zkSaaS

Zero-Knowledge SNARKs as a Service

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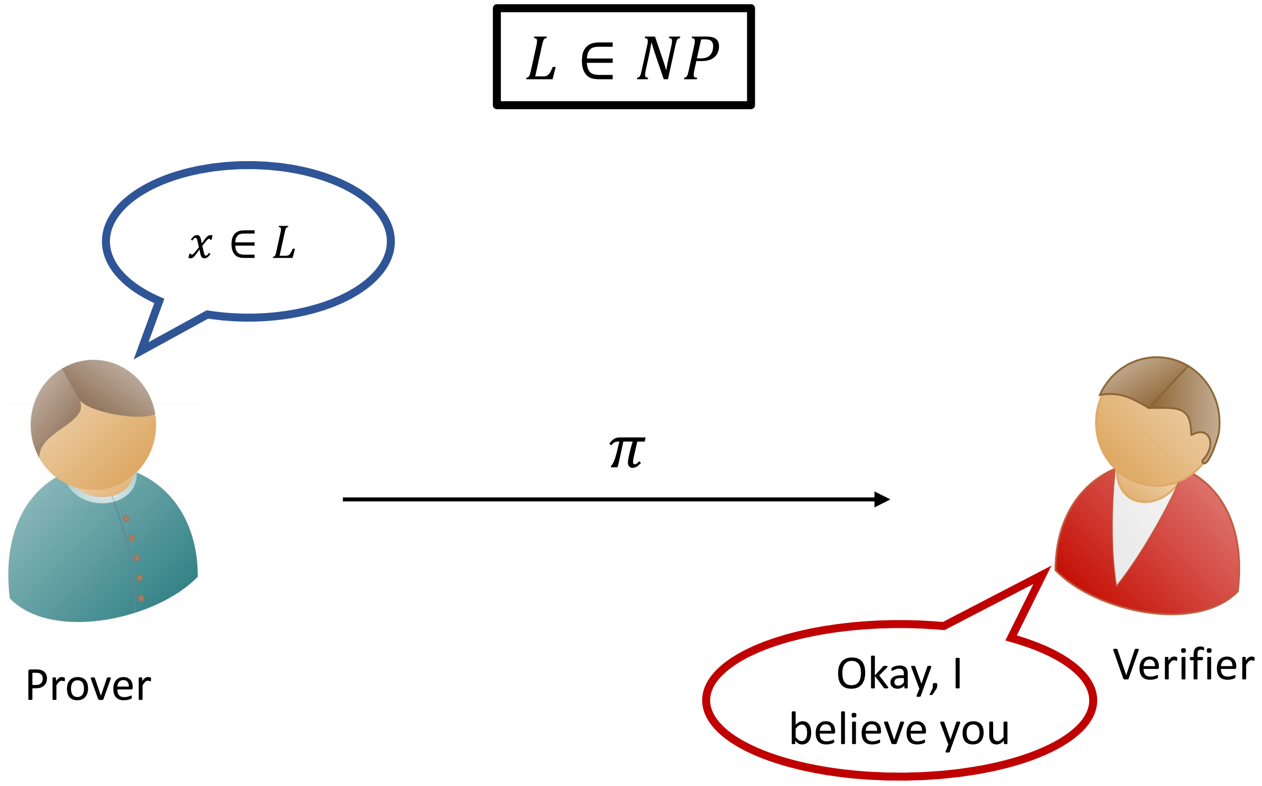
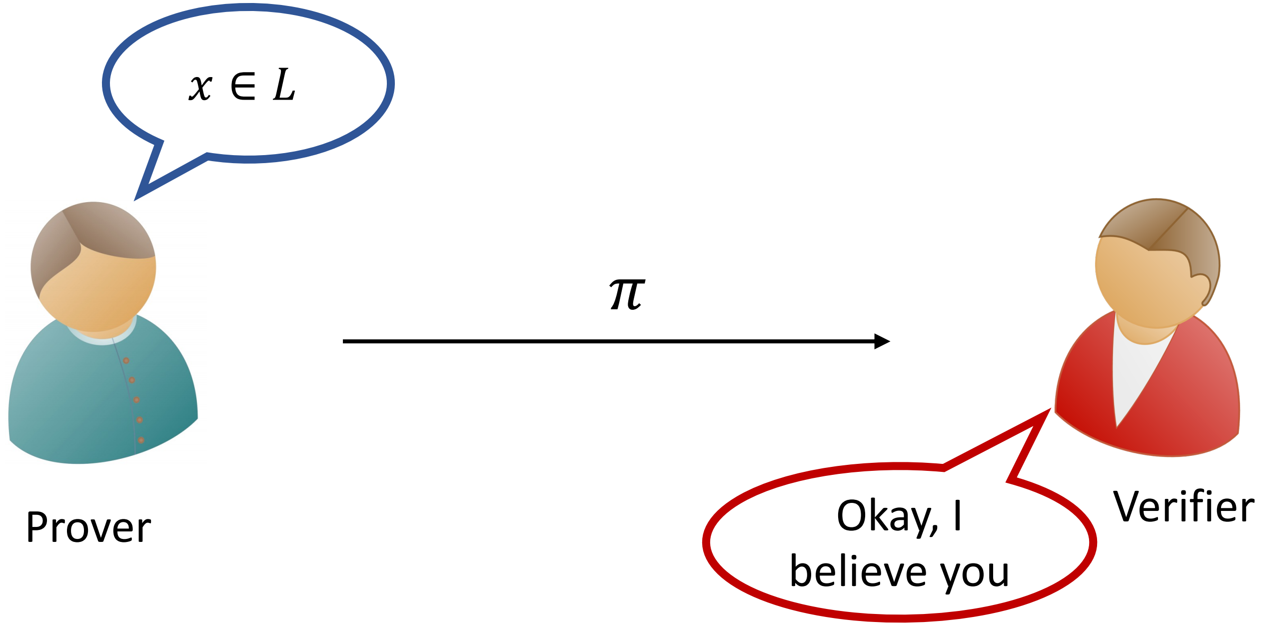
zk-SNARKs: Zero-Knowledge Succinct Non-Interactive Arguments of Knowledge



