From NAND to Verifiable TETRIS

INGONYAMA

Omer Shlomovits , ZKProof 5 Workshop

Scope

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Algorithms	Software	Hardware

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Groth16		

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- For HW to make sense, we must focus on real-world systems
- Bias towards SNARKs, STARKs
- Proving time is the main bottleneck

ZK Hardware Landscape

Much action, much stealth

PipeZK: Accelerating Zero-Knowledge Proof with a Pipelined Architecture

Ye Zhang[1,5] Shuo Wang[1] Xian Zhang[3] Jiangbin Dong[4,7] Xingzhong Mao[7] Fan Long[6]
Cong Wang[8] Dong Zhou[2] Mingyu Gao[2,7*] Guangyu Sun[1*]

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PipeMSM: Hardware Acceleration for Multi-Scalar Multiplication

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cuZK: Accelerating Zero-Knowledge Proof with A Faster Parallel Multi-Scalar Multiplication Algorithm on GPUs

Tao Lu, Chengkun Wei, Ruijing Yu, Yi Chen, Li Wang, Chaochao Chen,
Zeke Wang, and Wenzhi Chen

ZPRIZE

Prizes

* General interest prize category for public goods which benefit multiple protocols/proof systems

OPEN DIVISION	OPEN DIVISION	OPEN DIVISION
Accelerating MSM Operations on GPU/FPGA	Accelerating NTT Operations on an FPGA	Plonk-DIZK GPU Acceleration

PRIZE AMOUNT **$1,250,000 USD**

Why Hardware Acceleration

A brief detour into gaming

Quake, 1997

Call of Duty, 2022

The difference - GPU

Multiplayer games

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Happy to Discuss!

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- **ZK MLaaS of ImageNet scale inference:** 2457[s] proving time at <80% accuracy [3]
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Answer: We are not far!

ZPU

Zero-Knowledge Processing Unit

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1. What goes into a ZPU? (hint: standardization can help)
2. What can be done until we have ZPUs?

