Full accounting for verifiable outsourcing

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Justin Thaler[△], Michael Walfish[∘], and Thomas Wies[∘]

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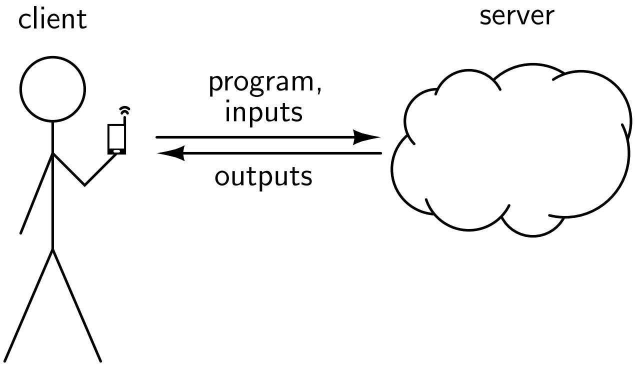
[‡]Northeastern University
[△]Georgetown University

July 6th, 2017

Probabilistic proofs enable outsourcing



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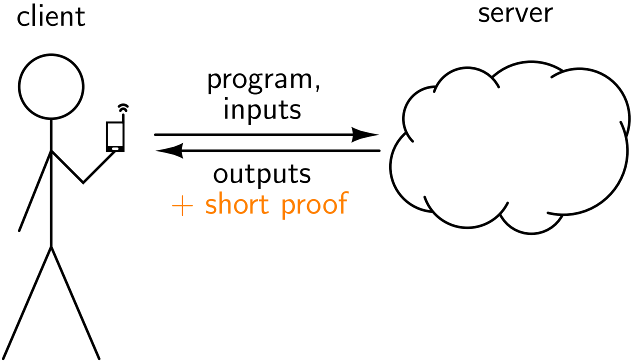
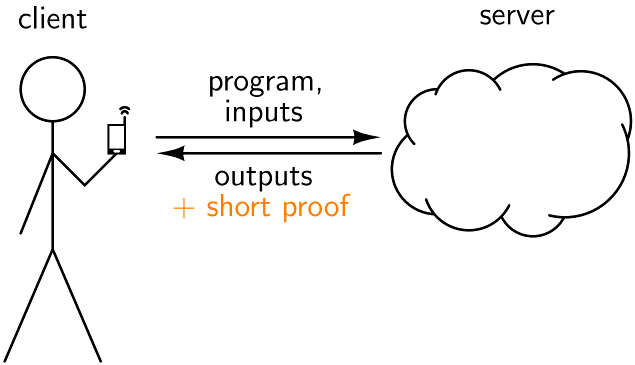


Approach: Server's response includes short proof of correctness.

[Babai85, GMR85, BCC86, BFLS91, FGLSS91, ALMSS92, AS92, Kilian92, LFKN92, Shamir92, Micali00, BG02, BS05, GOS06, BGHSV06, IKO07, GKR08, KR09, GGP10, Groth10, GLR11, Lipmaa11, BCCT12, GGPR13, BCCT13, Thaler13, KRR14, . . .]

Probabilistic proofs enable outsourcing

SBW11
CMT12
SMBW12
TRMP12
SVPBBW12
SBVBPW13
VSBW13
PGHR13
BCGTV13
BFRSBW13
BFR13
DFKP13
BCTV14a
BCTV14b



BCGGMTV14
FL14
KPPSST14
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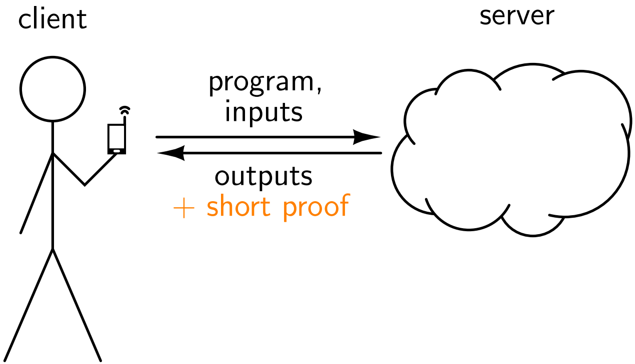

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Goal: outsourcing should be less expensive than just executing the computation

Do systems achieve this goal?

Verifier: can easily check proof (asymptotically)

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Prover: assume $> 10^8\times$ cheaper than verifier

Our contribution

Giraffe: first system to consider all costs and win.

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- an asymptotically optimal proof protocol that improves on prior work [Thaler, CRYPTO13]
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Roadmap