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

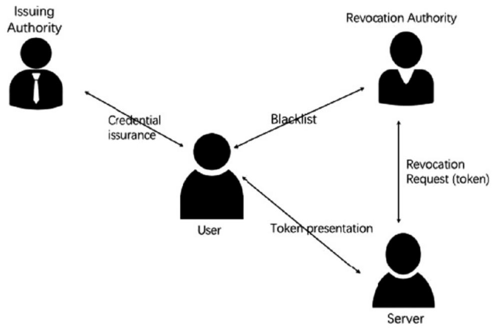
Soundness

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]

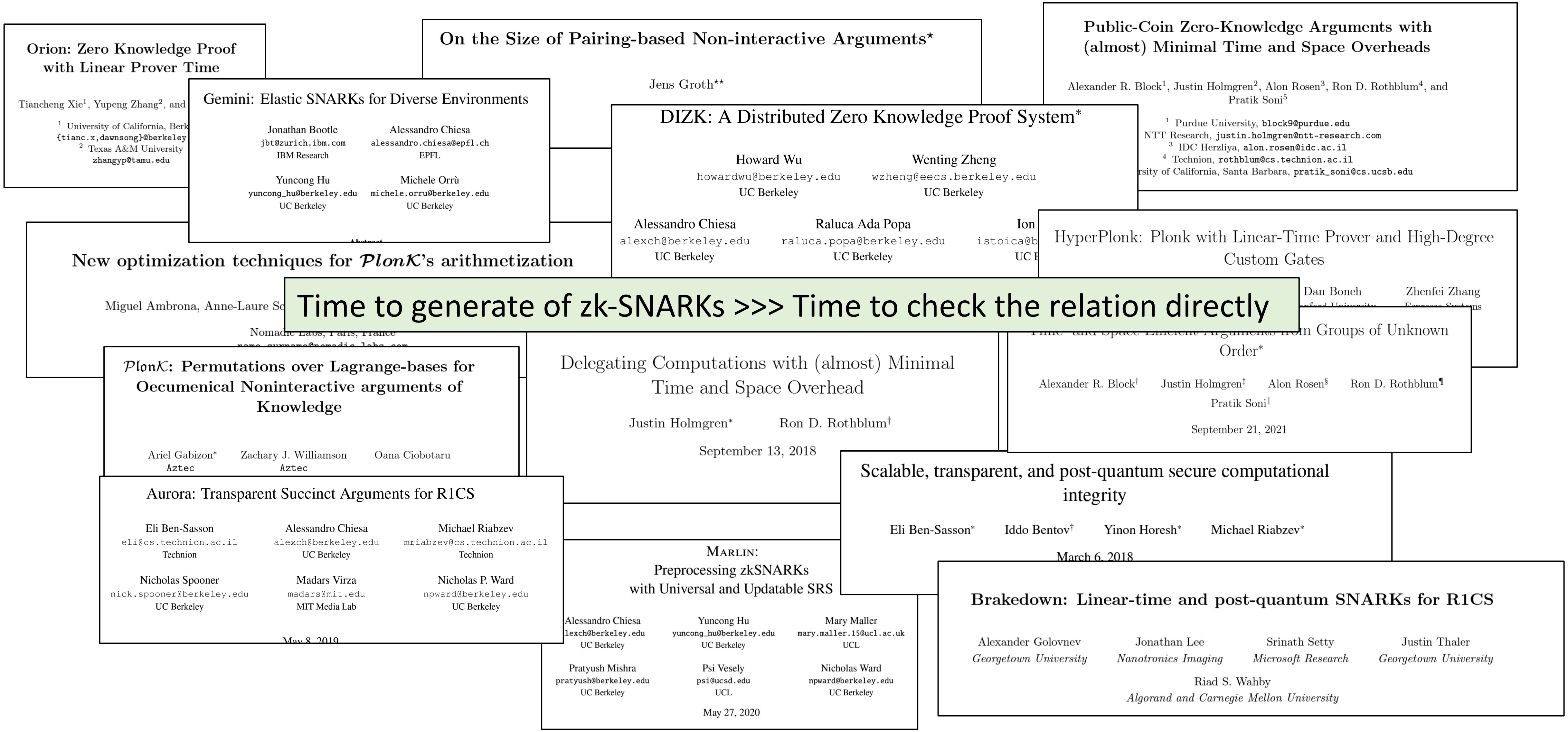
Private Smart Contracts [BCGMMW20]