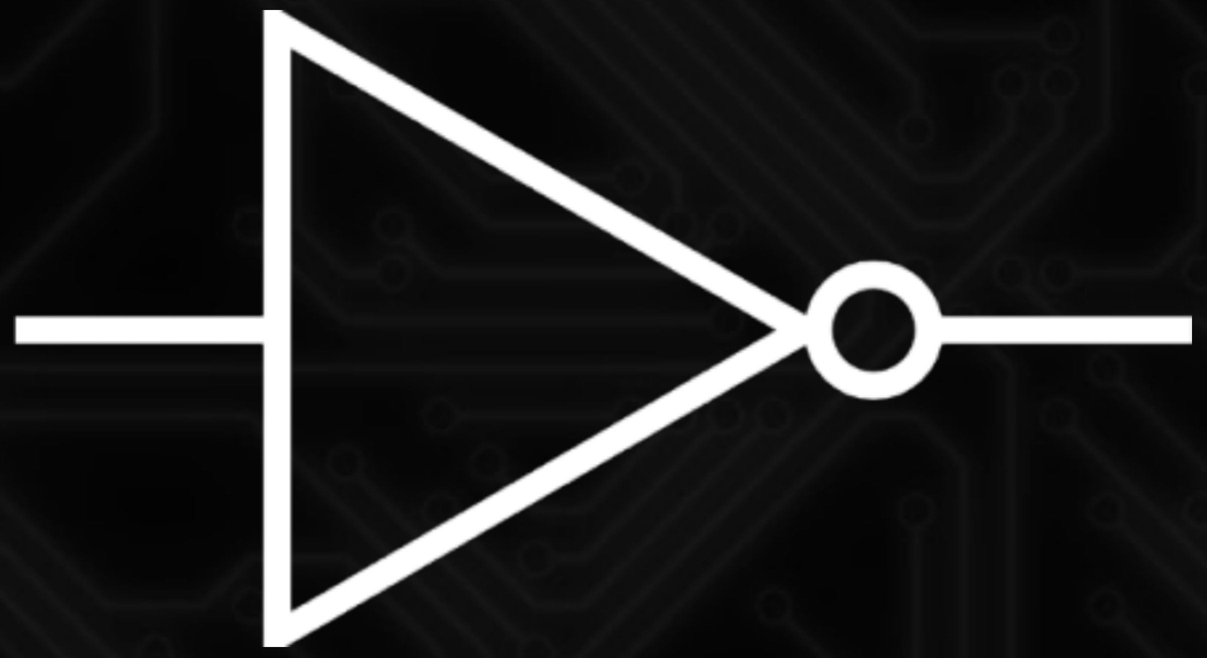
ZPU

How to identify one when you see one?

ZPU

How to identify one when you see one?

- AES-NI but for ZK
  - Fixed standardized algorithm vs. moving, evolving target
- A dedicated CPU
  - Good for integer and bitwise arithmetic, we work with finite fields



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- Polynomial arithmetic over finite field(s) (FFT acceleration)
- Elliptic curve(s) operations acceleration (MSM acceleration)
- Vectorized arithmetic (Hash function(s) acceleration)

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Small area
Less performance
Less Power

Large area
More performance
More Power

Prioritized list for standardization for ZKProof6

Opinionated list!

- Finite Field/s arithmetic:
  - (e.g. 64bit prime vs. 256bit prime)
  - Elliptic Curve
- NTT-less (STARK vs. SNARK)
  - Standardize Protocol/s
- Vector operations:
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  - Arithmetization (Plonk style vs. R1CS style)
- Range of circuit size

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What can be done today?

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- Do Science
- Build solutions on existing Hardware

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- More HW-Friendly ZK protocols
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Build

- Available Hardware
- What to build?
- Examples

Available Hardware

GPUs

FPGAs

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Name	FPGAs	vCPUs	Instance Memory (GiB)	SSD Storage (GB)	Enhanced Networking	EBS Optimized	On-Demand Price/hr*
f1.2xlarge	1	8	122	470	Yes	Yes	$1.65
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- Empirically: Gaming GPUs perform better
  - Cons: Form factor, Energy
- Open-source libraries: e.g. sppark, ec-gpu

ec-gpu & ec-gpu-gen

crates.io v0.2.0 docs passing circleci passing rustc 1.54+

crates.io v0.4.0 docs passing circleci passing rustc 1.54+

CUDA/OpenCL code generator for finite-field arithmetic over prime fields and elliptic curve arithmetic constructed with Rust.

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- Open-source

cloud-ZK

A toolkit for developing ZKP acceleration in the cloud

Build

- **Infra & Foundations**
  - Prover-as-a-Service
    - Decentralized Prover-as-a-Service
  - ZK marketplace
  - App-specific, e.g. Filecoin miner, Danksharding Builder
- **Frameworks Integrations**, e.g. Arkworks, Circom

