22× speed-up when run with 128 parties for $2^{21} - 2^{25}$ constraints

zkSaaS Framework

Typical zk-SNARKs

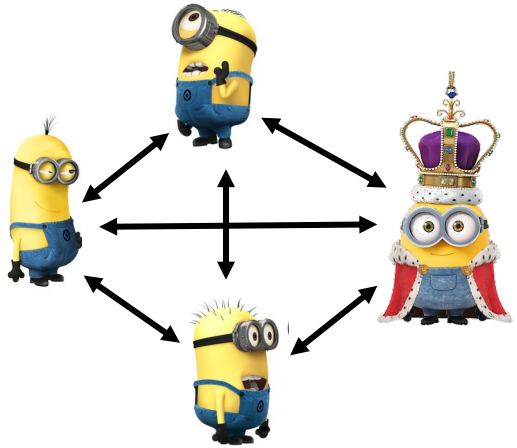
Step 1: Computing Extended Witness

Step 2: Generating Proof
(Cryptographic Operations + Field Operations)

Pre-Processing: each server gets a part of the correlated randomness

Secret Shares "Extended Witness"

π



Cryptographic Operations get equally divided amongst all servers

Field Operations get equally divided amongst small servers. King does work linear in the number of field operations.

Client computes Step 1

Servers collectively compute Step 2

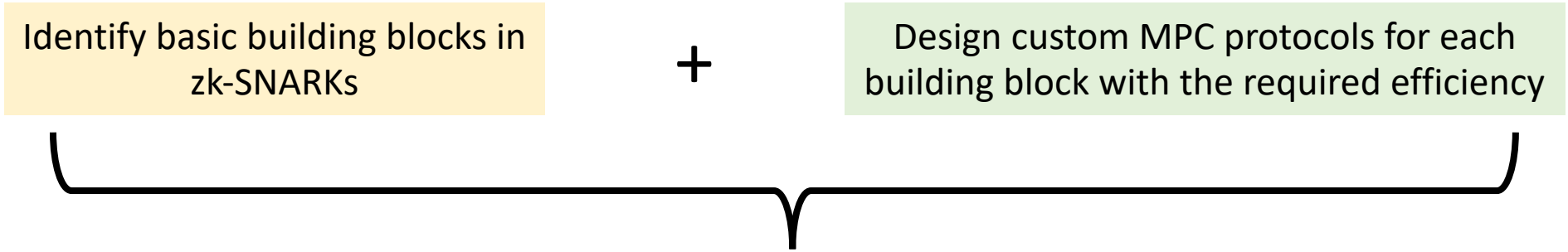
Applicability of zkSaaS

To aid users with small devices

For extremely large computations

Designing zkSaaS

General Template [OB22]



Building Blocks in Groth16, Marlin, Plonk

Multi-Scalar Multiplications (MSM)