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



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?

aws

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

Details of his despicable achievements

π

zk-SNARK attesting to his achievements

π

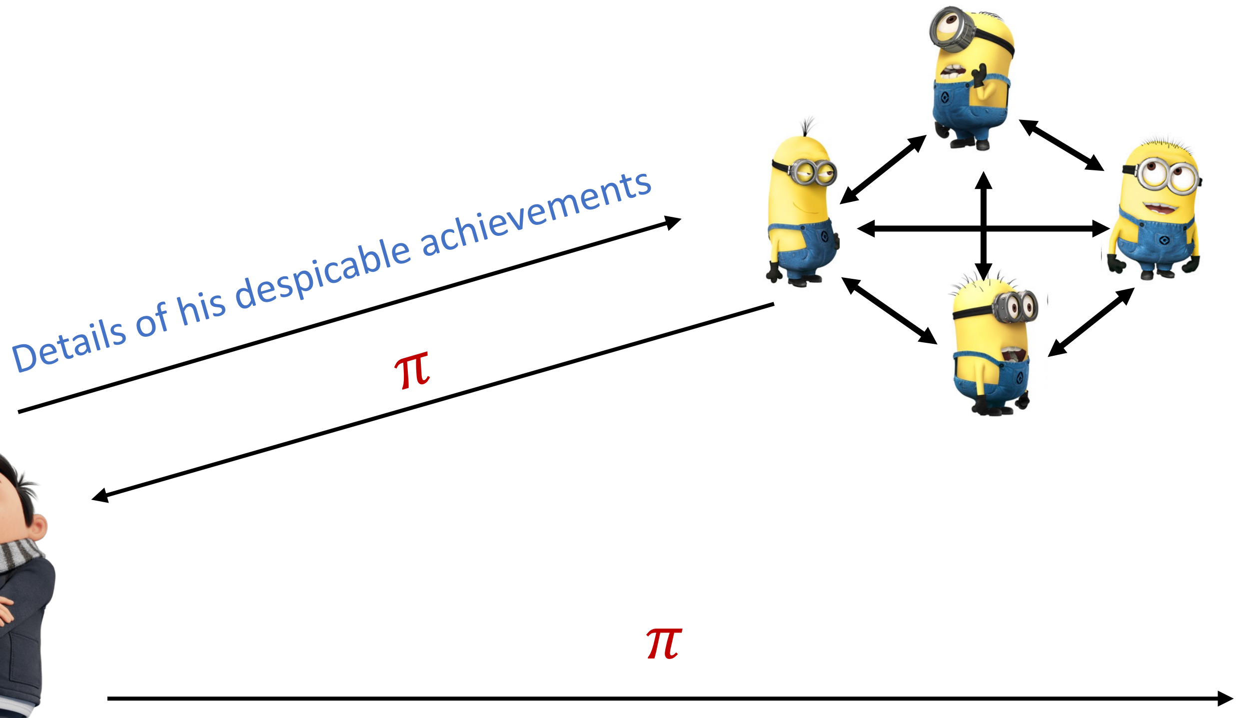
Gru: Rising Villain

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

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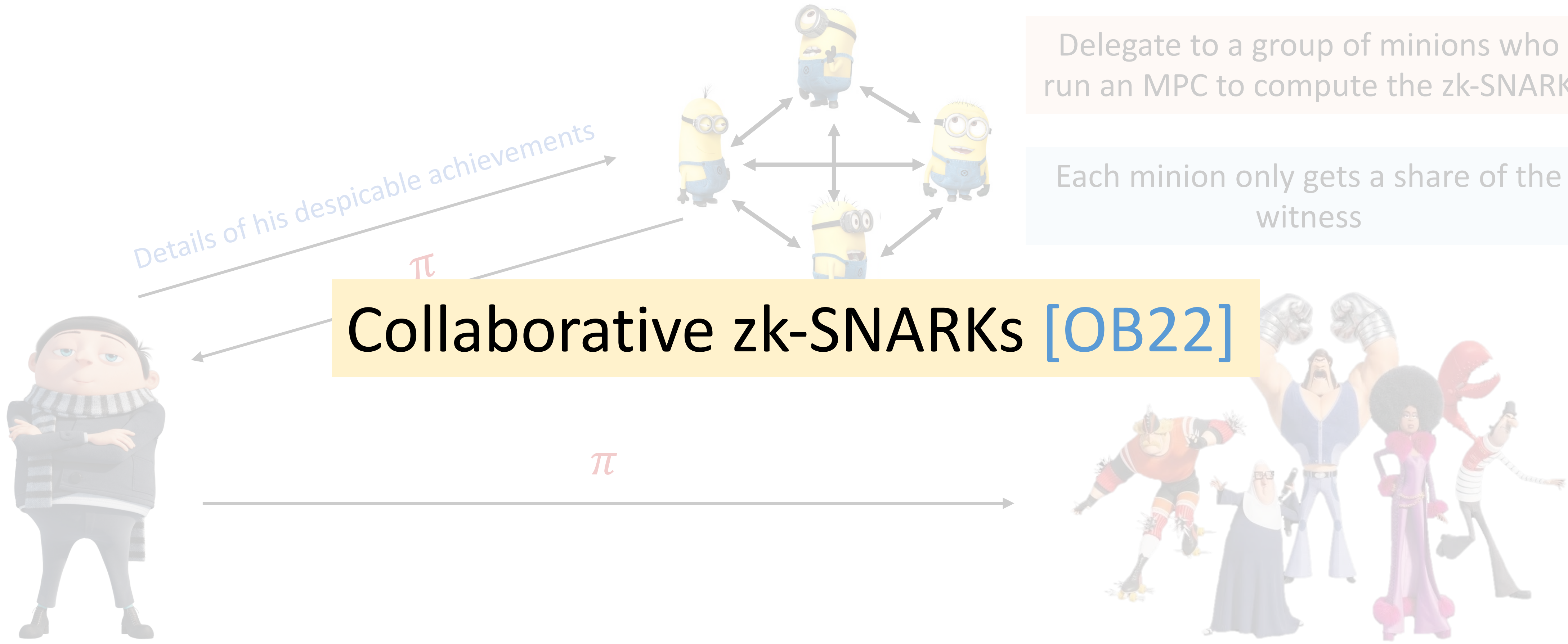

