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STEALTH

SIEVE Circuit IR Specification

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James Parker (james@galois.com), **Kimberlee Model** (kimee@stealthsoftwareinc.com), Paul Bunn, David Darais, Daniel Genkin, Steve Lu, Tarik Riviere, Muthuramakrishnan Venkitasubramaniam, Xiao Wang, Steven Eker, Karim Eldefrawy, Stephane Graham-Lengrand, Vitor Pereira, Hadas Zeilberger, Michael Adjedj, Daniel Benarroch Guenun, Eran Tromer, Aurelien Nicolas, Constance Beguier, Alex Malozemoff, Chris Phifer, Mayank Varia

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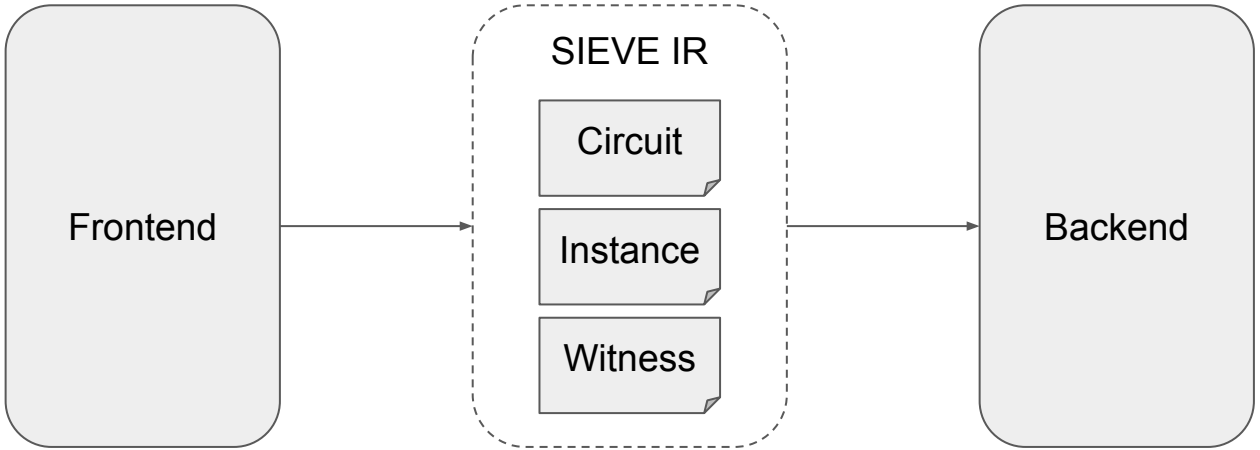
Background: SIEVE

- DARPA program focused on improving the utility and efficiency of (mostly interactive) ZK protocols
- Teams are split into two categories:
  - Frontends - Produce ZK statements for different applications
  - Backends - Efficiently verify ZK statements generated by frontends
- There are many frontend and backend teams, and they need a standard way to represent ZK statements

SIEVE Circuit IR



- Standardized circuit representation of ZK proofs
- Designed by a committee made up of all the SIEVE teams
- Enables backends to run all* ZK statements produced by frontends

Target Applications

- Proofs of software vulnerabilities
- Early focus on “really big” proofs
- Mobile <-> cloud proofs
- Policy Enforcement
  - Healthcare
  - Government Regulations
  - Transparency
  - Geo-fencing and location history

Why Circuits?

- **R1CS?**
  - Theoretically equivalent to Circuits
  - Practically not so equivalent
  - Round trip translation grows about 10x
- **Plonk-ish?**
  - Didn’t have name recognition when we started
- **Memory Efficiency**
  - Statement Streaming
  - Delete temporary wires
- **Multi Field Proofs (“field switching”)**
- **Flexibility & Scalability**
  - Expectation: Frontend research yields smaller circuits
  - Reality: Frontend research yields additional features with higher circuit density

Language Overview: Types

```
// Index 0: Boolean
@type field 2;

// Index 1: GF(2^63) with polynomial modulus x^63 + x + 1
@type ext field 0 63 0x8000000000000003;

// Index 2: Unsigned 32-bit integers
@type ring 32;
```

For some prime p and polynomial P, with coefficients $c_{0...n}$ we encode:

$$P = \Sigma c_i * p^i$$

- Supported types: prime fields, extension fields, rings
  - Circuits can contain multiple types in the same statement
  - Types are defined in the circuit header
  - Types are referenced by index