1. Verifiable ASICs
2. Giraffe: a high-level view
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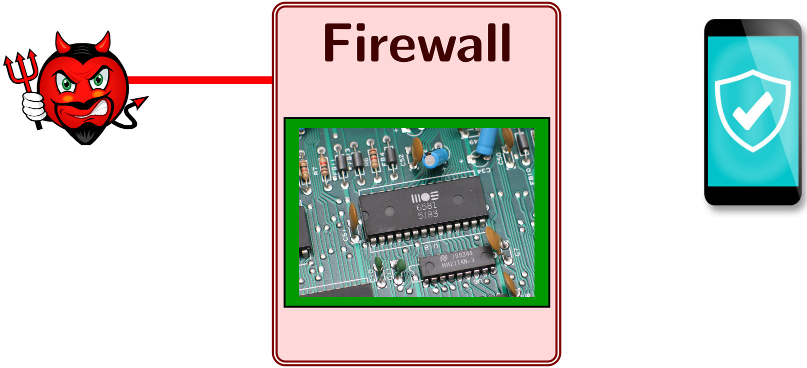
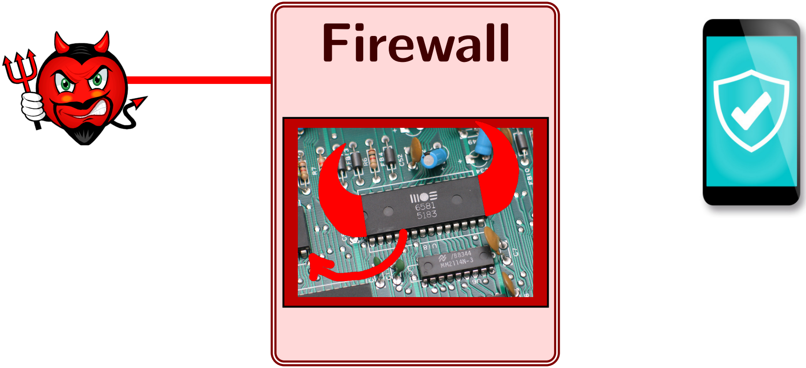
How can we build trustworthy hardware?



e.g., a custom chip for network packet processing
whose manufacture we outsource to a third party

Untrusted manufacturers can craft hardware Trojans



What if the chip's manufacturer inserts a **back door**?

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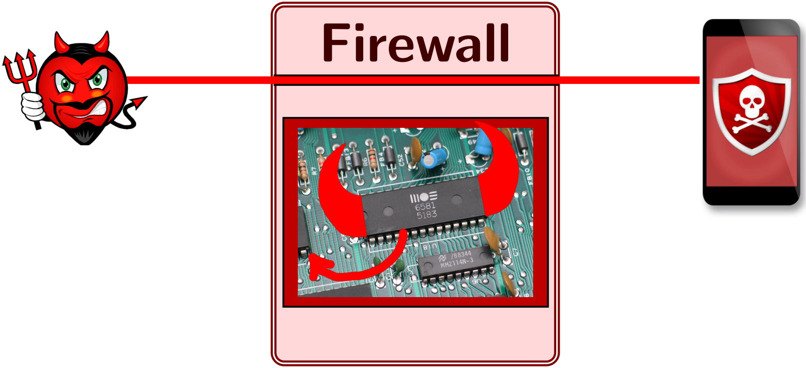

What if the chip's manufacturer inserts a **back door**?

Threat: incorrect execution of the packet filter

(Other concerns, e.g., secret state, are important but orthogonal)

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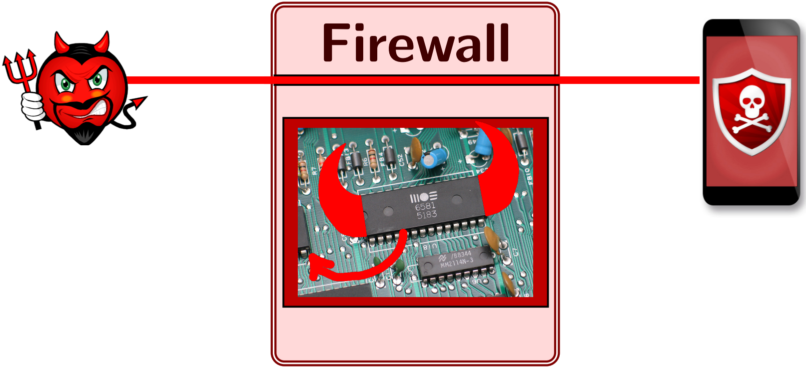

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The Cybercrime Economy

Fake tech gear has infiltrated the U.S. government

by David Goldman @DavidGoldmanCNN

November 8, 2012: 3:10 PM ET

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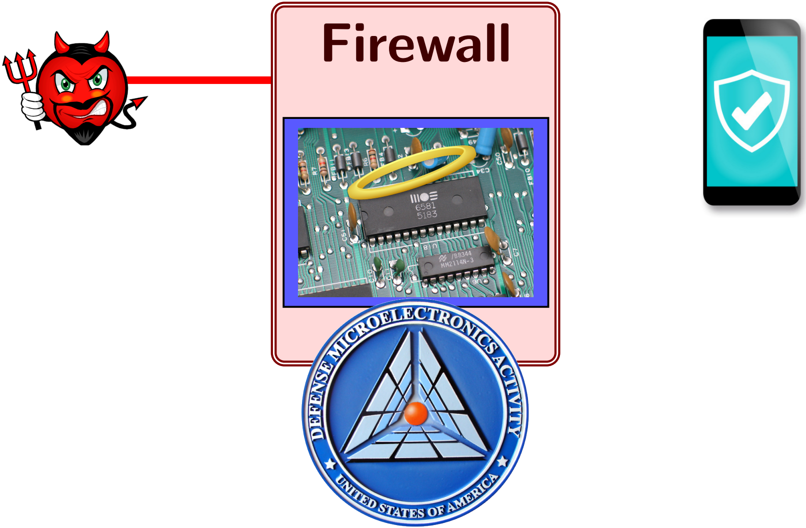

US DoD controls supply chain with **trusted foundries**.

