Hochschule **RheinMain**
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VORONOI BASED N-DIMENSIONAL PARAMETER OPTIMIZATION FOR FAULT INJECTION ATTACKS

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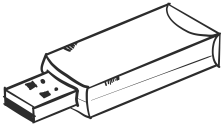
MOTIVATION

→ Evidence from digital electronic devices is becoming increasingly important in court

→ More and more devices implement various security mechanisms to protect user data

→ Security mechanisms must be bypassed to obtain data from victims or perpetrators

→ Besides software exploits, various hardware attacks exist
  - → invasive - e.g. Microprobing
  - → semi-invasive - e.g. Laser Fault Injection
  - → non-invasive - e.g. Voltage Glitching



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PARAMETER OPTIMIZATION CHALLENGES

→ Non-invasive attacks use laboratory equipment to manipulate the target's environment

→ Semi-invasive attacks also modify equipment parameters but require package removal

→ Advanced attacks on modern hardware require multiple devices

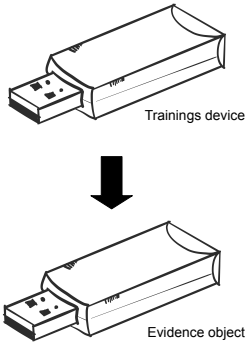
→ Professional devices further increase parameter granularity

Problem

Brute force iteration of all parameter combinations not feasible!

SPECIFIC CHALLENGES FOR LAW ENFORCEMENT

→ Data corruption and data loss are to be avoided at all cost
- → Intensive tests on comparison device
- → The attack must work across devices
- → Attack should at best be successful on the first try



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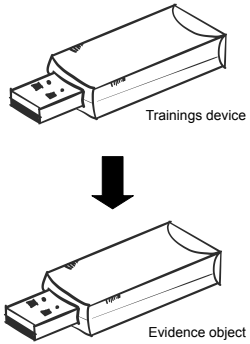
- → Seldom access to intellectual property of the device vendors
  - → Typically black-box scenarios
  - → Missing documentation of the device and its chips
  - → No insight about countermeasures
  - → Unknown typical operating conditions



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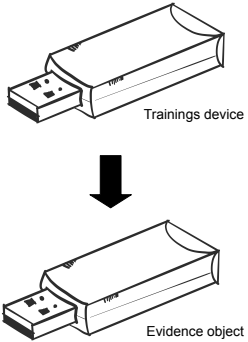

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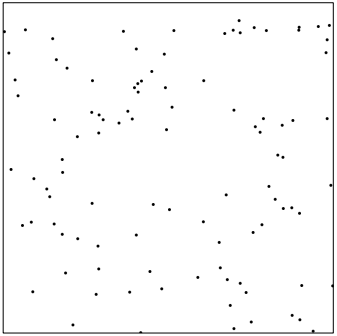
Challenge

We need to find the overall most reliable parameter combination across devices not only just one that worked once!

VORONOI TESSELLATION



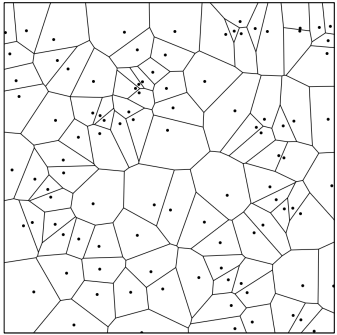
VORONOI TESSELLATION

→ Voronoi tessellation partitions a (multidimensional) space into cells

→ Each cell surrounds one input point

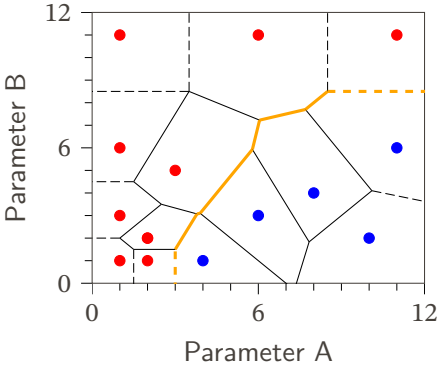
→ All coordinates that are closer to a cells point than to all other points are contained