Language Overview: Gates

```
$0 <- @private(0);
$1 <- @private(0);

$2 <- @mul($0, $0);
$3 <- @mul($1, $1);
$4 <- @add($2, $3);

@assert_zero($4);
```

- Basic gates: `@add`, `@mul`, `@assert_zero`
- Read from witness or instance: `@private`, `@public`
  - Values are streamed from a separate file
- Text and flatbuffer representations

Language Overview: Functions

```
@function(dot_prod_10, @out: 1:1, @in: 1:10, 1:10)
    $21 <- @mul($1, $11);
    // ...
@end

$25 <- @call(dot_prod_10, $0 ... $9, $10 ... $19);
```

- Users can define and call function gates
  - Useful for frequently used subcircuits

Language Overview: Plugin Extensions

```
@plugin(ram, init,  <size>)
@plugin(ram, read,  <addr>)
@plugin(ram, write, <addr>, <value>)
```

- ZK is moving quickly, so the IR needs a way to support the latest features and protocols
- IR supports plugins, which allow users to define their own gadgets
  - Typically useful when backends have efficient protocols for specific operations
- Official plugins: RAM, permutations, iterators, vectors, arithmetic
- Unofficial plugins: Polynomial equality checks, disjunctions

Language Overview: New and Delete

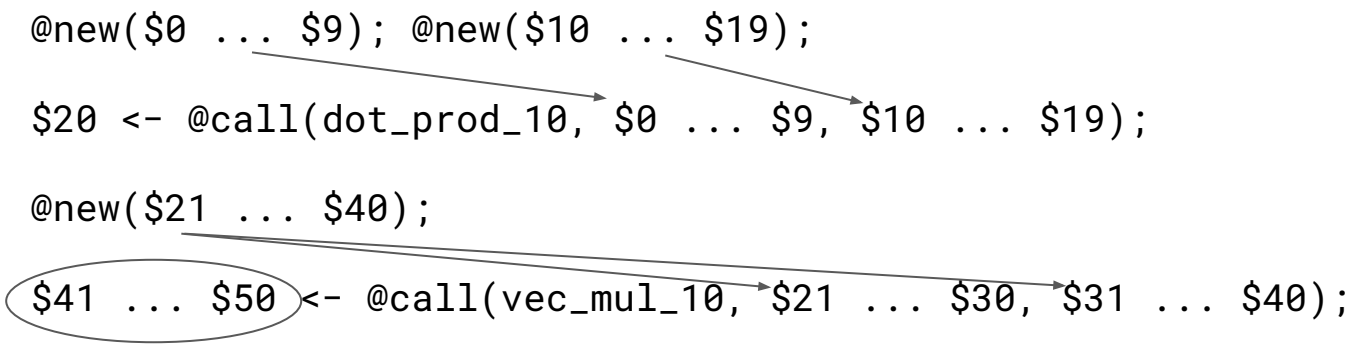
```
@new($10... $20);

// Assignments and usage of $10, $11, … $20

@delete($10 ... $20);
```

- Allocate a block of contiguous wires with @new
  - Subsequent gates may assign within the block
- Delete a block of wires