Trusted fabs are the only way to get strong guarantees

For example, stealthy trojans can thwart post-fab detection
[A2: Analog Malicious Hardware, Yang et al., Oakland16;
Stealthy Dopant-Level Trojans, Becker et al., CHES13]

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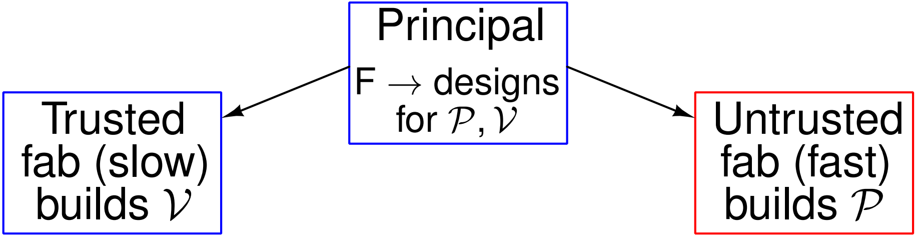
Idea: outsource computations to untrusted chips

Verifiable ASICs [WHGsW16]

Principal

F $\rightarrow$ designs for $\mathcal{P}, \mathcal{V}$

Verifiable ASICs [WHGsW16]



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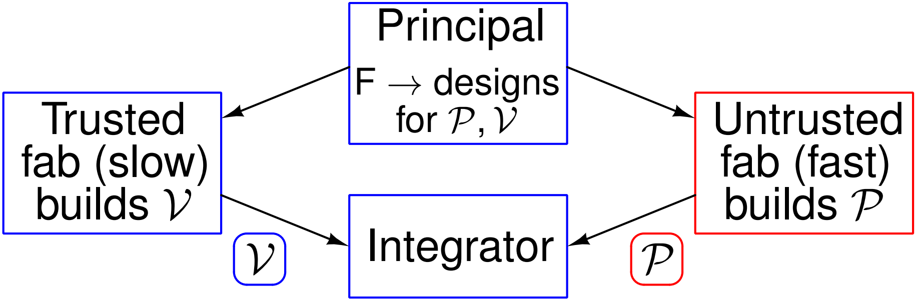

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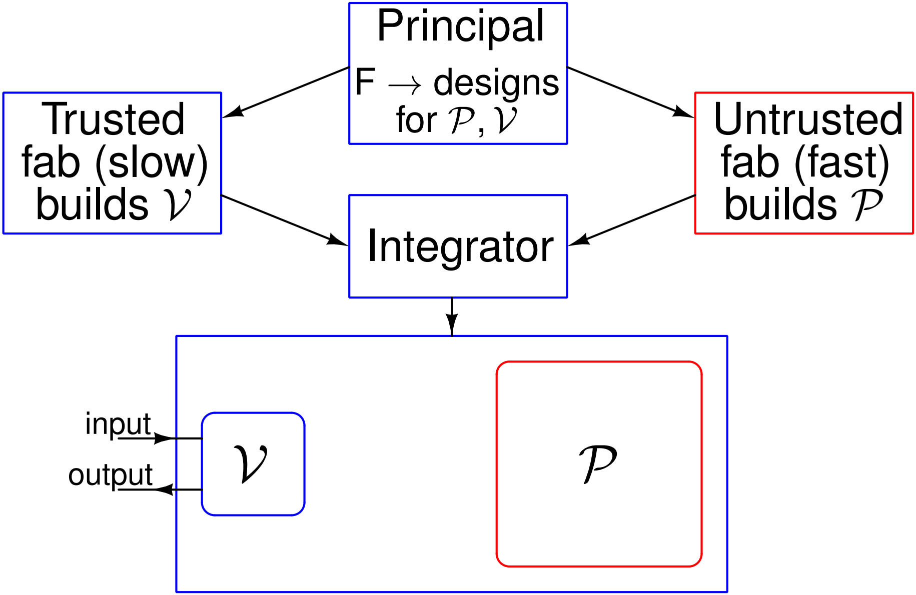

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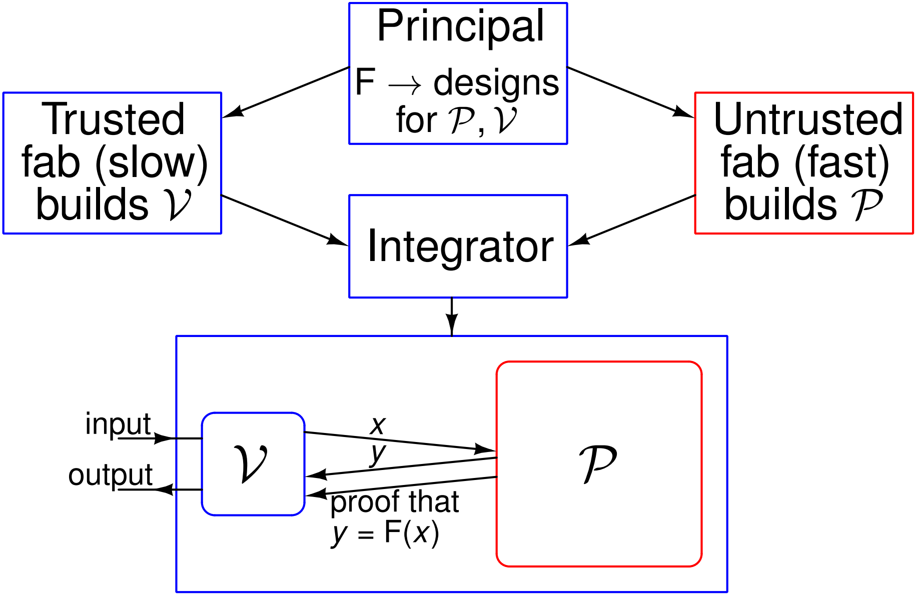
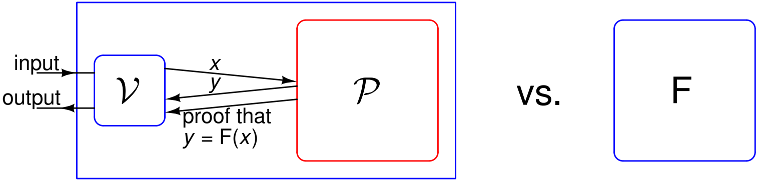


Can Verifiable ASICs be practical?