$$F(g_1, \alpha_1, \dots, g_m, \alpha_m) = \prod_{i \in [m]} {g_i}^{\alpha_i}$$

Partial Products

$$F(x_1, \dots, x_m) = \left(\prod_{i \in [j]} x_i \right)_{j \in [m]}$$

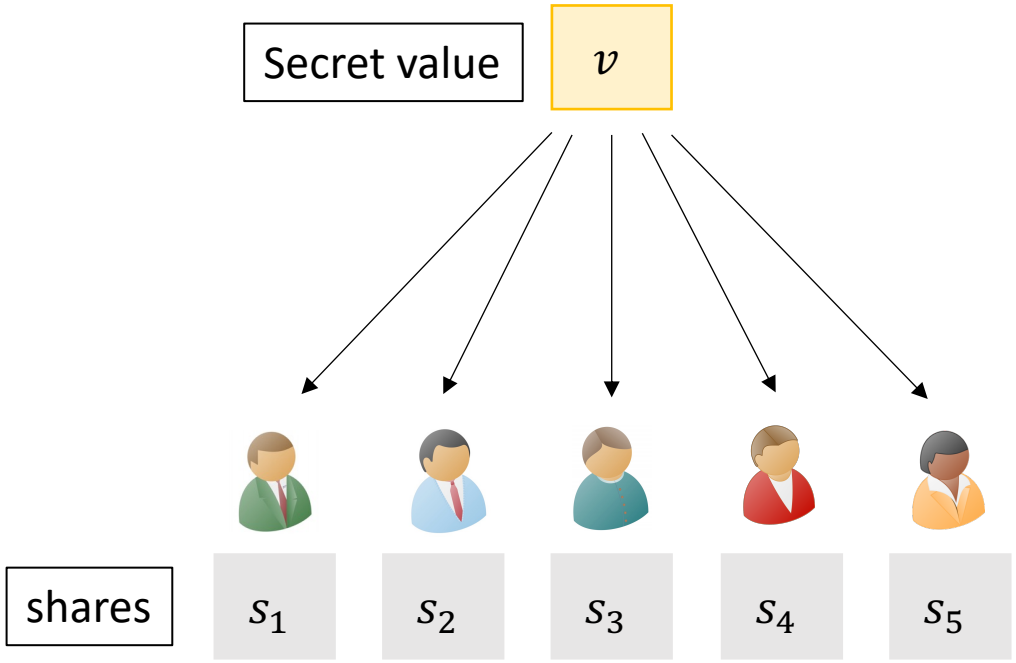
Fast Fourier Transform (FFT)

For converting between coefficient and evaluation representation of polynomials

Polynomial Multiplication and Division

A combination of addition, multiplication and FFT operations

Packed Secret Sharing (PSS) [FY92]

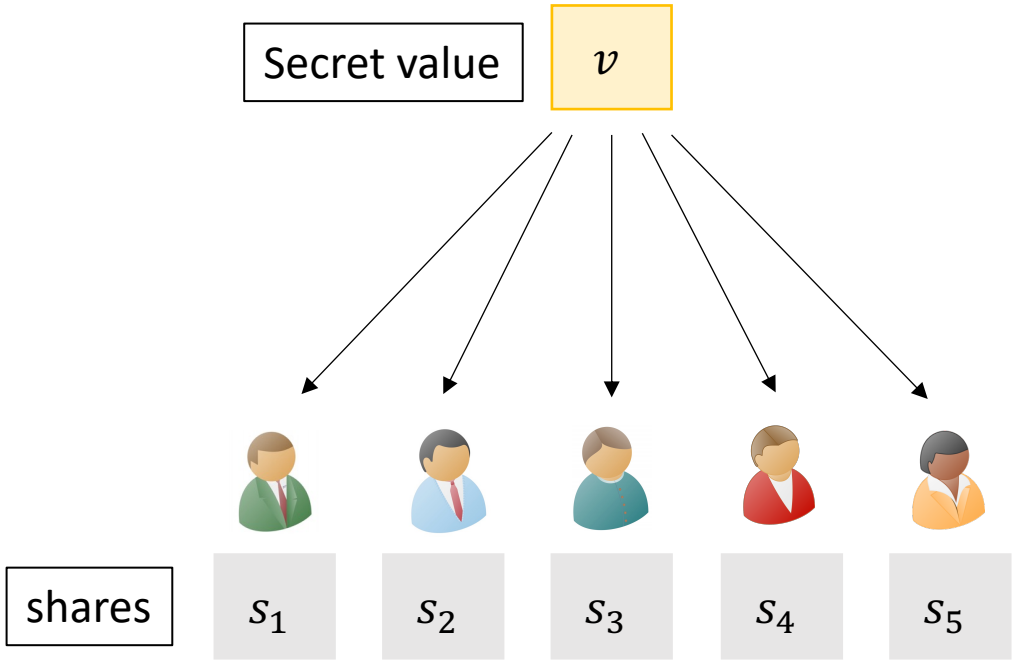


Regular Secret Sharing

1 Value → n shares

Corruption threshold: $t < \frac{n}{2}$

Packed Secret Sharing (PSS) [FY92]



