Physical Unclonable Functions and Applications

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Problem:

Storing digital information in a device in a way that is resistant to physical attack is difficult and expensive.

IBM 4758

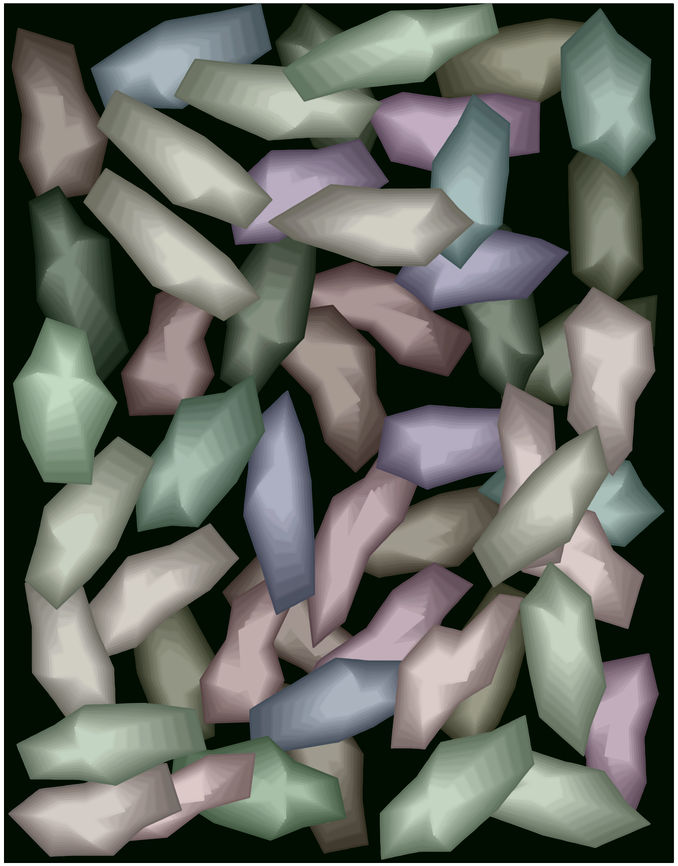
Tamper-proof package containing a secure processor which has a secret key and memory

- Tens of sensors, resistance, temperature, voltage, etc.
- Continually battery-powered

~ $3000 for a 99 MHz processor and 128MB of memory

Our Solution:

Extract key information from a complex physical system.



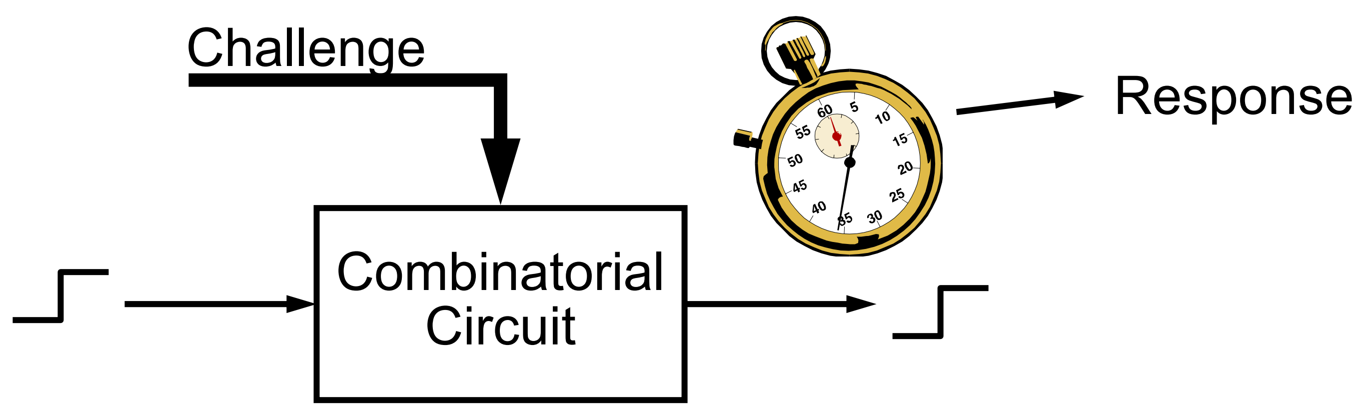
Definition

A Physical Random Function or **Physical Unclonable Function (PUF)** is a function that is:

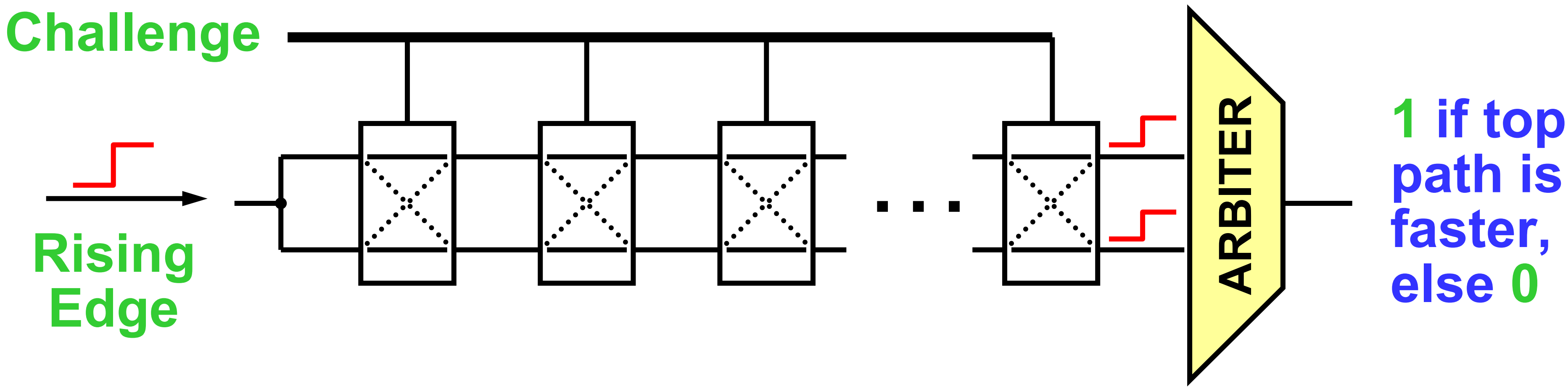
- Based on a physical system
- Easy to evaluate (using the physical system)
- Its output looks like a random function
- Unpredictable even for an attacker with physical access

Silicon PUF – Proof of Concept

- **Because of process variations, no two Integrated Circuits are identical**
- **Experiments in which *identical circuits with identical layouts* were placed on different FPGAs show that path delays vary enough across ICs to use them for identification.**



A Candidate Silicon PUF

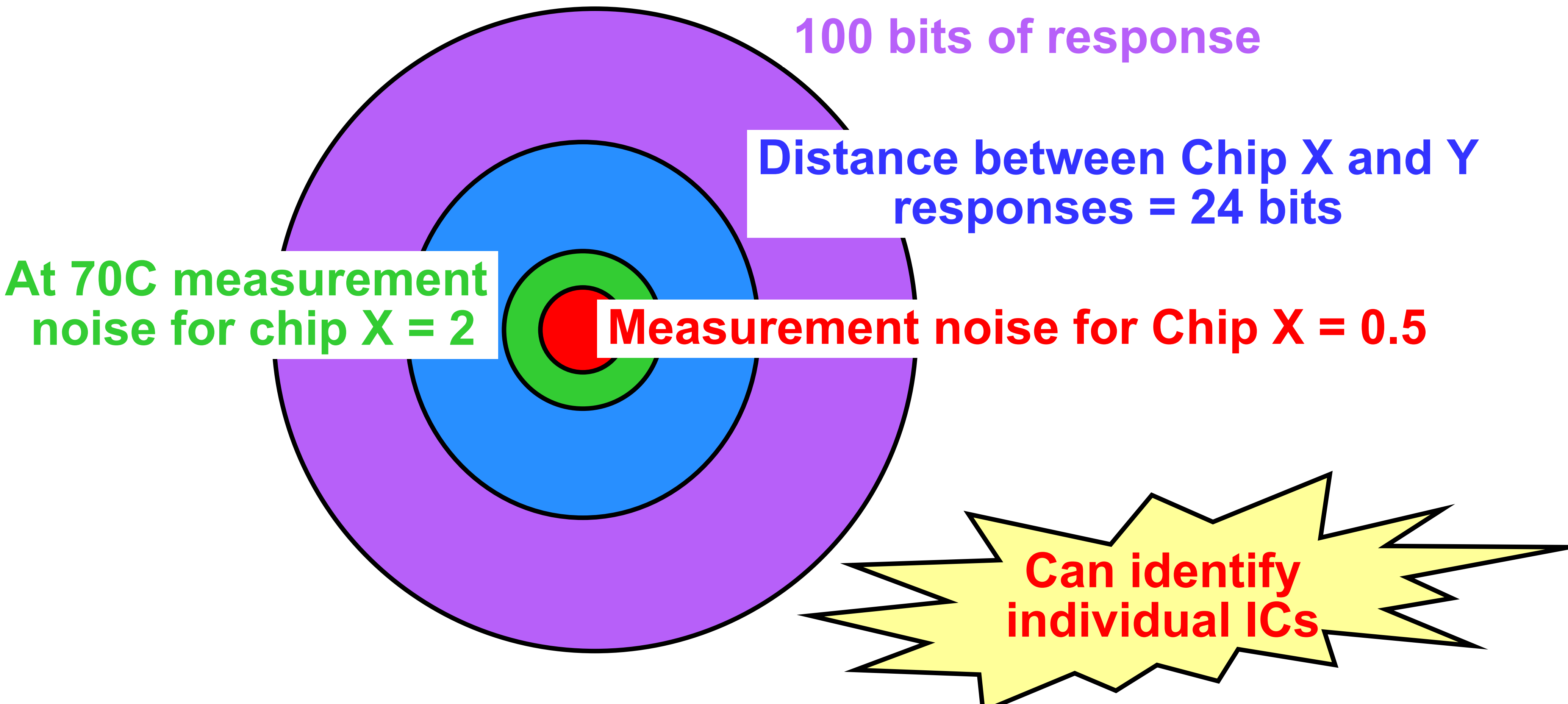


Each challenge creates two paths through the circuit that are excited simultaneously. The digital response is based on a (timing) comparison of the path delays.