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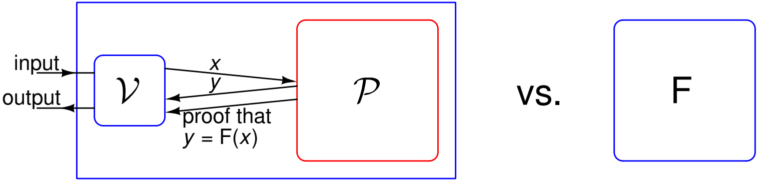

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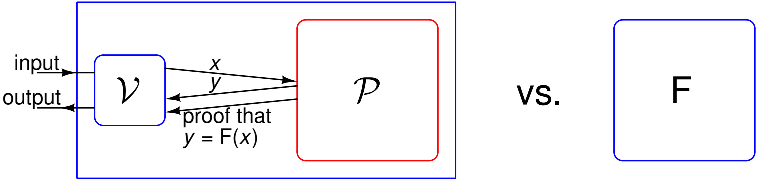

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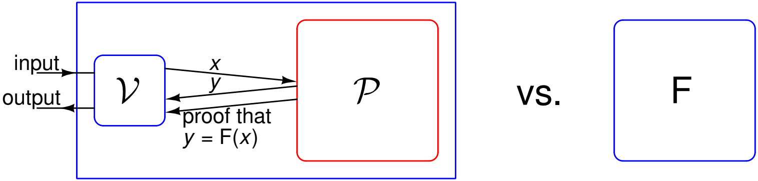

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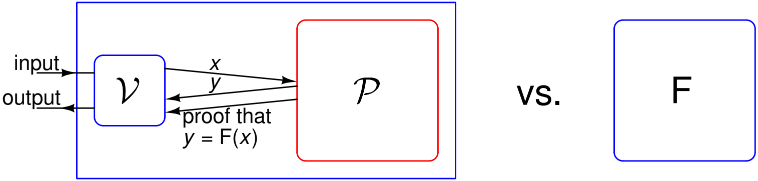

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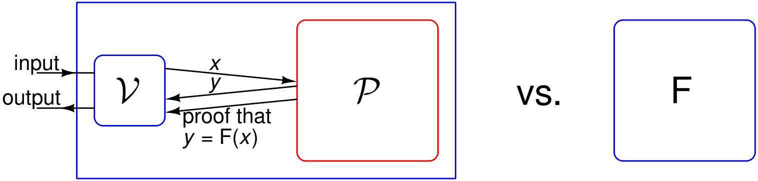

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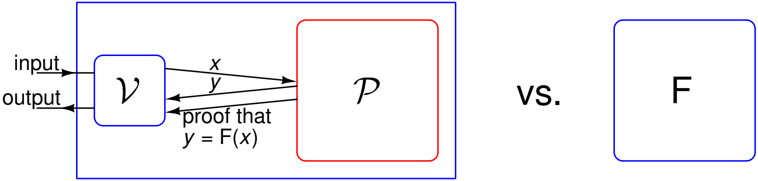

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Our goal:

$\mathcal{V} + \mathcal{P} + \text{Precomp} < \text{F}$

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Evolution of Giraffe's back-end

GKR08 base protocol

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(plus optimizations for $\mathcal{V}$; see paper)

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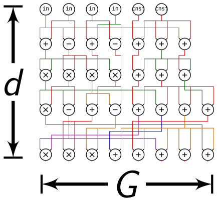
Let's take a high-level look at how these optimizations work.
(The following all use a nice simplification [Thaler15].)

GKR08 (a quick reminder)

For each layer of an arithmetic circuit, $\mathcal{P}$ and $\mathcal{V}$ engage in a sum-check protocol.



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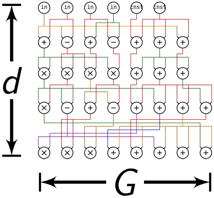

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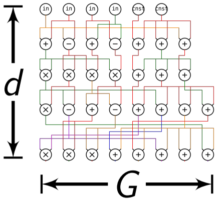

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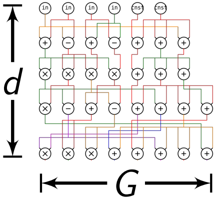
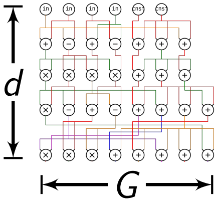
Precomputation is one evaluation of $\tilde{\text{add}}$ and $\tilde{\text{mul}}$, costing O(poly(G)).