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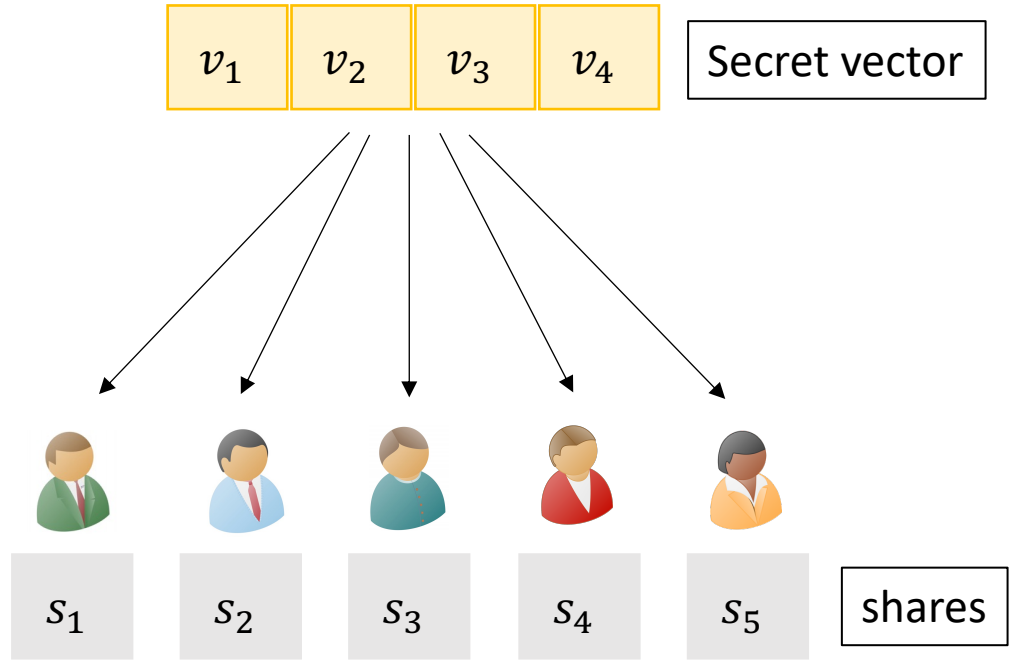
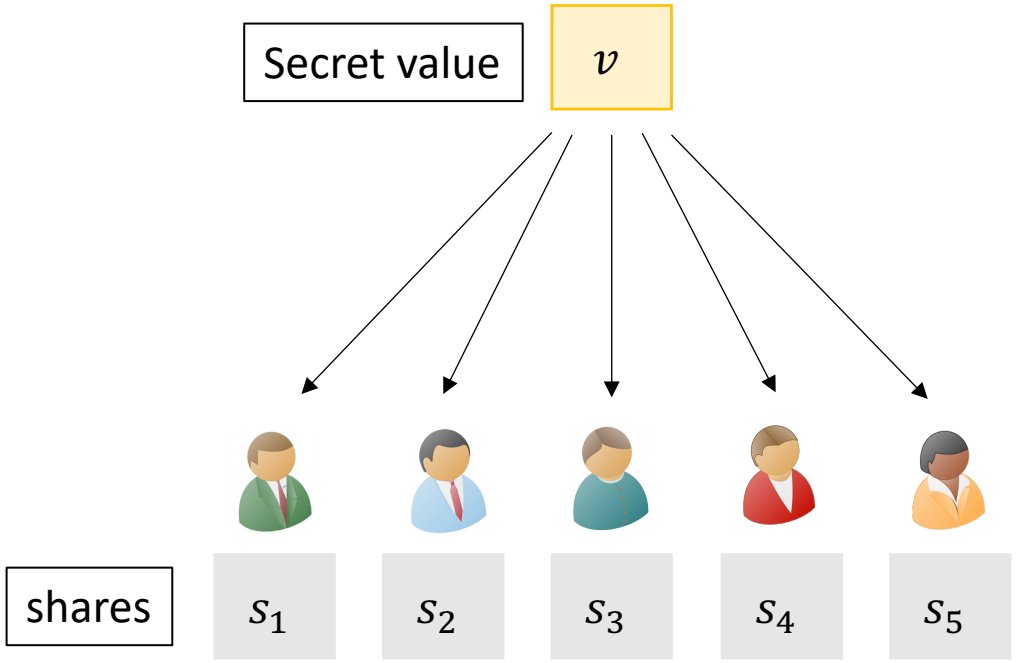