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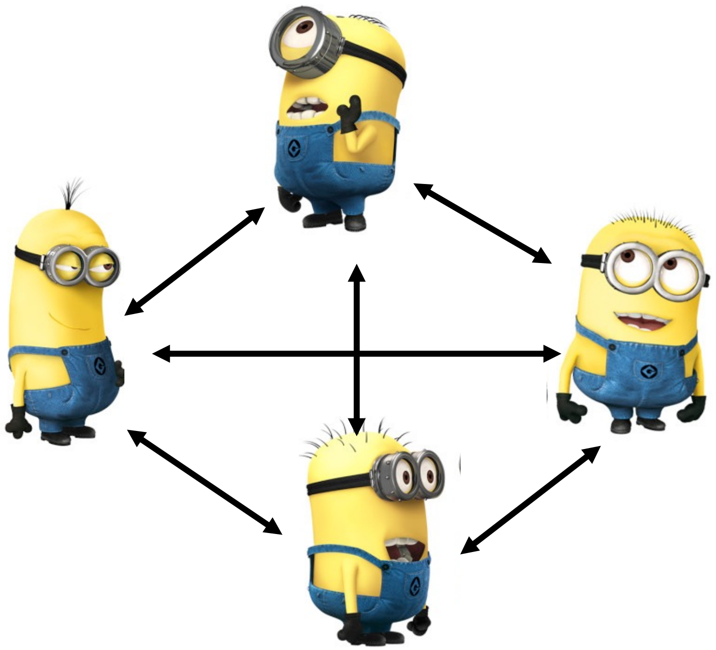
Collaborative zk-SNARKs [OB22]

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
$\approx$ $22\times$ speed-up when run with 128 parties for $2^{21} - 2^{25}$ constraints