CMT12: from polynomial to quasilinear

$\text{add}(g_O, g_L, g_R) = 0$ except when g_O is $+$ with inputs g_L, g_R



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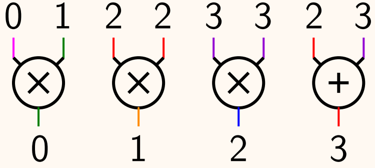
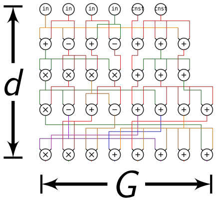


$\mathrm{add}(3, 2, 3) = 1$, otherwise $\mathrm{add}(\cdots) = 0$



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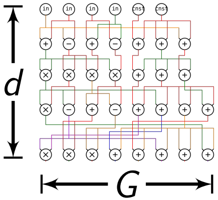

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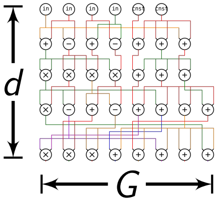

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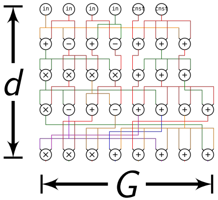
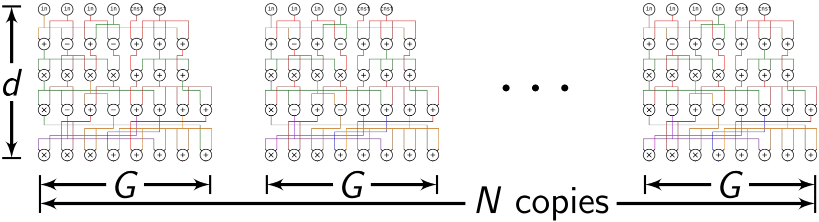


Thaler13: more structure, less precomputation

Idea: for a *batch* of identical subckts, $\tilde{\text{add}}$ and $\tilde{\text{mul}}$ can be "small."



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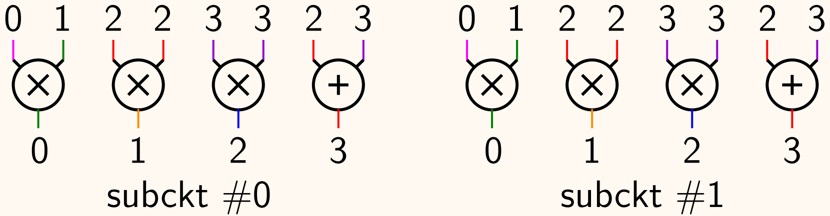
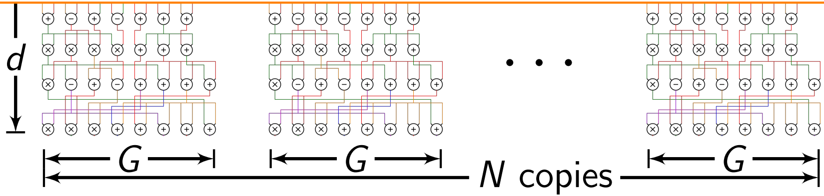


$\text{add}(3,2,3) = 1$, otherwise $\text{add}(\cdots) = 0$

Notice that $\tilde{\text{add}}$ does not comprehend subcircuit number!



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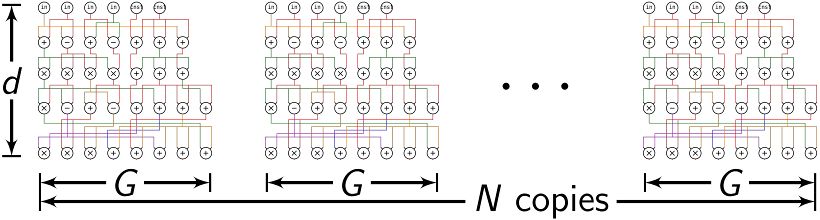

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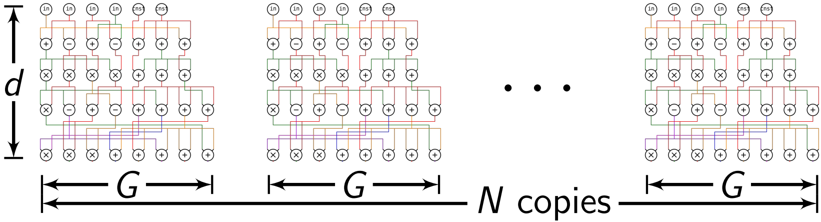

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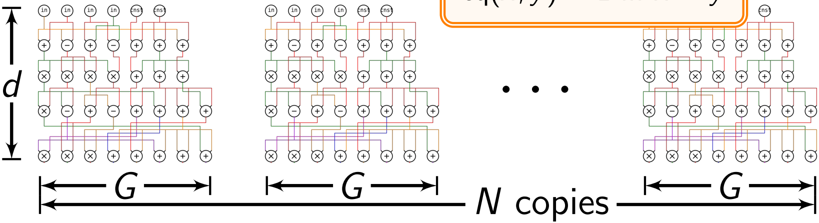
eq$(x, y) = 1$ iff $x = y$



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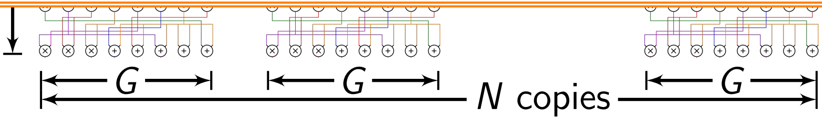

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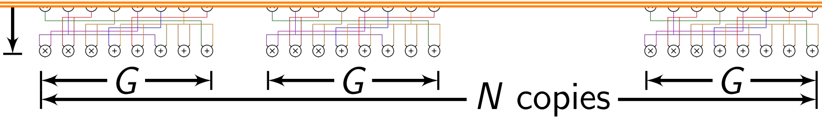