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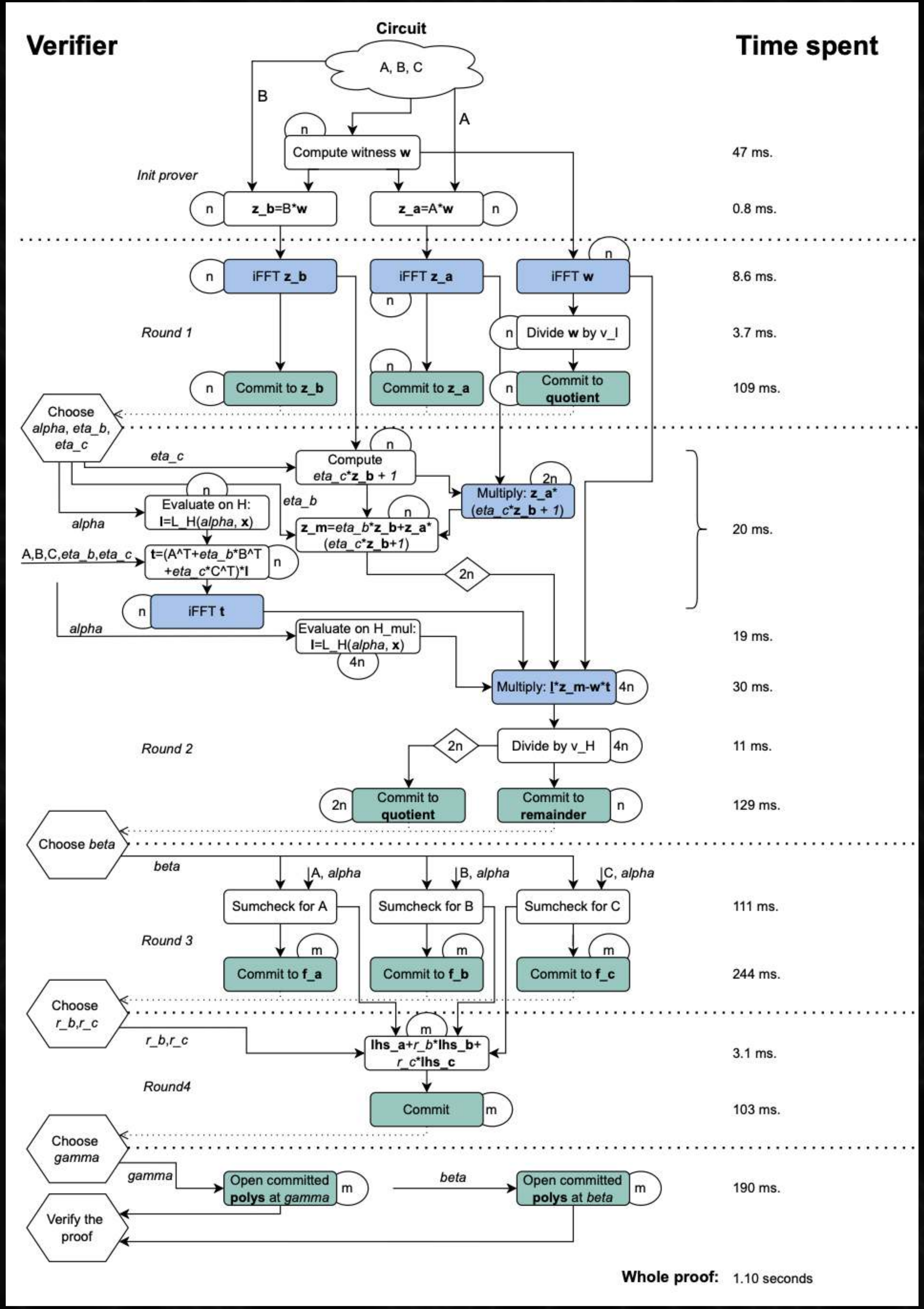

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CPU: 0.9 [proofs/sec]

HW: 8 [proofs/sec]

Example 2: Rapid RapidSnark

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rapidsnark

rapid snark is a zkSnark proof generation written in C++ and intel assembly. That generates proofs created in circom and snarkjs very fast.

