Pensieve: Microarchitectural Modeling for Formal Security Evaluation

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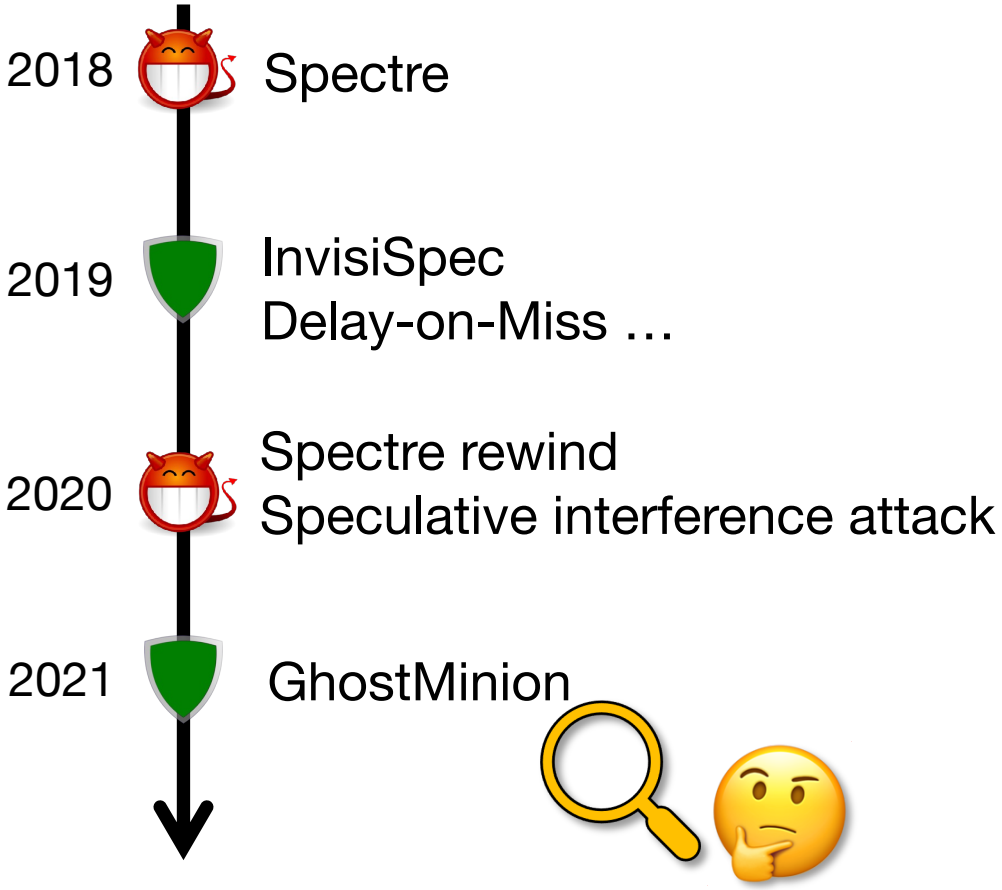
Problem: the Cat-and-Mouse Game



Problem: Weak Security Evaluation

Step 1:

Defense Proposal → 

→

↑ Spectre Attack

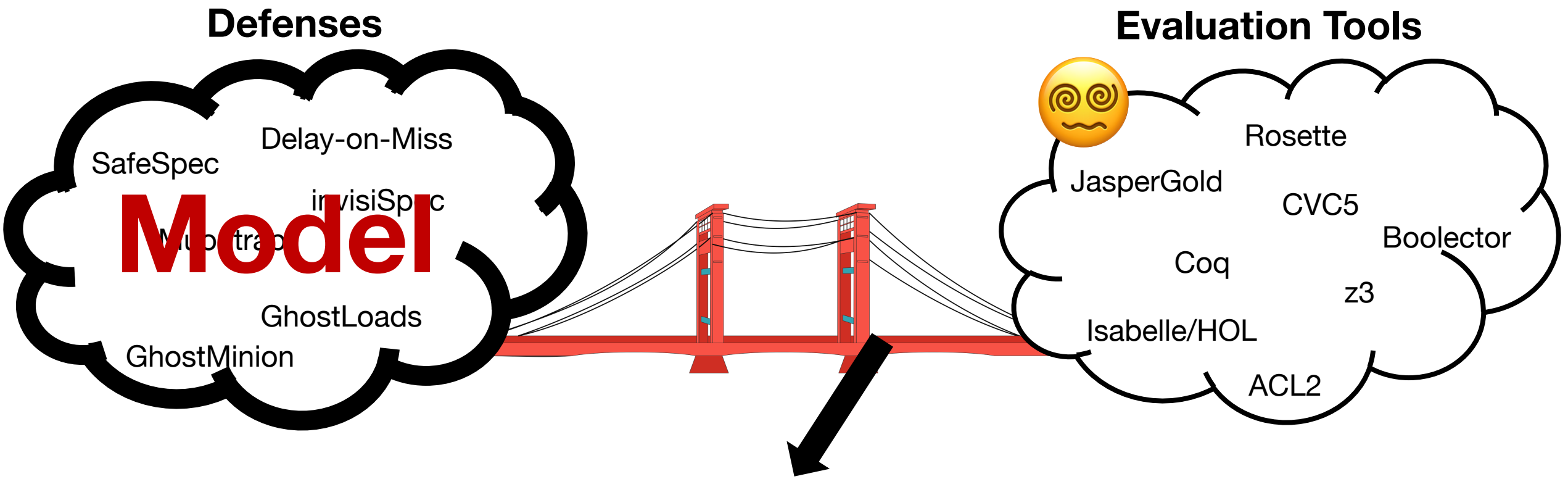
Step 2:

The defense works for all possible attack variations.

?

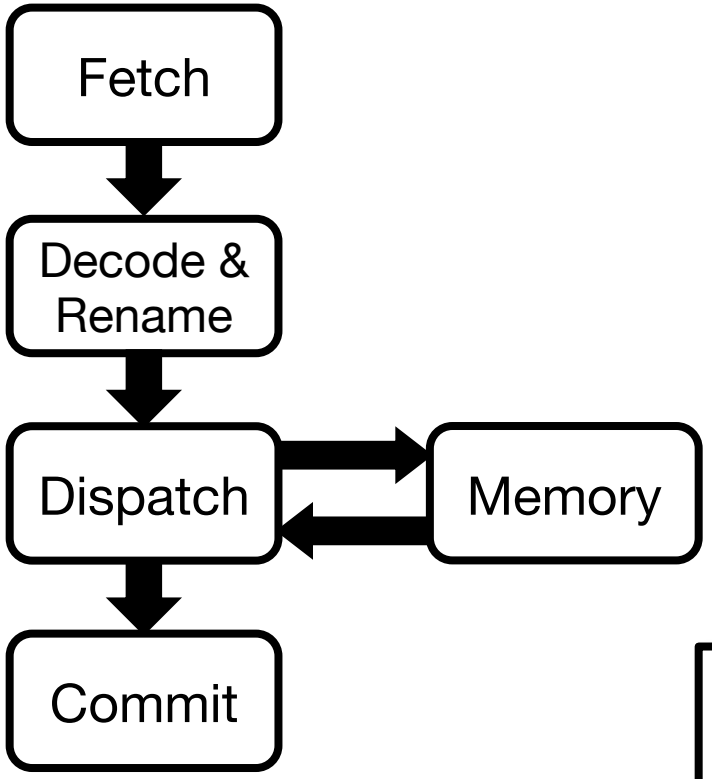
We need a principled, trustworthy security evaluation tool!

Challenge: Bridge the Gap

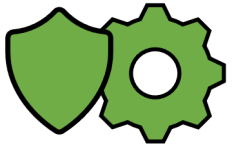


Aligned with architectural design flow.

Defense Design flow



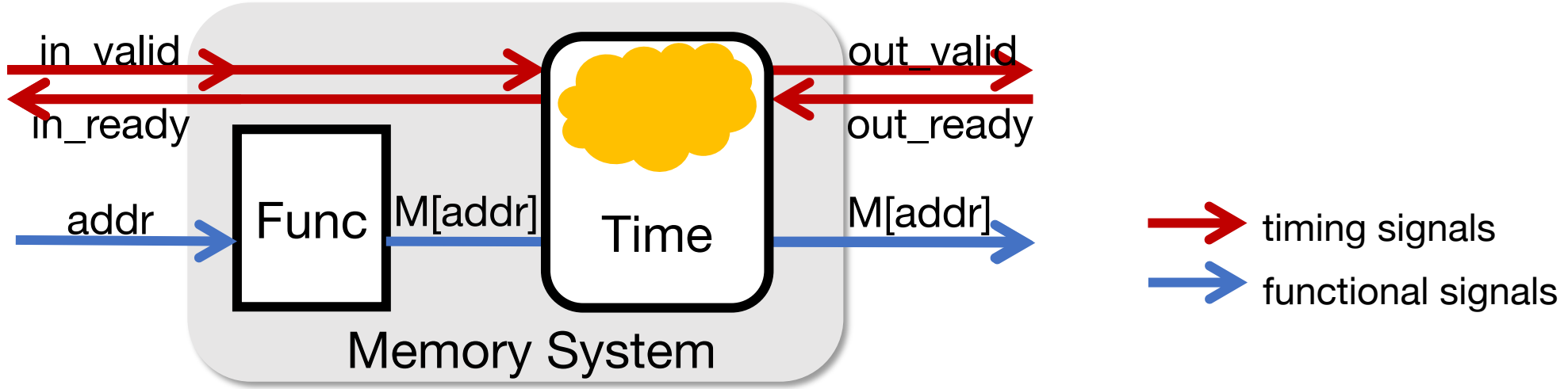
Example: delay speculative requests



An architecture modeling method should be
1. Modular
2. Precise on describing timing behaviors
3. Represent a space of designs