Packed Secret Sharing

$O(n)$ Values → n shares

Packed Secret Sharing (PSS) [FY92]



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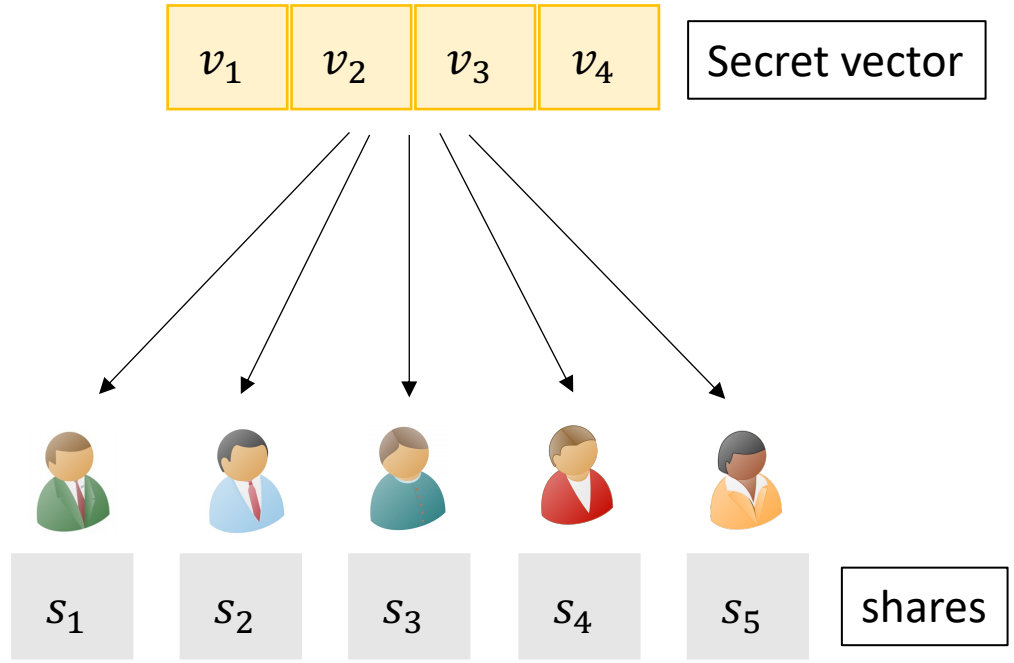