zkSaaS Framework

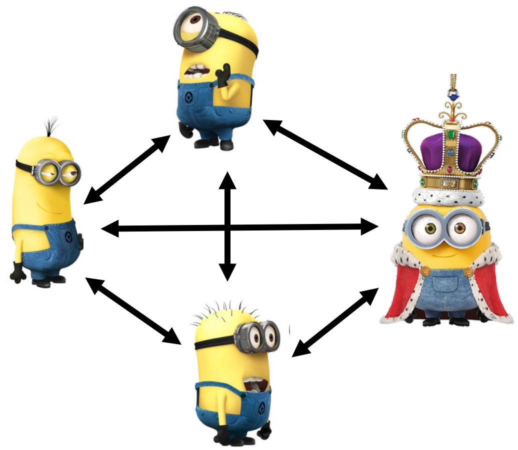
Typical zk-SNARKs

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



Client computes Step 1

Servers collectively compute Step 2

zkSaaS Framework

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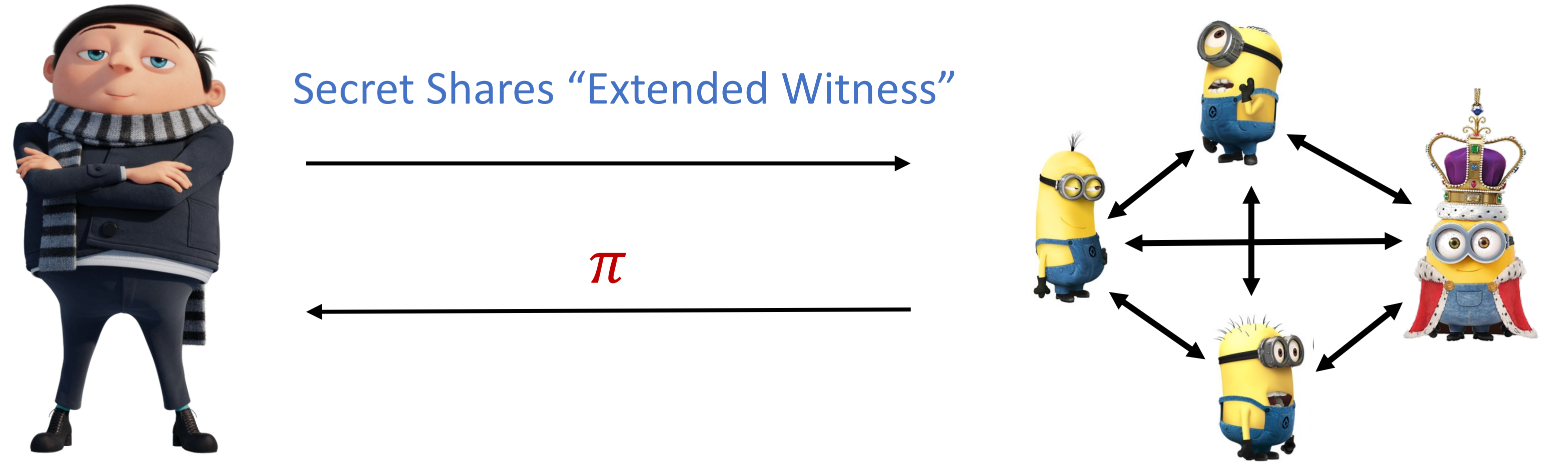


Cryptographic Operations get equally divided amongst all servers

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]

Identify basic building blocks in zk-SNARKs

+

Design custom MPC protocols for each building block with the required efficiency

Combine them to get a **zkSaaS** for the corresponding zk-SNARK

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

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

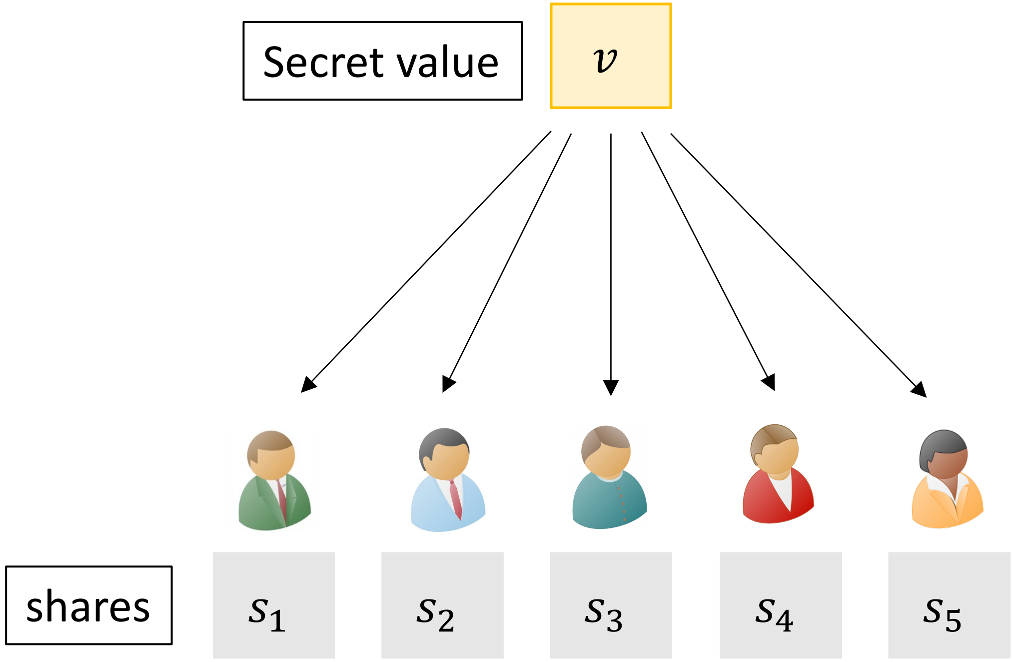
Fast Fourier Transform (FFT)

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

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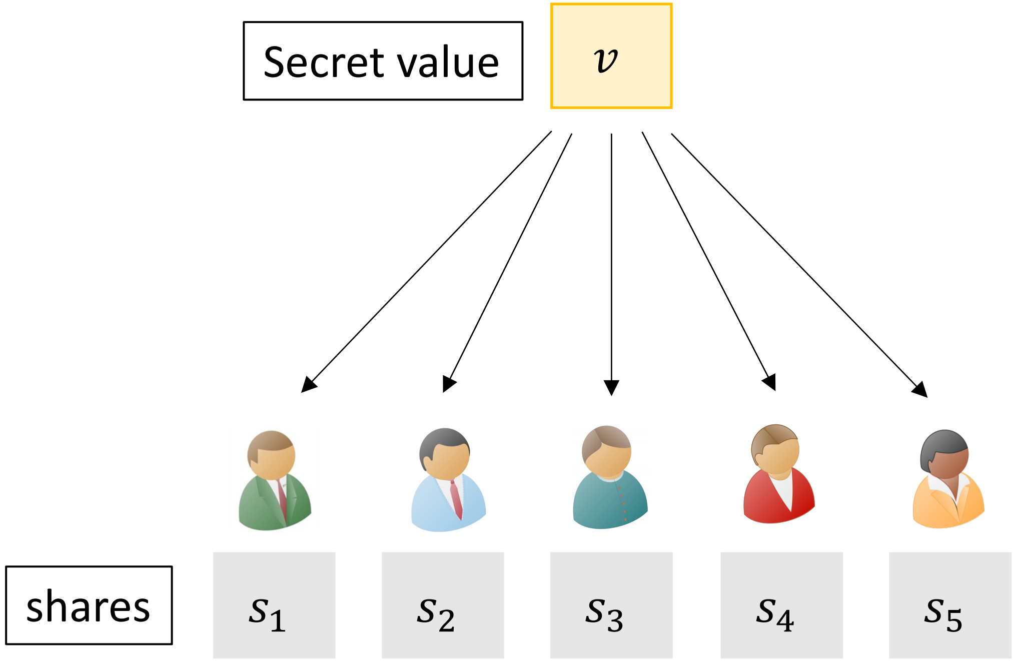