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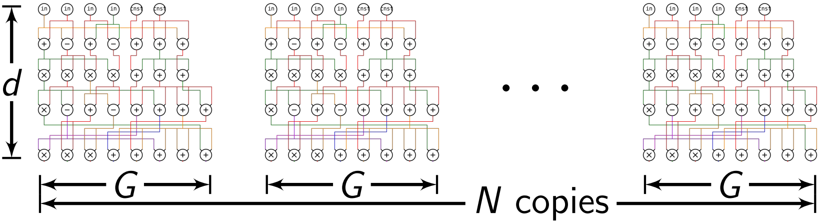
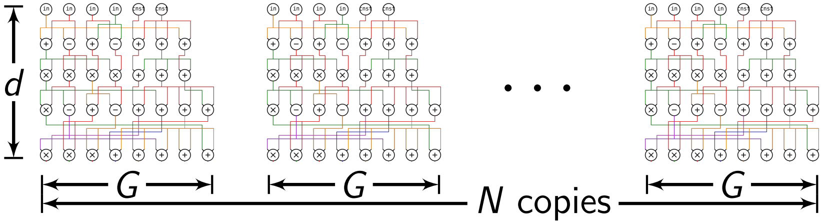
NG terms/round in first $2 \log G$ rounds: $\mathcal{P}$'s work is $\Omega(NG \log G)$.



Giraffe: leveraging structure to reduce $\mathcal{P}$ costs

Idea: arrange for copies to "collapse" during sum-check protocol.



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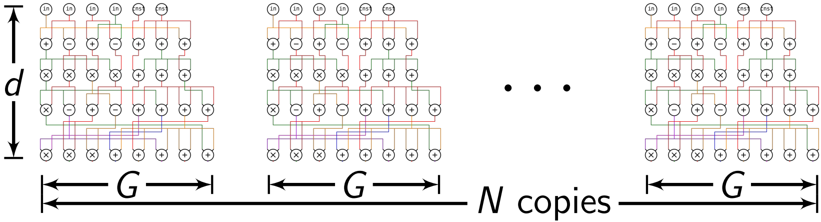

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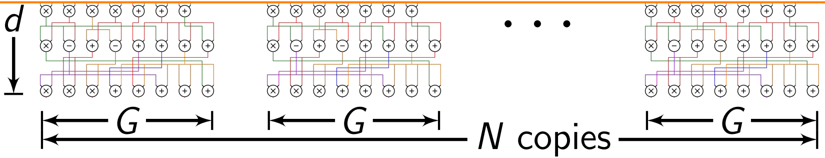

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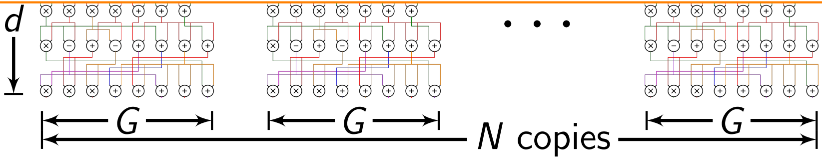

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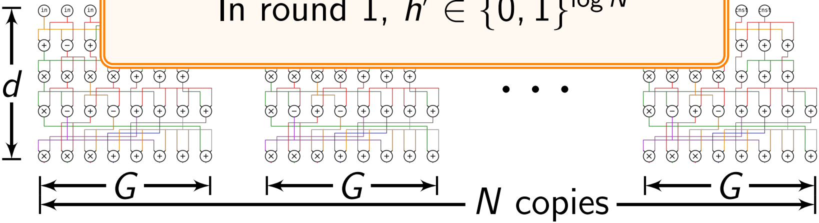
In round 1, $h' \in \{0, 1\}^{\log N}$



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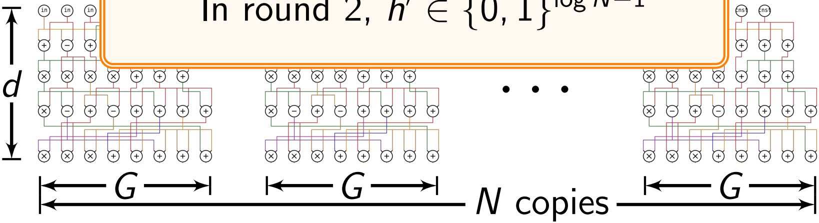
In round 2, $h' \in \{0,1\}^{\log N - 1}$



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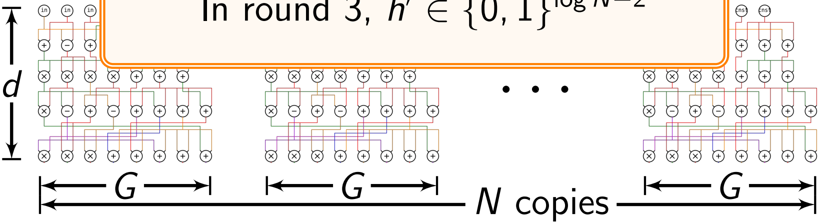
In round 3, $h' \in \{0,1\}^{\log N - 2}$