Packed Secret Sharing

$O(n)$ Values → n shares

Corruption threshold $t < n(\frac{1}{2} - \frac{1}{\varepsilon})$

Experimental Results

zkSaaS for Groth16: Setup

N1 GCP Instances

Local Prover

1vCPU and 4 GB RAM

zkSaaS Servers

96vCPU and 128 GB RAM

1vCPU and 2 GB RAM each

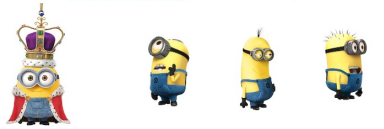
zkSaaS for Groth16

No. of Servers = 128
Packing constant = 32
No. of corrupt servers =31

Local Prover

1vCPU and 4 GB RAM

zkSaaS Servers



96vCPU and 128 GB RAM

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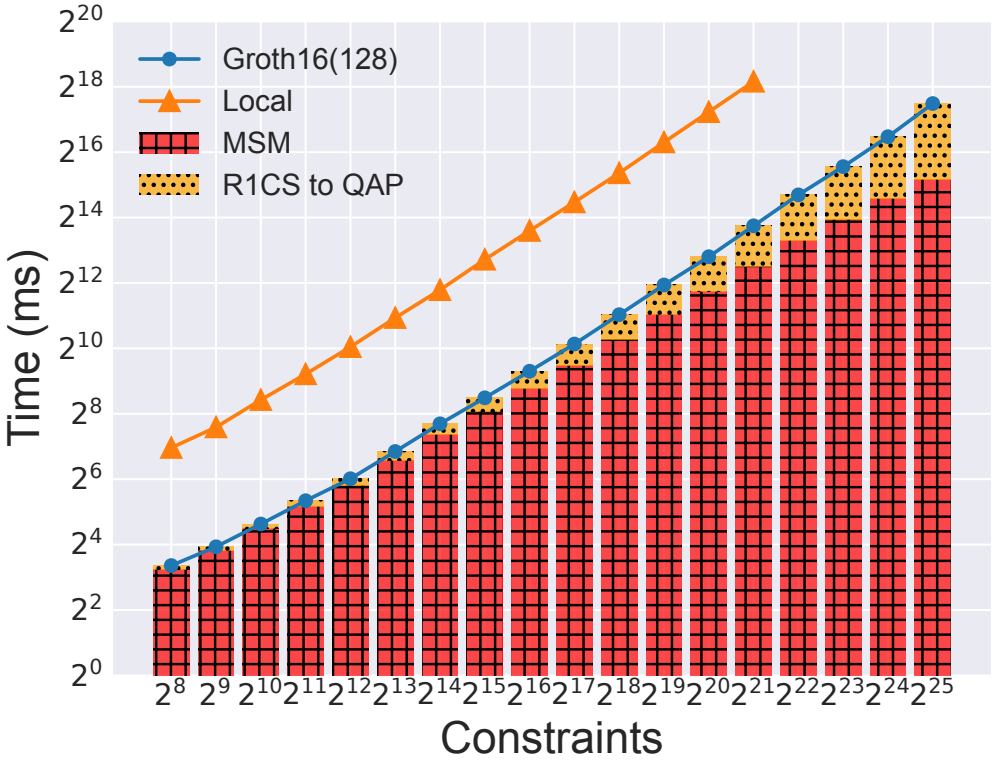


Memory Exhaustion

Weak servers can handle 16 times more constraints than consumer machine before running out of memory