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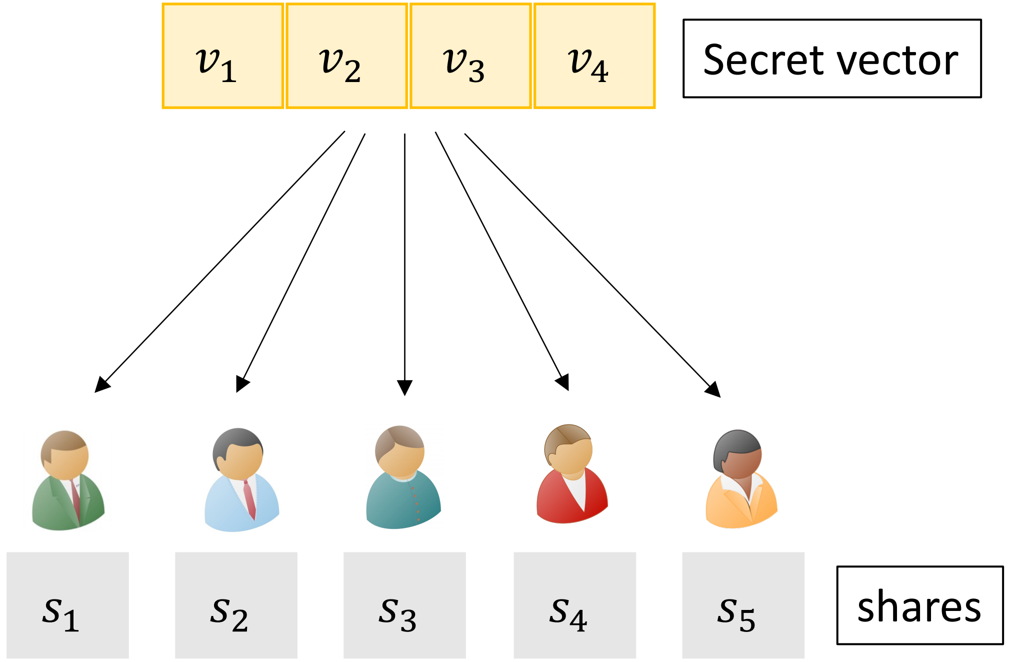

Packed Secret Sharing

$O(n)$ Values → n shares

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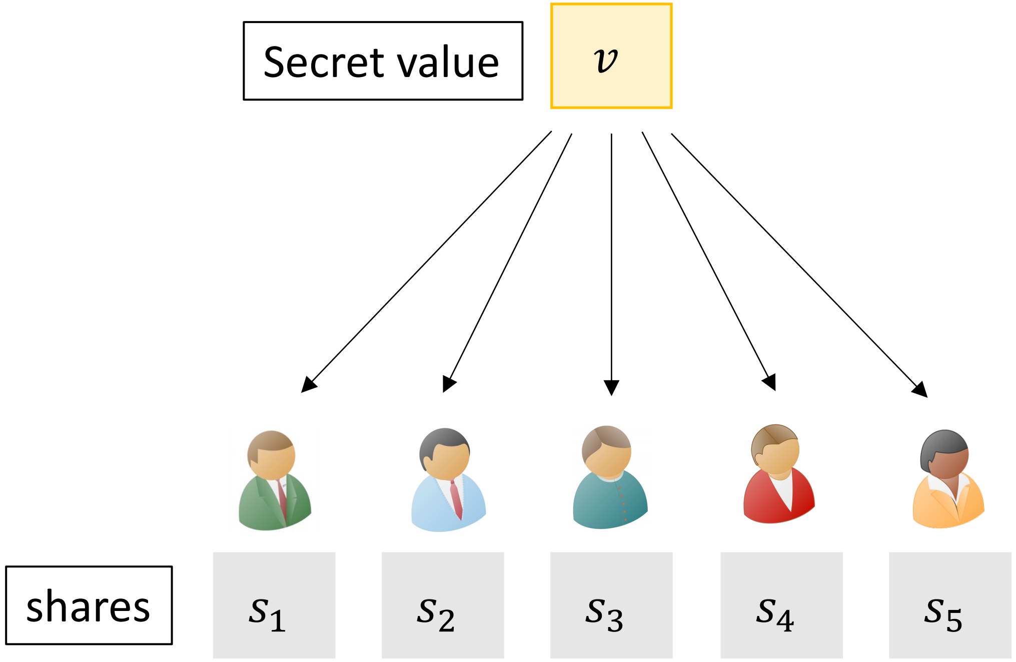