Path delays in an IC are statistically distributed due to random manufacturing variations.

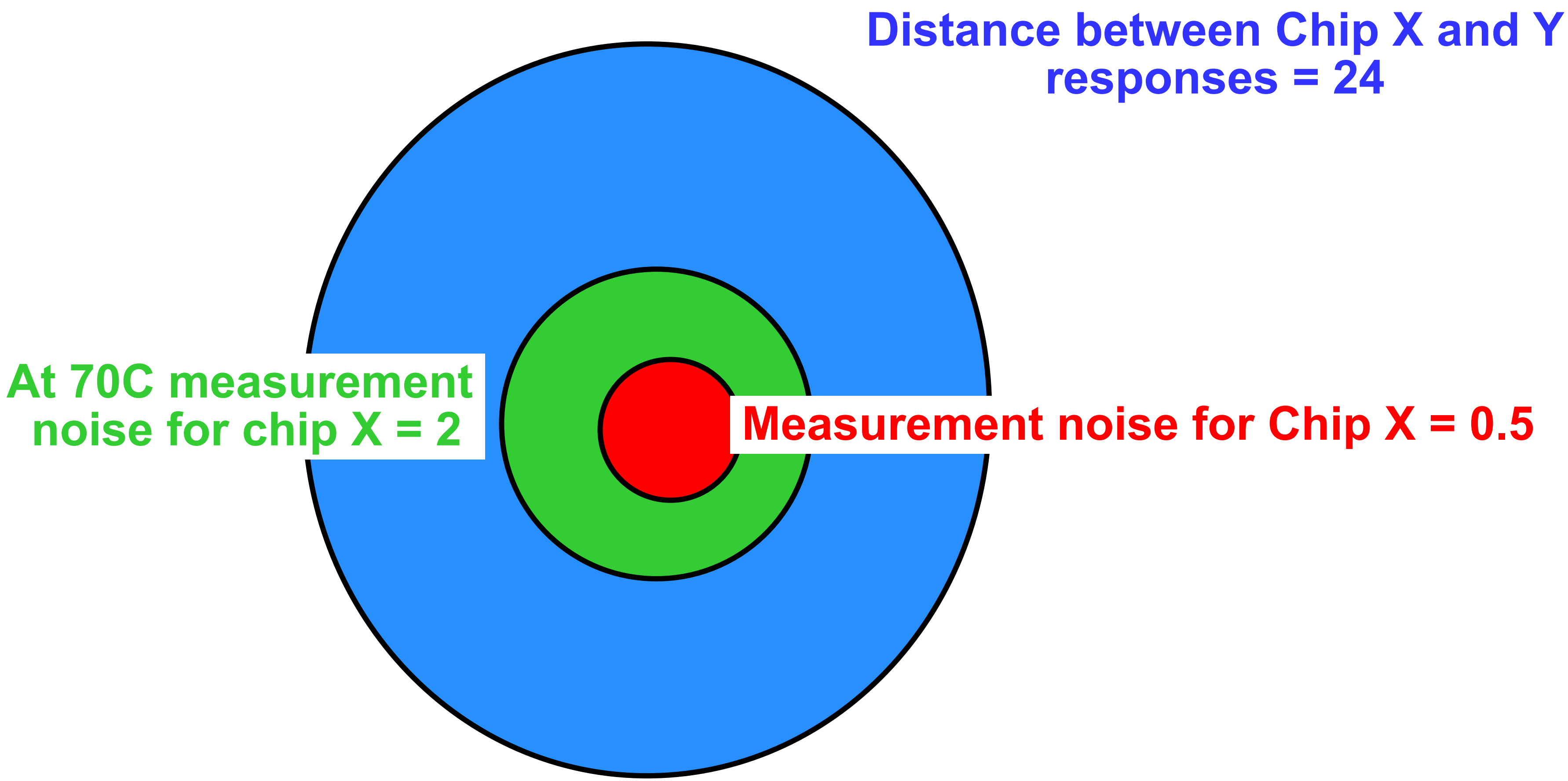
Experiments

- **Fabricated candidate PUF on multiple IC's, 0.18μ TSMC**
- **Apply 100 random challenges and observe response**



Measurement Attacks and Software Attacks

Can an adversary create a *software clone* of a given PUF chip?