Memory Management: Function Parameter Rules

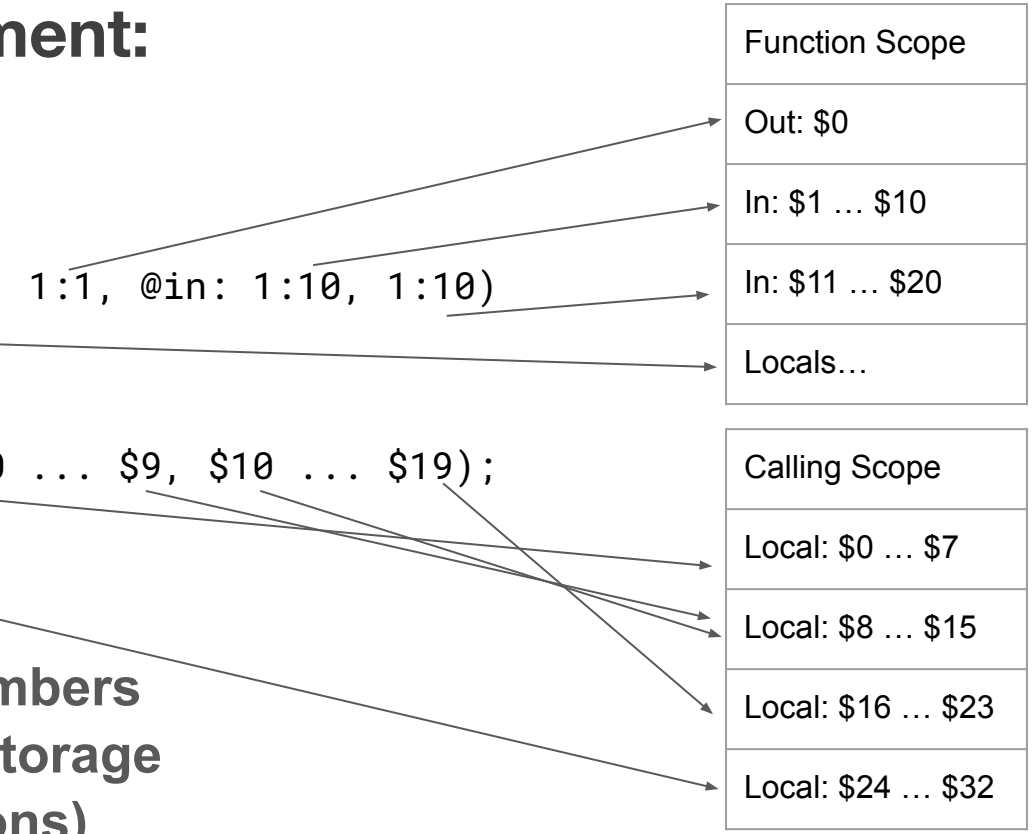


- Each Parameter Range must span within a single allocation
  - Subsets are okay
- Output parameters may implicitly allocate
  - May not conflict with prior allocations, even if unassigned

Memory Management: Why?

```
@function(dot_prod_10, @out: 1:1, @in: 1:10, 1:10)
    // gates...
@end

$25 <- @call(dot_prod_10, $0 ... $9, $10 ... $19);
```



- Consecutive wire numbers
- Discontiguous wire storage (e.g. distinct allocations)
- “shape” mismatch between caller and function

Conversion Gates

Convert a value from one type to another

- Enable conversions in the Circuit's Header

```
@type field 2;  // type 0: Booleans
@type field 2305843009213693951;  // type 1: Mersenne 61
// Allow bidirectional conversions
@convert(@out: 0:61, @in: 1:1);
@convert(@out: 1:1, @in: 0:61);
```

- Use conversions within the circuit's body (noti[illegible]e type indexes)

```
$0 <- 1: <12345>; // (assign a constant)
0: $0 … $60 <- @convert(1: $0, @modulus); // Convert to boolean
```

Allow overflow, or forbid it with @no_modulus (default)

Big-endian

- Compose or decompose as bits or digits, with the prime as a base.

SIEVE Circuit IR Ecosystem

Frontends

- Proofs of vulnerability: Cheesecloth (Galois), Reverie (Trail of Bits)
- General Purpose/Policy Enforcement: zk-SecreC (Cyberbernetica), PicoZK (Stealth/UVM)

“Mid-ends” (SIEVE IR tools/libraries)

- WizToolKit
- zkInterface-sieve

Backends

- VOLE: Mac’n’cheese (Galois), EMP (Stealth/NWU)
- LIGERO: LIGERO (Ligero)
- LPZK: (Stealth), Formally-Verified (SRI)

Lessons learned

- When designing the IR by committee, people had different visions and priorities
  - Human vs machine readable
  - Debuggable vs efficient
  - Featureful vs simpler abstractions
- DARPA required interoperability between all teams
- Suggestions for future standards:
  - Attempt to understand everyone’s vision and priorities
  - Define a process for proposing, debating, and agreeing on designs and features
  - Assign an unbiased arbiter to carry out the process

Beyond SIEVE

- SIEVE is ending in a year
- Hopefully the SIEVE Circuit IR standard will be useful outside of SIEVE
- Perhaps the standard will be adopted by ZKProof and continue to evolve with the wider community
  - PLONK plugin extension?
  - Compiler from SIEVE Circuit IR to PLONK?

Summary

- SIEVE Circuit IR has proven to be a useful language for encoding ZK statements
  - Enabled interoperability between ZK frontends and backends
- Consider using the SIEVE Circuit IR in your next project!

https://github.com/sieve-zk/ir/

- Resources
  - Blog: https://stealthsoftwareinc.github.io/wizkit-blog/blog.html
  - WizToolKit: https://stealthsoftwareinc.github.io/wiztoolkit/
  - zkInterface: https://crates.io/crates/zki_sieve