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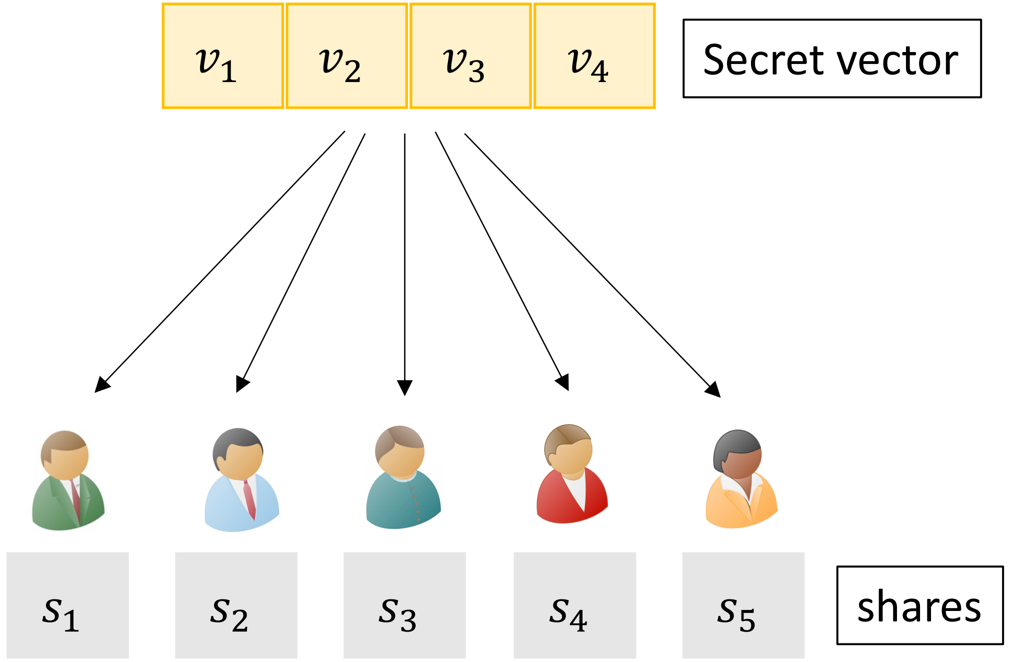