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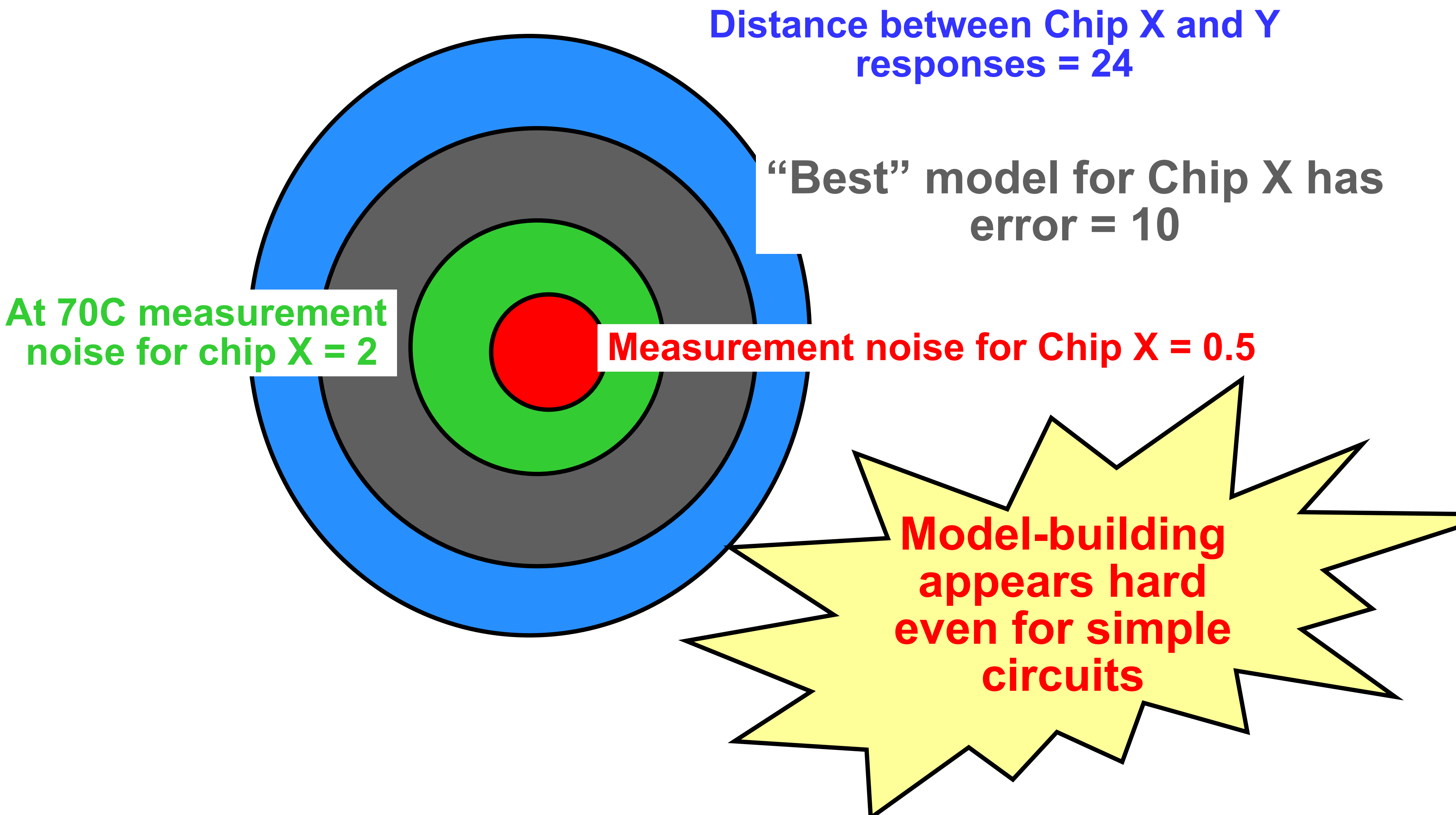