→ Cells are separated by lines, even in high dimensions



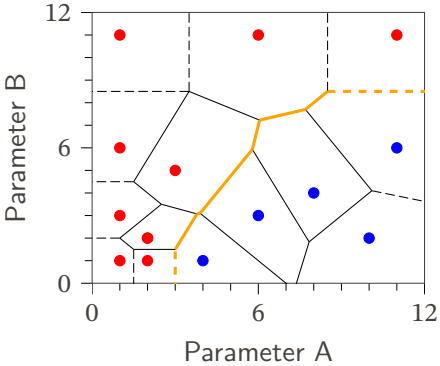
VORONOI TESSELLATION FOR POINT OF INTEREST DETERMINATION

→ Can be used for optimization during fault injection attacks
  - → Results define input points
  - → Edges define border between results
  - → Borders between result classes define polytope of interest



VORONOI TESSELLATION FOR POINT OF INTEREST DETERMINATION

- → Can be used for optimization during fault injection attacks
  - → Results define input points
  - → Edges define border between results
  - → Borders between result classes define polytope of interest
- → Result improves with each point added
- → Identifies successful parameters between classes
- → Creates a cartography of the parameter space

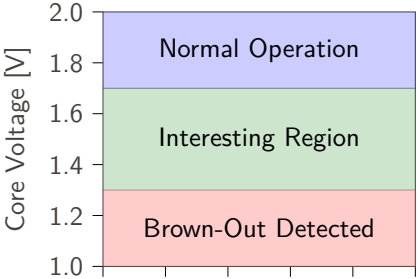


MAPPING OPTIONS

→ Failures are more time consuming

→ Some setups require long restart times

→ Tests leading to failures should be avoided



MAPPING OPTIONS

→ Failures are more time consuming

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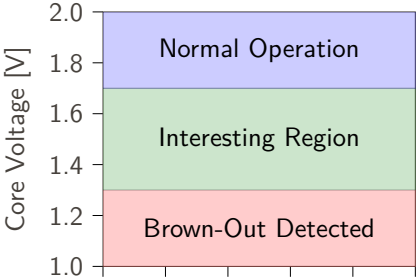
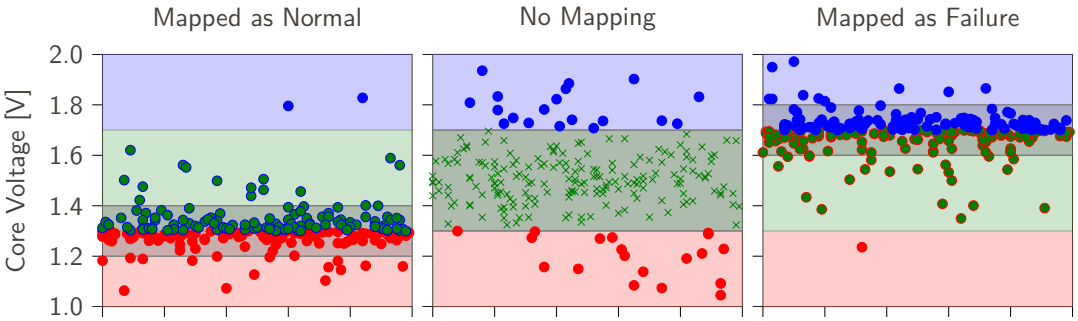
→ Tests leading to failures should be avoided

→ We can shift the polytope of interest by interpreting successful results as failures.



2D MAPPING OPTIONS VISUALIZATION

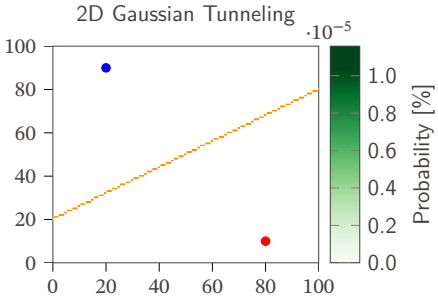


GAUSSIAN TUNNELING

→ Voronoi tessellation provides edges

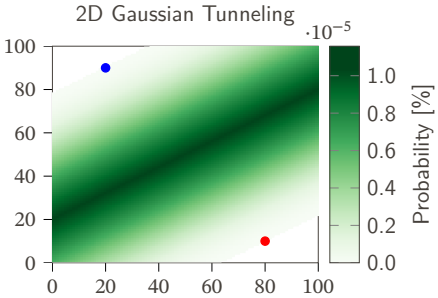
→ Edges are considered the most interesting parameter combinations