Packed Secret Sharing

$O(n)$ Values → n shares

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

Experimental Results

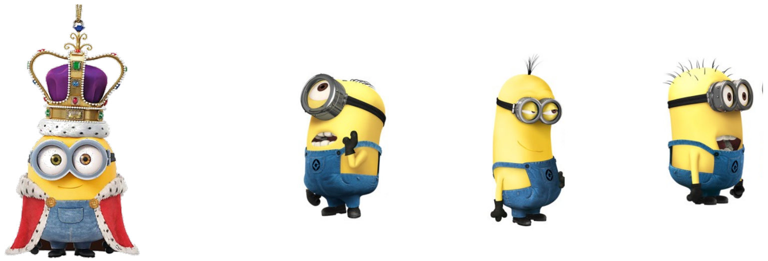
zkSaaS for Groth16: Setup

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

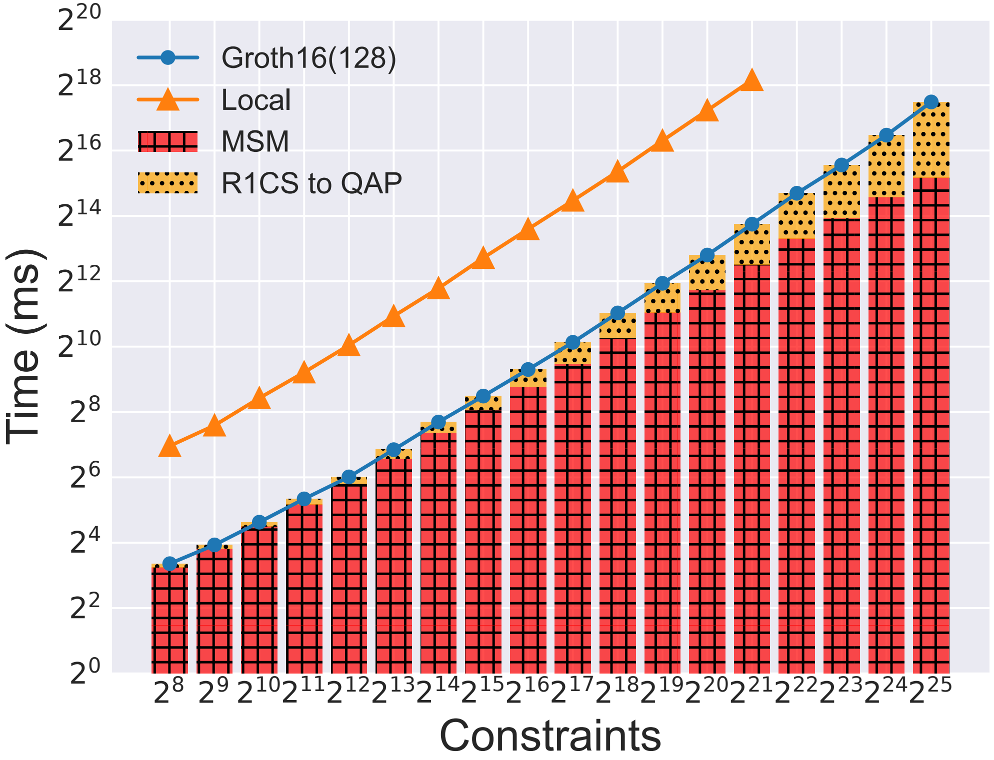
Local Prover

1vCPU and 4 GB RAM

zkSaaS Servers

96vCPU and 128 GB RAM

1vCPU and 2 GB RAM each



Memory Exhaustion

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

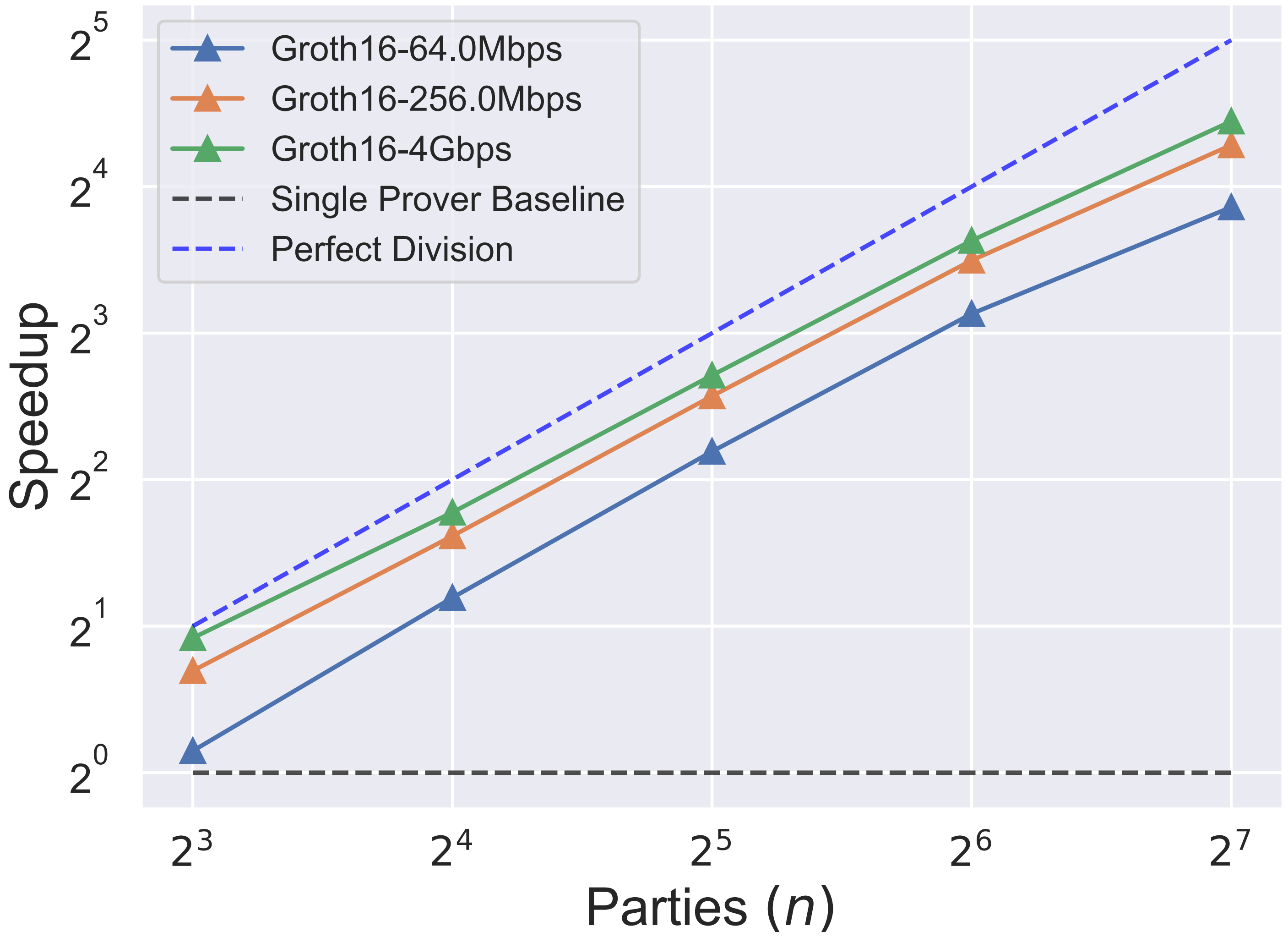
Running Time

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



Local Prover

1vCPU and 4 GB RAM

zkSaaS Servers

96vCPU and 128 GB RAM

1vCPU and 2 GB RAM each

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/