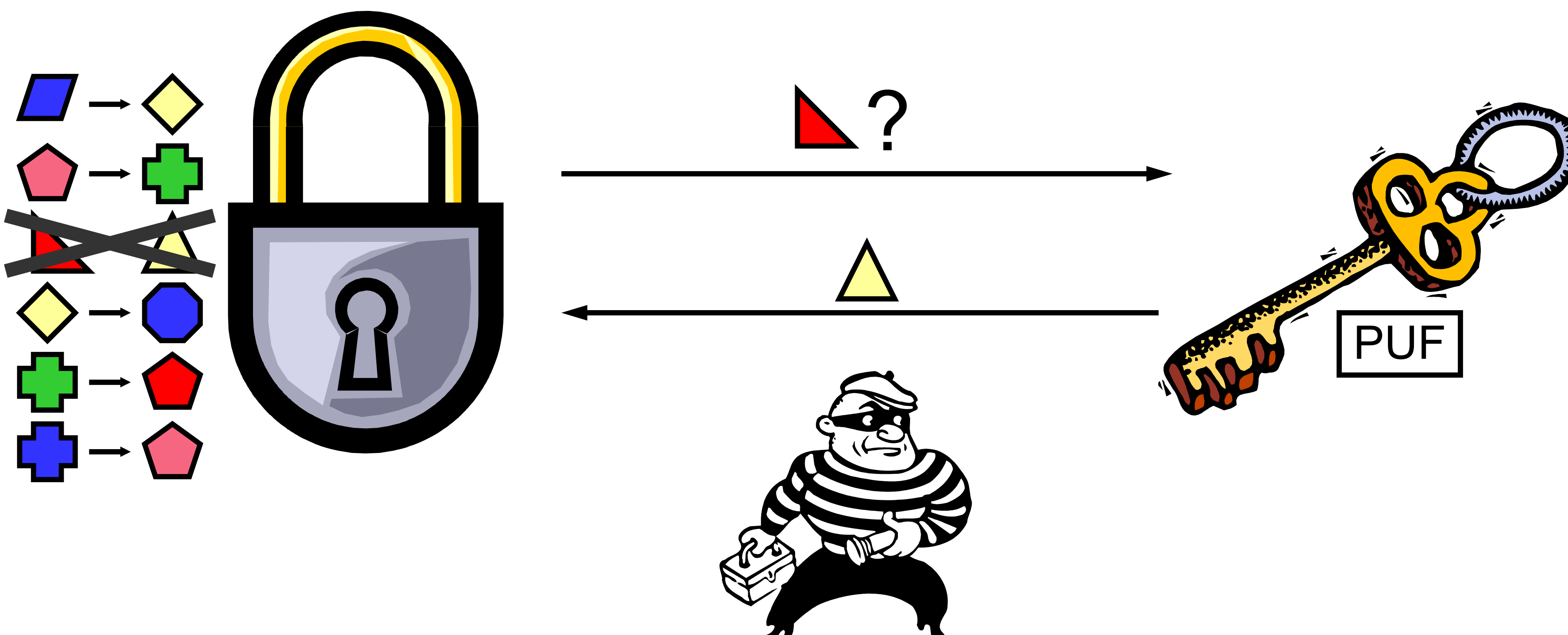
Physical Attacks

- **Make PUF delays depend on overlaid metal layers and package**
- **Invasive attack (e.g., package removal) changes PUF delays and destroys PUF**
- **Non-invasive attacks are still possible**
  - **To find wire delays need to find precise relative timing of transient signals as opposed to looking for 0’s and 1’s**
  - **Wire delay is not a number but a function of challenge bits and adjacent wire voltages**

Using a PUF as an Unclonable Key

A Silicon PUF can be used as an unclonable key.

- **The lock has a database of challenge-response pairs.**
- **To open the lock, the key has to show that it knows the response to one or more challenges.**

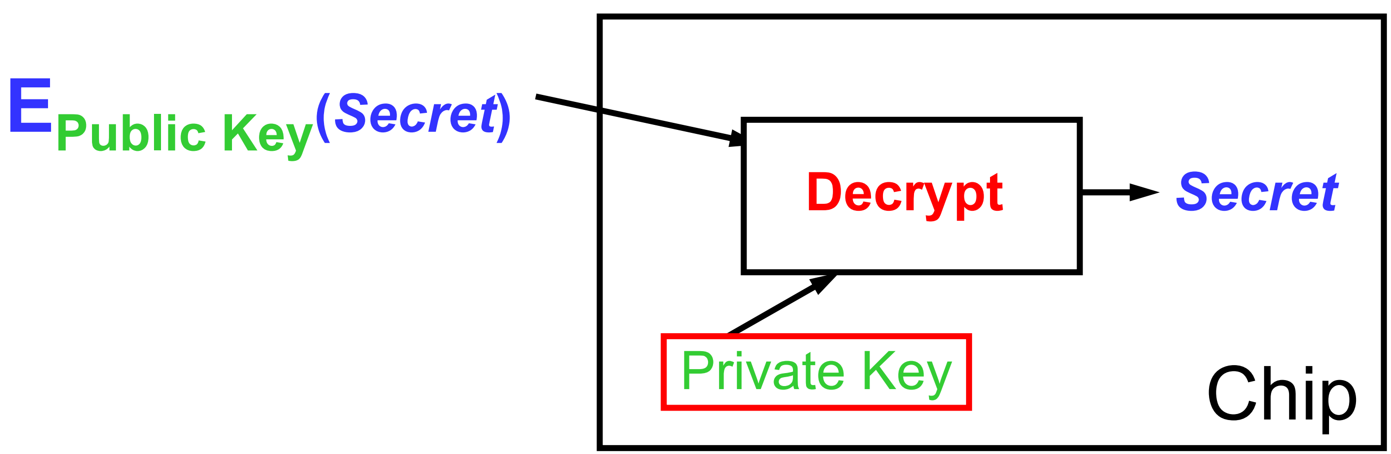


Private/Public Keys

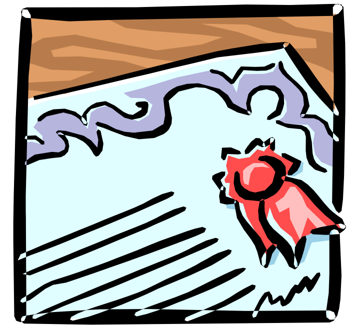
If a remote chip stores a private key, Alice can *share a secret* with the chip since she knows the public key corresponding to the stored private key