→ The global maximum can still be next to the edge

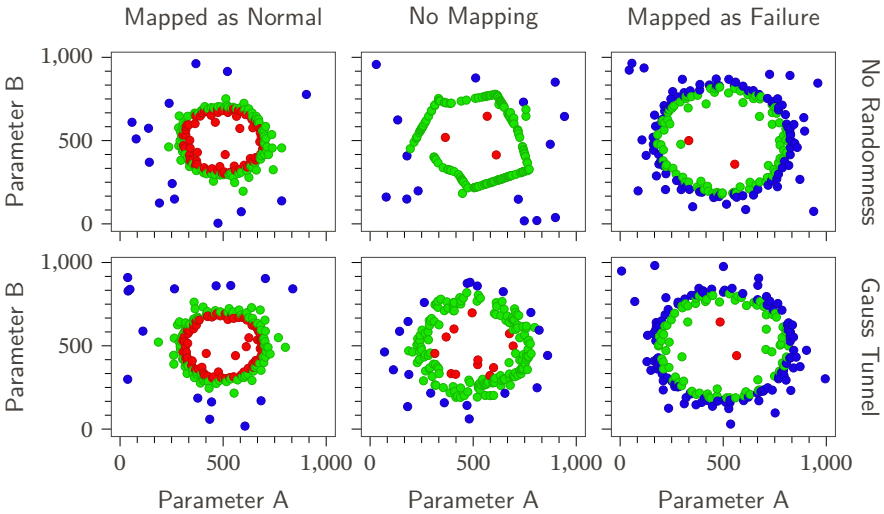


GAUSSIAN TUNNELING

- → Voronoi tessellation provides edges
- → Edges are considered the most interesting parameter combinations
- → The global maximum can still be next to the edge
- → We can perform only one test at a time
  - → Exploration space expansion through Gaussian tunneling
  - → Speedup through randomized edge point selection



MAPPING AND TUNNELING SIMULATION



SIMULATION SETUP

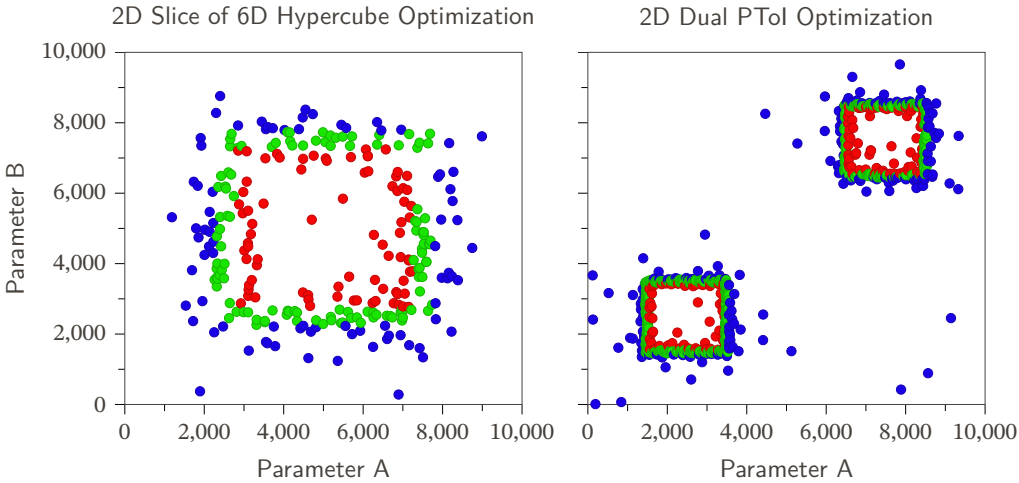
→ Simulations uses hypercubic result space

→ Each dimension is a uniformly distributed parameter
  - → 45% of the center defined as failure
  - → next 10% defined as success
  - → everything else defined as normal

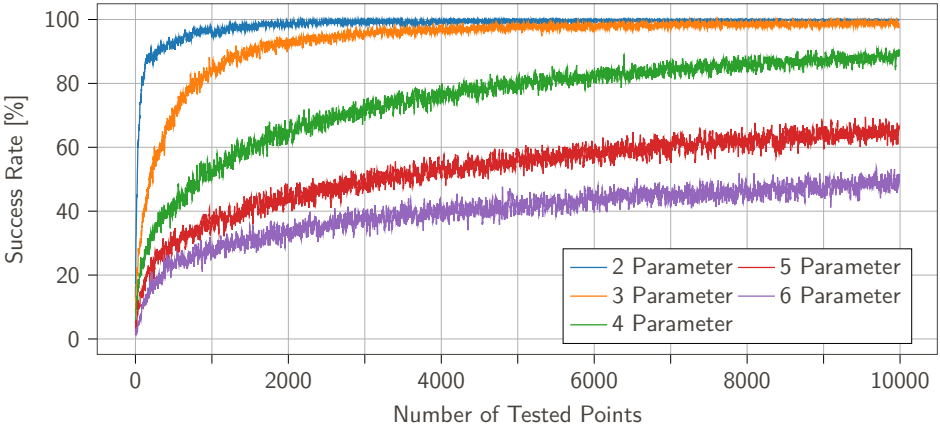
→ Pro: Constant possibility for successful outcomes per dimension