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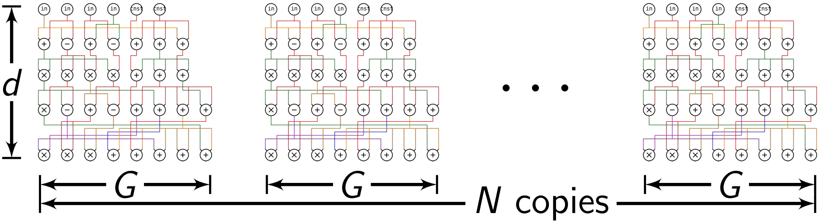

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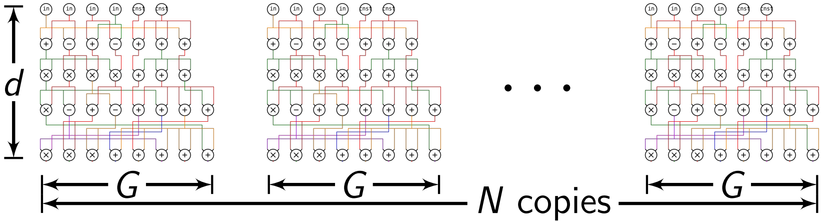
➔ Linear in size of computation when $N > \log G$!



Roadmap

1. Verifiable ASICs
2. Giraffe: a high-level view
3. Evaluation

Implementation

Giraffe is an end-to-end hardware generator:

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a hardware *design template*

given computation, chip parameters (technology, size, . . .),
produces optimized hardware designs for $\mathcal{P}$ and $\mathcal{V}$

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a (subset of) C compiler

produces the representation used by the design template

Evaluation questions

How does Giraffe perform on real-world computations?

1. Curve25519 point multiplication
2. Image matching

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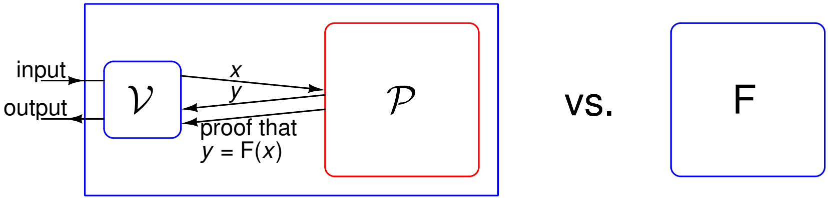
2. Image matching

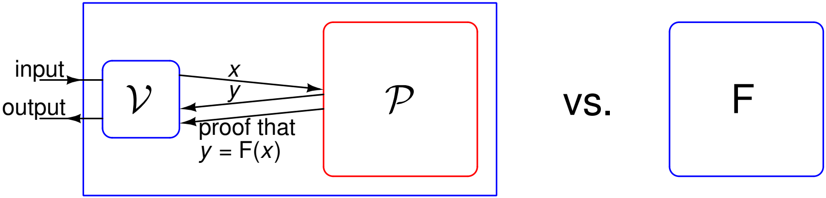
Goal: total cost of $\mathcal{V}$, $\mathcal{P}$, and precomputation should be less than building F on a trusted chip

Evaluation method



Baselines: Zebra; implementation of F in same technology as $\mathcal{V}$

Evaluation method



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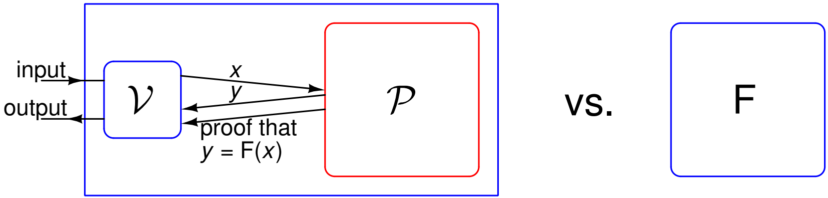

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Measurements: based on circuit synthesis and simulation, published chip designs, and CMOS scaling models

Charge for $\mathcal{V}$, $\mathcal{P}$, communication; precomputation; PRNG

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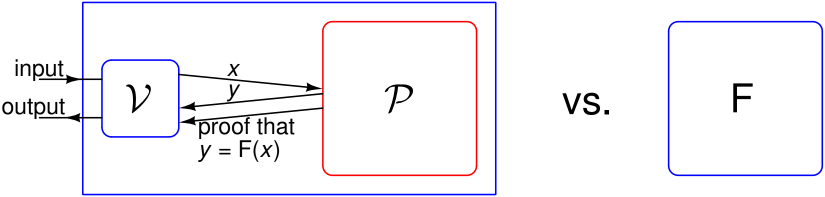

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Measurements: based on circuit
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350 nm: 1997 (Pentium II)
7 nm: $\approx$ 2018
$\approx$ 20 year gap between
trusted and untrusted fab

Charge for $\mathcal{V}$, $\mathcal{P}$, communication; precomputation; PRN

Constraints: trusted fab = 350 nm; untrusted fab = 7 nm
200 mm^2 max chip area; 150 W max total power