Encrypt *Secret* using chip's public key

Only the chip can decrypt *Secret* using the stored private key



Applications

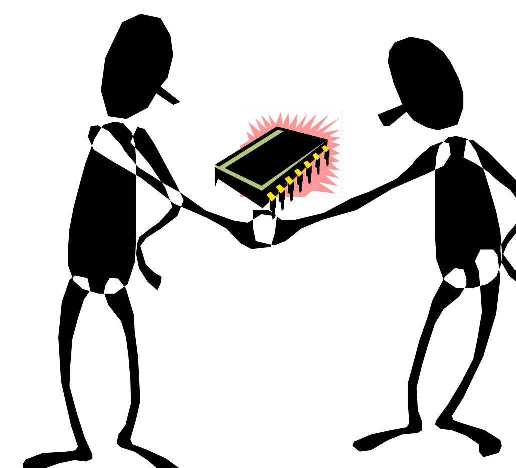


- **Anonymous Computation**

  Alice wants to run computations on Bob's computer, and wants to make sure that she is getting correct results. A certificate is returned with her results to show that they were correctly executed.

- **Software Licensing**

  Alice wants to sell Bob a program which will only run on Bob's chip (identified by a PUF). The program is copy-protected so it will not run on any other chip.



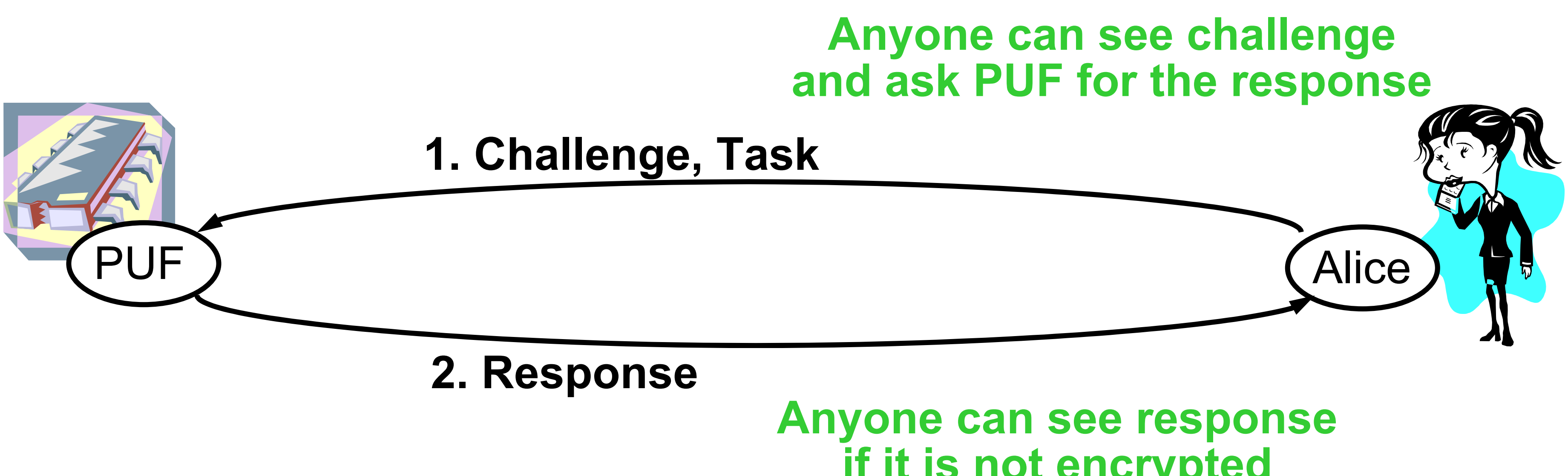
How can we enable the above applications by trusting only a single-chip processor that contains a silicon PUF?

Sharing a Secret with a Silicon PUF

Suppose Alice wishes to share a secret with the silicon PUF

She has a challenge response pair that no one else knows, which can authenticate the PUF