https://github.com/iden3/rapidsnark

Example 2: Rapid RapidSnark

- A popular tool chain for ZK applications
- Optimized Groth 16
  - BN254
  - 4 MSMs with G1, 1 MSM with G2, rest are NTTs
- Dev-ops: Beefy CPU instance.
- Rapid RapidSnark
  - replace CPU with GPU/FPGA in the cloud (AWS)
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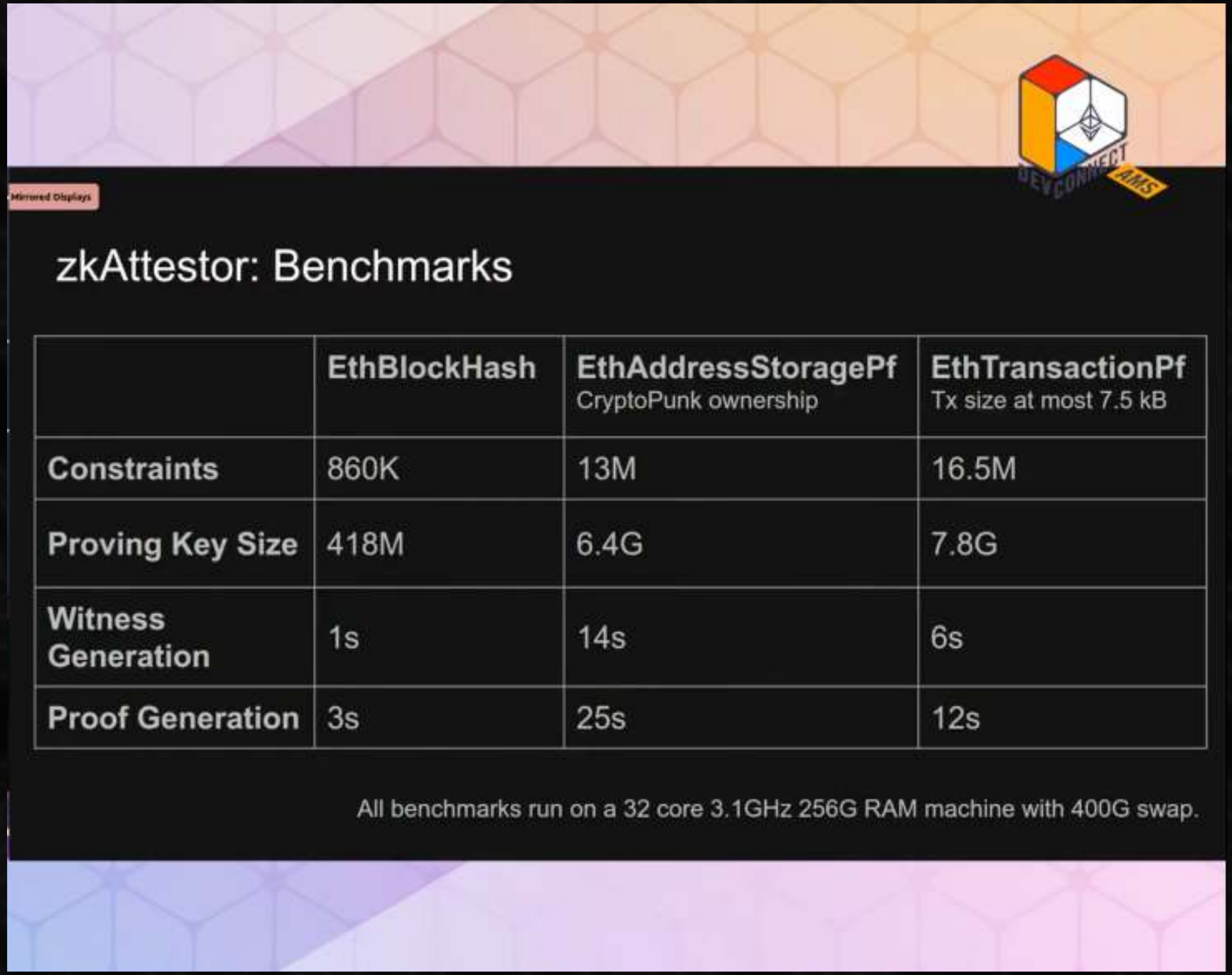

zkAttestor: Benchmarks

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Proving Key Size	418M	6.4G	7.8G
Witness Generation	1s	14s	6s
Proof Generation	3s	25s	12s

All benchmarks run on a 32 core 3.1GHz 256G RAM machine with 400G swap.