Application #1: Curve25519 point multiplication

Curve25519: a commonly-used elliptic curve

Point multiplication: primitive, e.g., for ECDH

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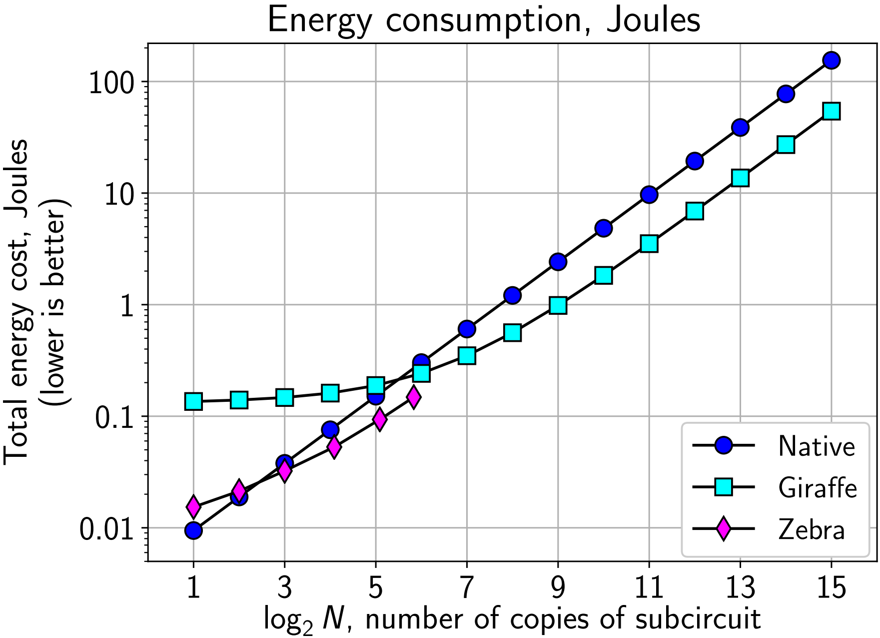

Application #2: Image matching

Image matching via Fast Fourier transform

C implementation, compiled by Giraffe's front-end to $\mathcal{V}$ and $\mathcal{P}$ hardware designs—no hand tweaking!

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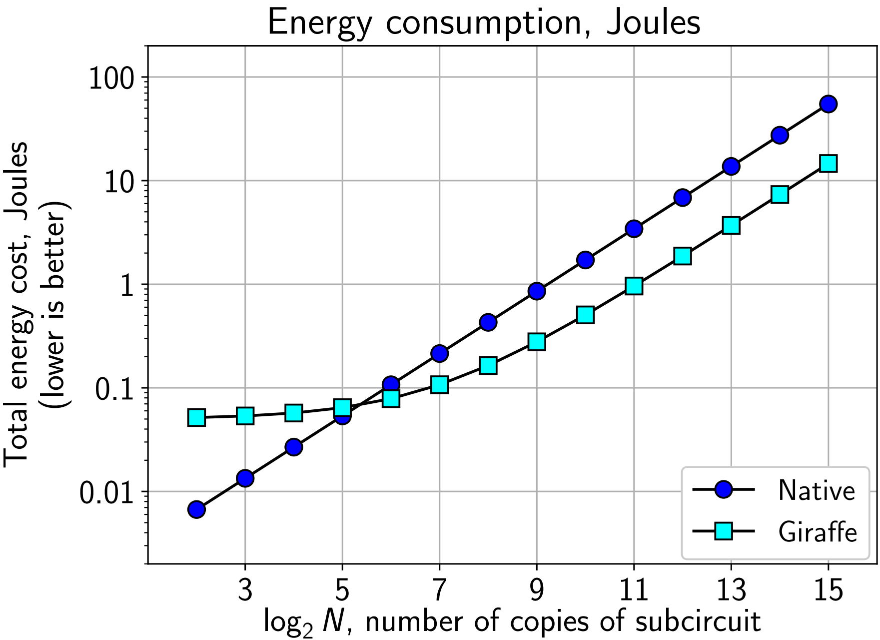
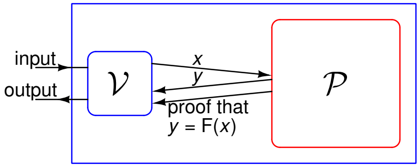


Recap: is it **practical**?



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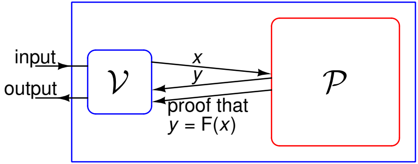

✗ Giraffe is restricted to batched computations

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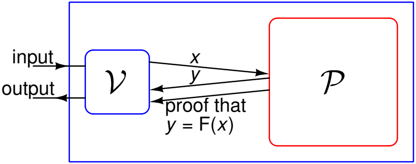

✗ Giraffe is restricted to batched computations

Giraffe's front-end includes two static analysis passes:

Slicing extracts only the parts of programs that can be efficiently outsourced

Squashing extracts batch-parallelism from serial computations

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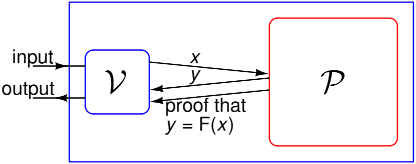

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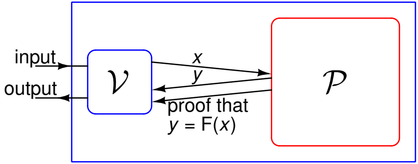

- ✗ Giraffe is restricted to batched computations
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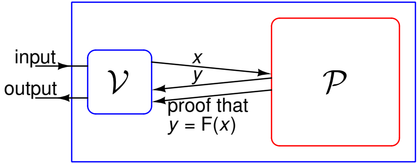

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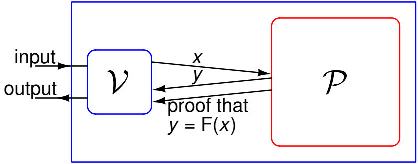

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https://giraffe.crypto.fyi

http://www.pepper-project.org