She asks the PUF for the response to a challenge

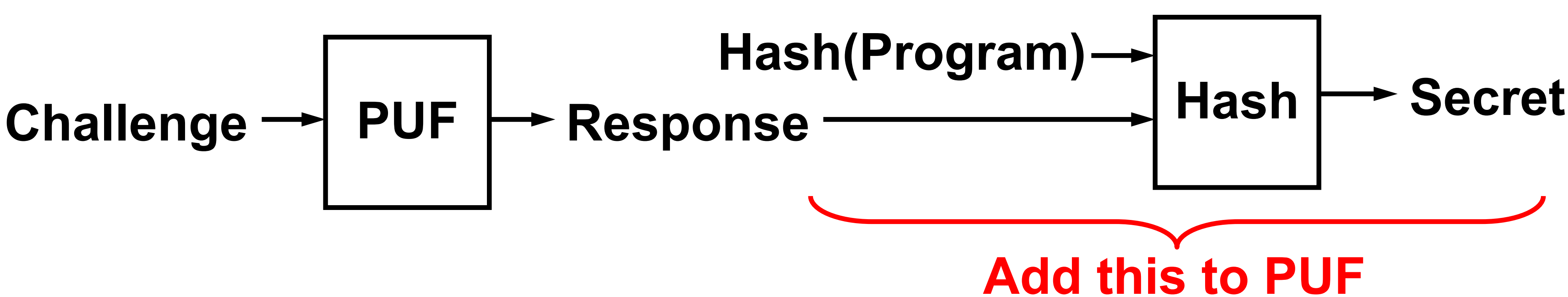


Restricting Access to the PUF

- To prevent the attack, the man in the middle must be prevented from finding out the response.
- Alice's program must be able to establish a shared secret with the PUF, the attacker's program must not be able to get the secret.

$\Rightarrow$ **Combine response with hash of program.**

- The PUF can only be accessed via the GetSecret function:



Getting a Challenge-Response Pair

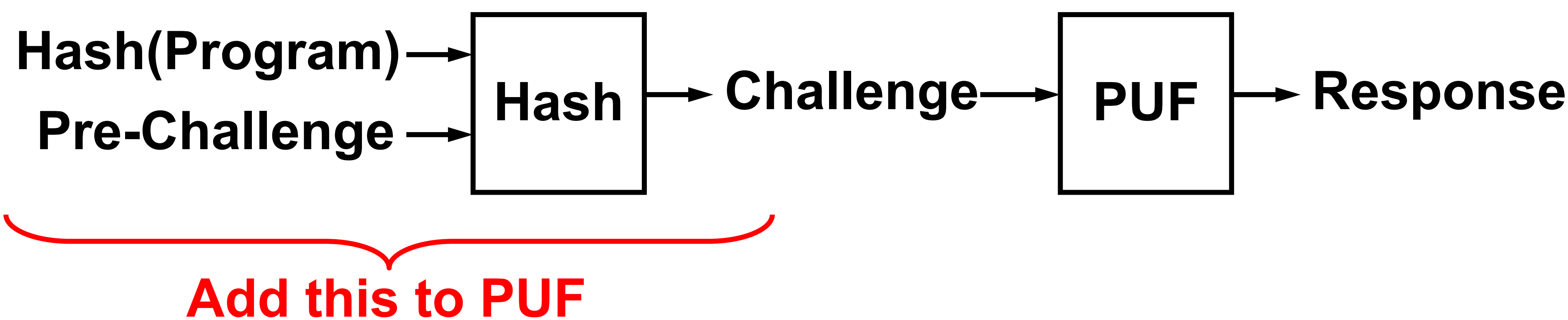
- Now Alice can use a Challenge-Response pair to generate a shared secret with the PUF equipped device.

- But Alice can't get a Challenge-Response pair in the first place since the PUF never releases responses directly.