→ Con: Volumetric percentage for successes decreases per dimension
(2D: 10%, 3D: 7.5%, 4D: 5%, 5D: 3.2%, 6D: 1.9%, ...)

6D AND DUAL PTOI SIMULATION RESULTS



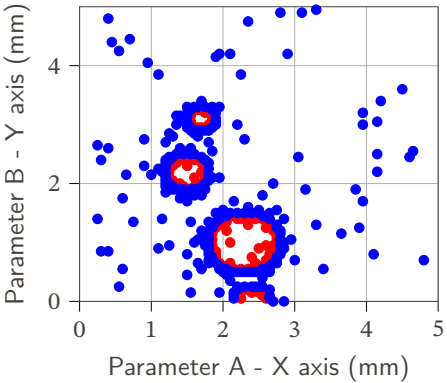
SUCCESS RATE EVALUATION



SPATIAL OPTIMIZATION EXPERIMENT SIMULATION

→ Spatial parameters seldom contain successes between failure and normal regions

→ To evaluate spatial parameters we simulated the scenario from Rais-Ali et. al[1]



[1] I. Rais-Ali, A. Bouvet, and S. Guilley, "Quantifying the speed-up offered by genetic algorithms during fault injection cartographies," in 2022 Workshop on Fault Detection and Tolerance in Cryptography (FDTC), 2022, pp. 61–72.

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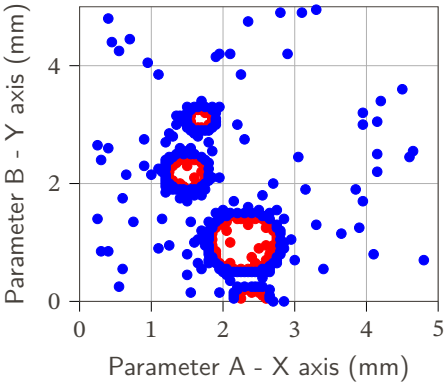

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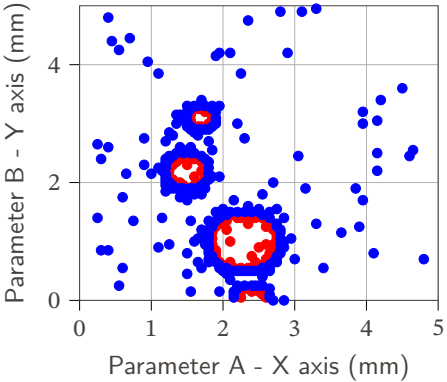
- → Idea: Test edges between failures after a certain point limit



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EXPERIMENTAL RESULTS

→ Target: LPC2129[1]
  → Implements simple counting loop
  → Commands and results sent over UART
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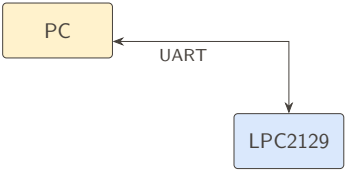

[1] https://www.nxp.com/products/processors-and-microcontrollers/arm-microcontrollers/general-purpose-mcus/lpc2000-arm7:MC_71580#/

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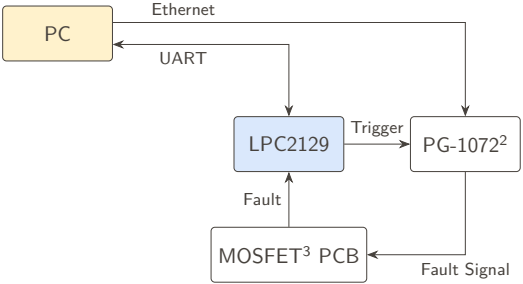

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[2] https://www.activetechnologies.it/pulse_rider_pg-1072_pg1074_revb/
[3] https://www.infineon.com/cms/en/product/power/mosfet/n-channel/irf7807z/

