UltraGroth: Interactive Groth16

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Distributed Lab

distributedlab.com/
github.com/rarimo/ultragroth

Why we should care?

Range Checks

Problem

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Using quite unsophisticated math, $128 \times 10000 =$ **1.28 mln**.

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Result: We pay 65.5k constraints once and then every 128-bit range checks costs only 8 constraints instead of 128!

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$x =$

x_0	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}

16 constraints

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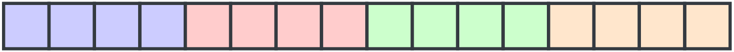

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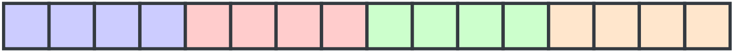

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Example: 10000 such range checks would cost $16 \times 10000 = 160\text{k}$ constraints for a regular R1CS while $2^4 + 4 \times 10000 \approx 40\text{k}$ constraints over ZK system with lookups.

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- Non-native field arithmetic: e.g., optimized ECDSA verification for Rarimo passport verification.
- And surely, zero-knowledge Machine Learning — Bionetta.

Framework	Metric	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	ResNet	MobileNet
Bionetta (UltraGroth)	Constraints #	68.4K	66.7K	106.8K	126.8K	108.4K	187.7K	1.03M	2.50M
	Proof Size (KB)	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
	PK (MB)	48.40	50.60	80.60	106.30	81.90	156.20	0.95GB	1.90GB
	VK (KB)	3.78	3.79	3.78	3.78	3.78	3.78	4.05	4.20
	Prove (s)	0.57	0.73	0.74	1.08	0.89	1.79	6.27	15.22
	Verify (s)	0.006	0.005	0.005	0.006	0.006	0.005	0.006	0.006
Bionetta (Groth16)	Constraints #	29.0K	5.9K	522.4K	779.4K	543.0K	1.56M	12.01M	31.78M
	Proof Size (KB)	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
	PK (MB)	21.30	10.20	396.20	560.20	409.30	1.2GB	≈9.0GB	≈23.8GB
	VK (KB)	3.65	3.65	3.65	3.65	3.65	3.65	≈4.0	≈4.0
	Prove (s)	0.12	0.27	2.19	2.20	2.22	4.72	≈180	≈480
	Verify (s)	0.006	0.006	0.006	0.006	0.006	0.005	≈0.005	≈0.006

Up to x12.7 boost in # of constraints!

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Surprising result: if the circuit consists of L range-checks, each costing b constraints, using lookup protocol, you can reduce $\mathcal{O}(n)$ constraints ($n = Lb$) down to $\mathcal{O}(n/\log n)$.

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Theorem (Some stuff from ZKDL Camp)

The inclusion check $\{z_i\}_{i\in[n]} \subseteq \{t_i\}_{i\in[v]}$ is satisfied if and only if there exists the set of multiplicities $\{\mu_i\}_{i\in[v]}$ where $\mu_i = \#\{j \in [n] : z_j = t_i\}$ such that for $\gamma \xleftarrow{\$} \mathbb{F}$:

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High-level idea: We can: (1) compute $\{\mu_i\}_{i\in[v]}$ off-circuit, (2) write circuit in $n + 2v$ constraints, given γ signal is passed randomly.

Circom-like Implementation

```
signal input t[M];          // The lookup table
signal random input gamma; // Random challenge value
signal input z[N];          // The array of values to check

var sum_z, sum_t = 0;
for (var i = 0; i < N; i++) {
    inv_z[i] <== 1 / (z[i] + gamma);
    sum_z += inv_z[i]; // Compute the left-hand side
}

for (var j = 0; j < M; j++) {
    mu[j] <-- 0; // Compute the multiplicities off-circuit
    for (var k = 0; k < N; k++) {
        mu[j] += (t[j] == z[k]);
    }
    inv_t[i] <== mu[j] / (t[j] + gamma);
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UltraGroth Explained

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One important consequence

The protocol is **safe**. It is sound and zero-knowledge! And it is now proven in **three** different independent papers.

UltraGroth Performance

Now, let us recap the **Groth16** performance over the circuit of size n and statement size ℓ.

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Recap: Proof in Groth16 consists of three points $g_1^{a(\tau)}$, $g_1^{c(\tau)}$, $g_2^{b(\tau)}$:

$$a(X) = \alpha + \sum_{i \in [n]} z_i \ell_i(X) + r\delta, \quad b(X) = \beta + \sum_{i \in [n]} z_i r_i(X) + s\delta,$$

$$c(X) = \delta^{-1} \left(\sum_{i \in \mathcal{I}_W} z_i \zeta_i(X) + h(X)t(X) \right) + a(X)s + b(X)r - rs\delta.$$

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The **verification equation** is:

$$e(\pi_A, \pi_B) = e(g_1^{\alpha}, g_2^{\beta}) \cdot e(g_1^{i(\tau)}, g_2^{\gamma}) \cdot e(\pi_C, g_2^{\delta}).$$

for $\pi_A = g_1^{a(\tau)}$, $\pi_C = g_1^{c(\tau)}$, $\pi_B = g_2^{b(\tau)}$, $i(X)$ is a polynomial derived from the public statement.

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Note: This construction can be easily generalized for $d > 1$ rounds.

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- Implemented a single-round UltraGroth (essentially, a Mirage protocol). Credits to Artem Sdobnov, Vitalii Volovyk, Yevhenii Sekhin, and Illia Dovgopoly.
  - Forked `rapidsnark`.
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- Proved completeness, soundness, and zero-knowledge for general d-round UltraGroth. Formalized everything properly.

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- Proved completeness, soundness, and zero-knowledge for general d-round UltraGroth. Formalized everything properly.
- Applied UltraGroth to Bionetta and obtained incredible results.

Any Questions?

♥

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github.com/rarimo/ultragroth