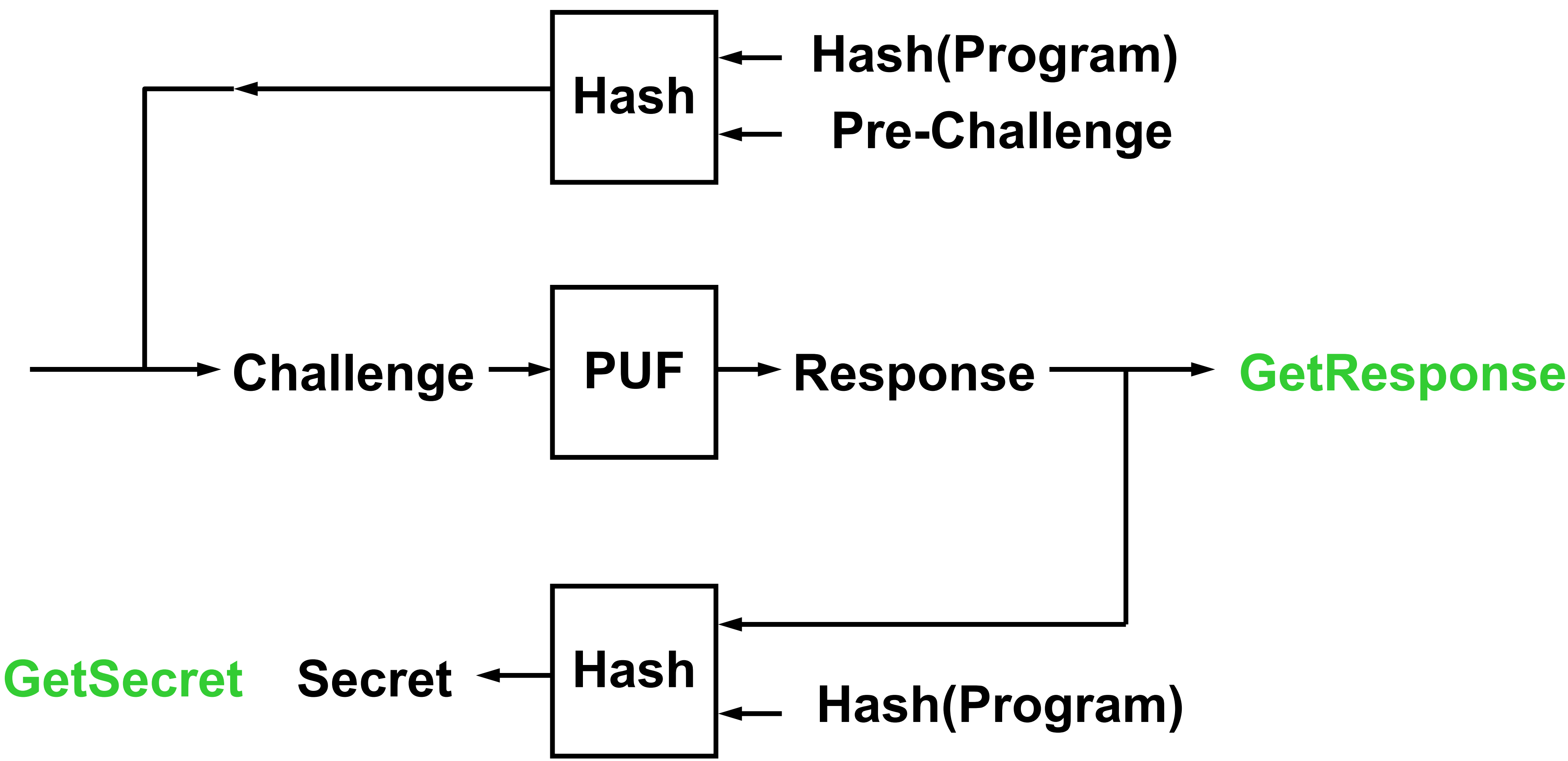
$\Rightarrow$ An extra function that can return responses is needed.

Getting a Challenge-Response Pair - 2

- Let Alice use a Pre-Challenge.
- Use program hash to prevent eavesdroppers from using the pre-challenge.
- The PUF has a GetResponse function



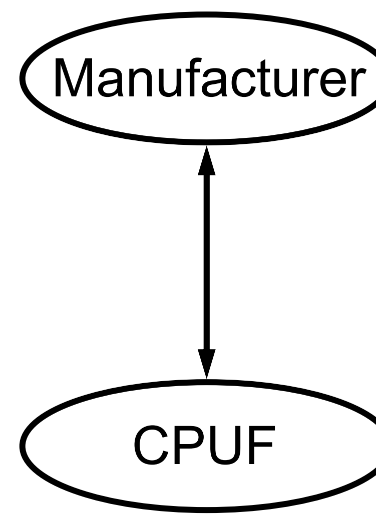
Controlled PUF Implementation



Challenge-Response Pair Management: Bootstrapping

When a CPUF has just been produced, the manufacturer wants to generate a challenge-response pair.

1. **Manufacturer provides Pre-challenge and Program.**
2. **CPUF produces Response.**
3. **Manufacturer gets Challenge by computing Hash(Hash(Program), PreChallenge).**
4. **Manufacturer has (Challenge, Response) pair where Challenge, Program, and Hash(Program) are public, but Response is not known to anyone since Pre-challenge is thrown away**



Software Licensing

$$\left.\begin{array}{l}\text{Program (Ecode, Challenge)}\\ \quad \text{Secret = GetSecret(Challenge)}\\ \quad \text{Code = Decrypt(Ecode, Secret)}\\ \quad \text{Run Code}\end{array}\right\}\ \text{Hash(Program)}$$

Ecode has been encrypted with Secret by Manufacturer

Software Licensing

Program (Ecode, Challenge)

  Secret = GetSecret(Challenge)

  Code = Decrypt(Ecode, Secret)

  Run Code

Hash(Program)

Ecode has been encrypted with Secret by Manufacturer

Secret is known to the manufacturer because he knows Response to Challenge and can compute

  Secret = Hash(Hash(Program), Response)

Software Licensing

Program (Ecode, Challenge)

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Ecode has been encrypted with Secret by Manufacturer

Secret is known to the manufacturer because he knows Response to Challenge and can compute

Secret = Hash(Hash(Program), Response)

Adversary cannot determine Secret because he does not know Response or Pre-Challenge

If adversary tries a different program, a different secret will be generated because Hash(Program) is different

Summary

- PUFs provide secret "key" and CPUFs enable sharing a secret with a hardware device
- CPUFs are not susceptible to model-building attack if we assume physical attacks cannot discover the PUF response
  - Control protects PUF by obfuscating response, and PUF protects the control from attacks by "covering up" the control logic
  - Shared secrets are volatile
- Lots of open questions…