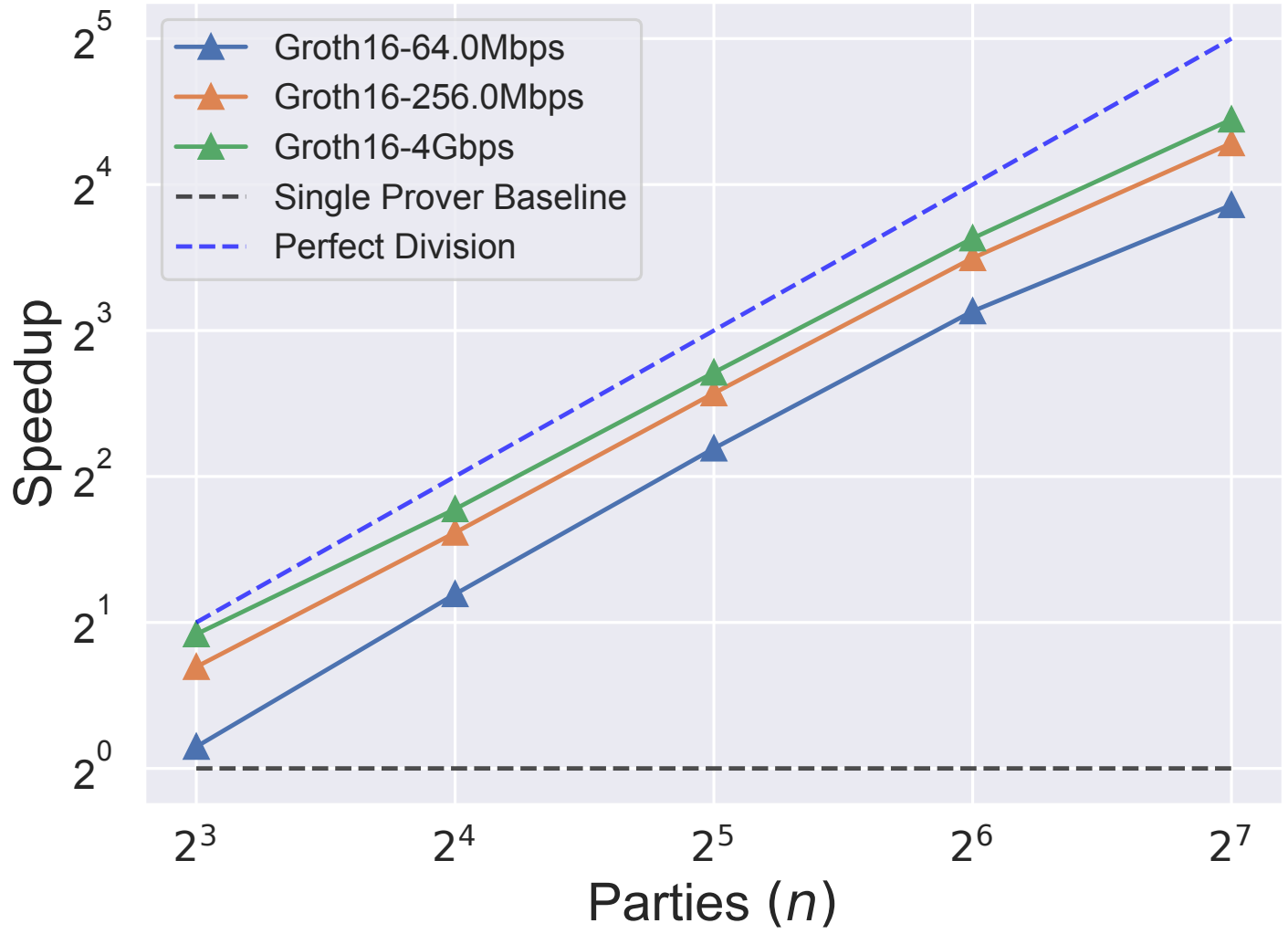
Running Time

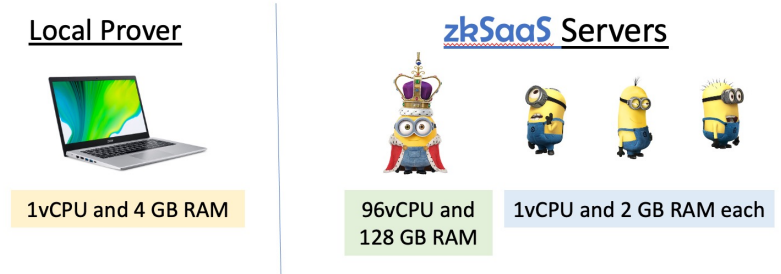
We get ≈ 22× speed-up over consumer machine

Why not 32 times?

1. FFT doesn't achieve equal division of work
2. Sub-optimal use of Pippenger's algorithm for MSMs

zkSaaS for Groth16





No. of Constraints = 2^{19}
Packing constant = n/4
No. of corrupt servers = n/4

Paper

Code

Thanks!

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https://aarushigoel.github.io/