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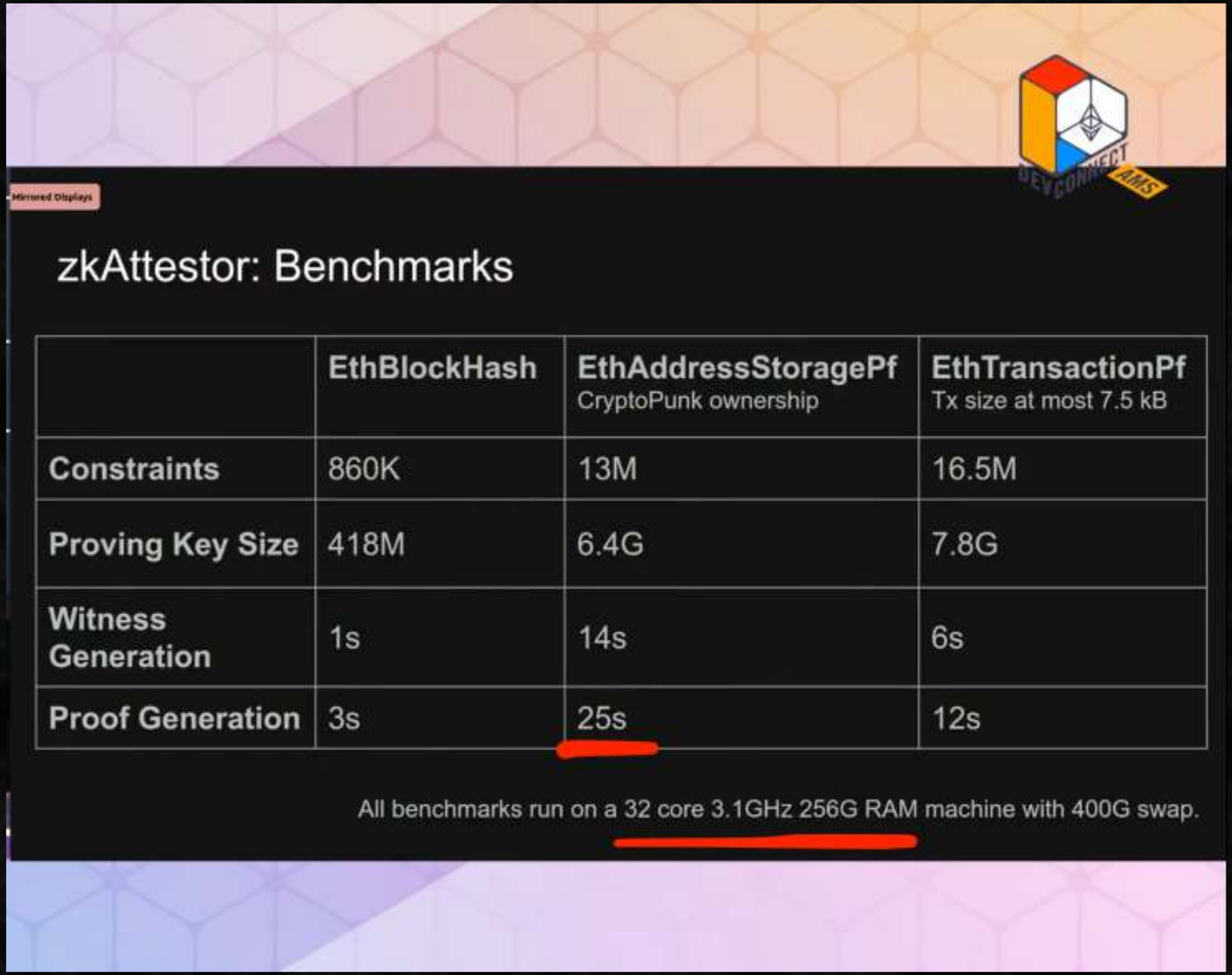
- Accelerated: G1,G2,NTT
- Challenges:
  - Two elliptic curves
  - Hardware is not fully utilized
  - NTT grows $O(n \log(n))$, MSM grows $O(n)$
- Metric: Latency, Throughput
- Result: 5x improvement (open source soon)



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