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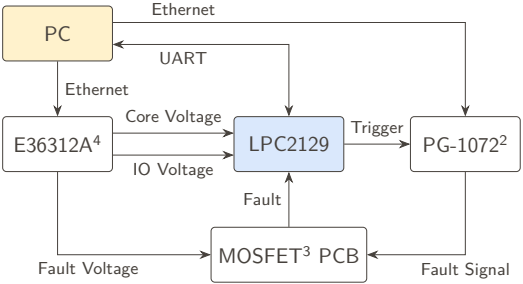

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[3] https://www.infineon.com/cms/en/product/power/mosfet/n-channel/irf7807z/
[4] https://www.keysight.com/de/de/support/E36312A/80w-triple-output-power-supply-6v-5a-2x-25v-1a.html

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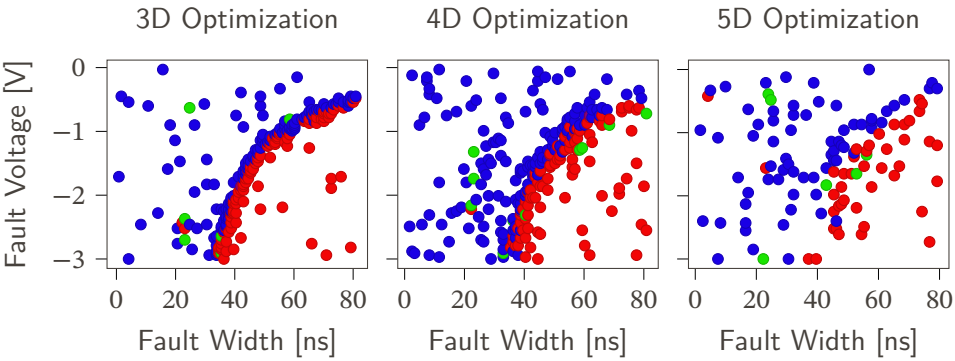

3D: Fault Voltage, Fault Width, Fault Delay
4D: Fault Voltage, Fault Width, Fault Delay, Core Voltage
5D: Fault Voltage, Fault Width, Fault Delay, Core Voltage, I/O Voltage

CONTRIBUTIONS & DISCUSSION

→ Contribution
- → Novel semi-deterministic method for identifying polytopes of interest
- → Effectiveness demonstrated with simulations and experiments
- → No restriction of parameters required
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  - → Effectiveness demonstrated with simulations and experiments
  - → No restriction of parameters required
  - → Can handle arbitrary result shapes
- → Discussion
  - → Focus on the border region, thus only outlines are identified
  - → For multiple interesting regions a random point selection is required
  - → High computation time for large number of input points in higher dimensions

FUTURE WORK

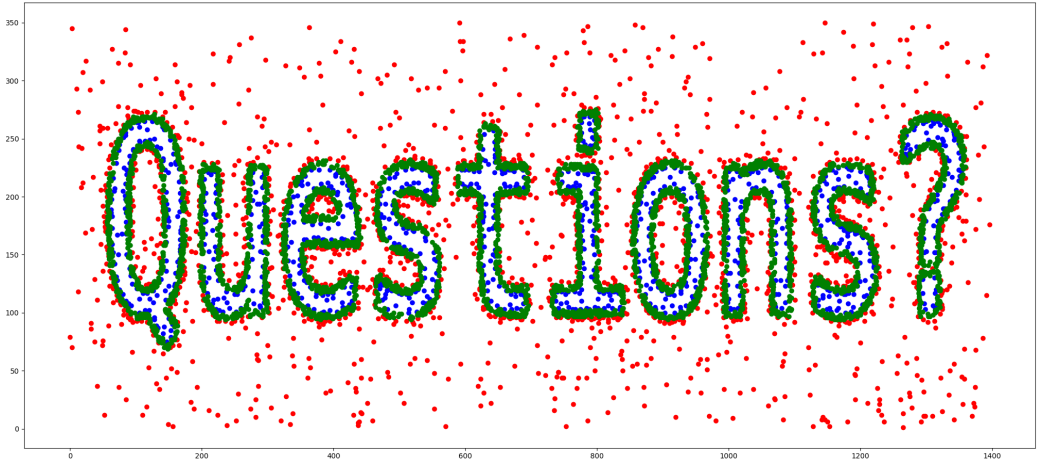
→ Calculation speed-up in higher dimensions

→ Likelihood evaluation for single successful parameter combinations

→ Combination with heuristic approaches

→ Restricting point selection to account parameter adjustment times

THANK YOU!


Questions?
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