Pensieve Modeling

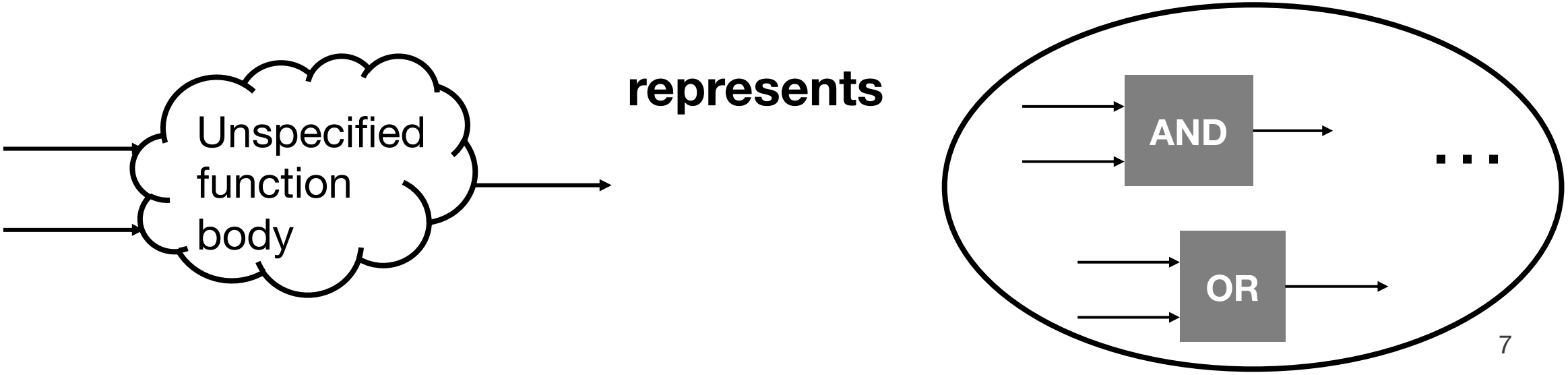
- Decouple timing and functionality using the hand-shaking interface
- Represent a space of timing behavior



An architecture modeling method should be
1. Modular ✓
2. Precise on describing timing behaviors ✓
3. Represent a space of designs ?

Uninterpreted Function (UF)

- A UF represents space of functions with the same input/output types
  - Example: `Bool UF(Bool, Bool)`
- UF helps us
  - state "**what**" affects the output,
  - abstract away the details on "**how**" the input affects the output



Pensieve Modeling: Using UFs

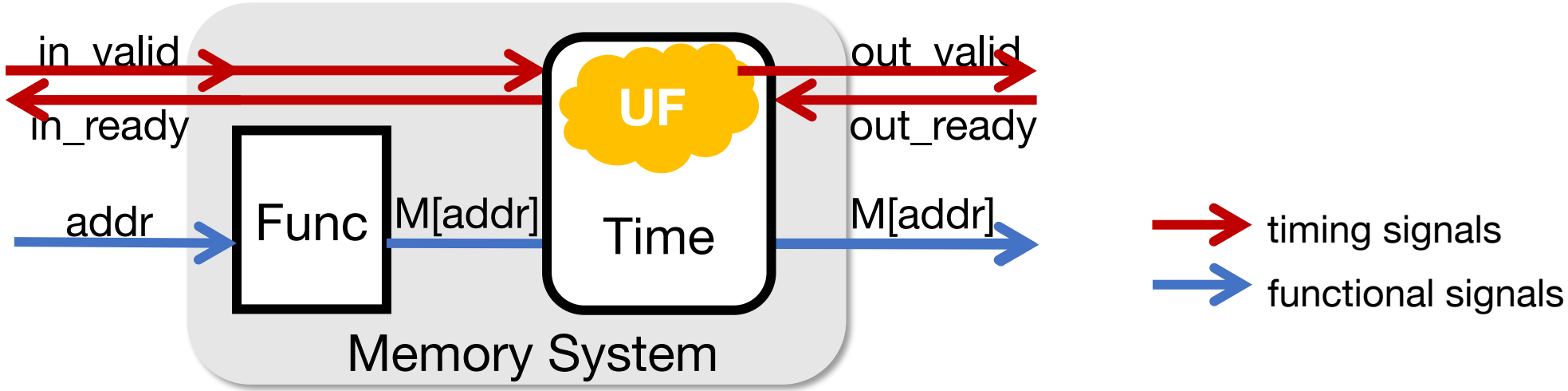
- Examples:

```
Multiply_req_latency = UF(historyOf(in_valid))

Multiply_req_latency = UF(historyOf(in_valid, in_operands))

  Memory_req_latency = UF(historyOf(in_valid, in_addr))
```

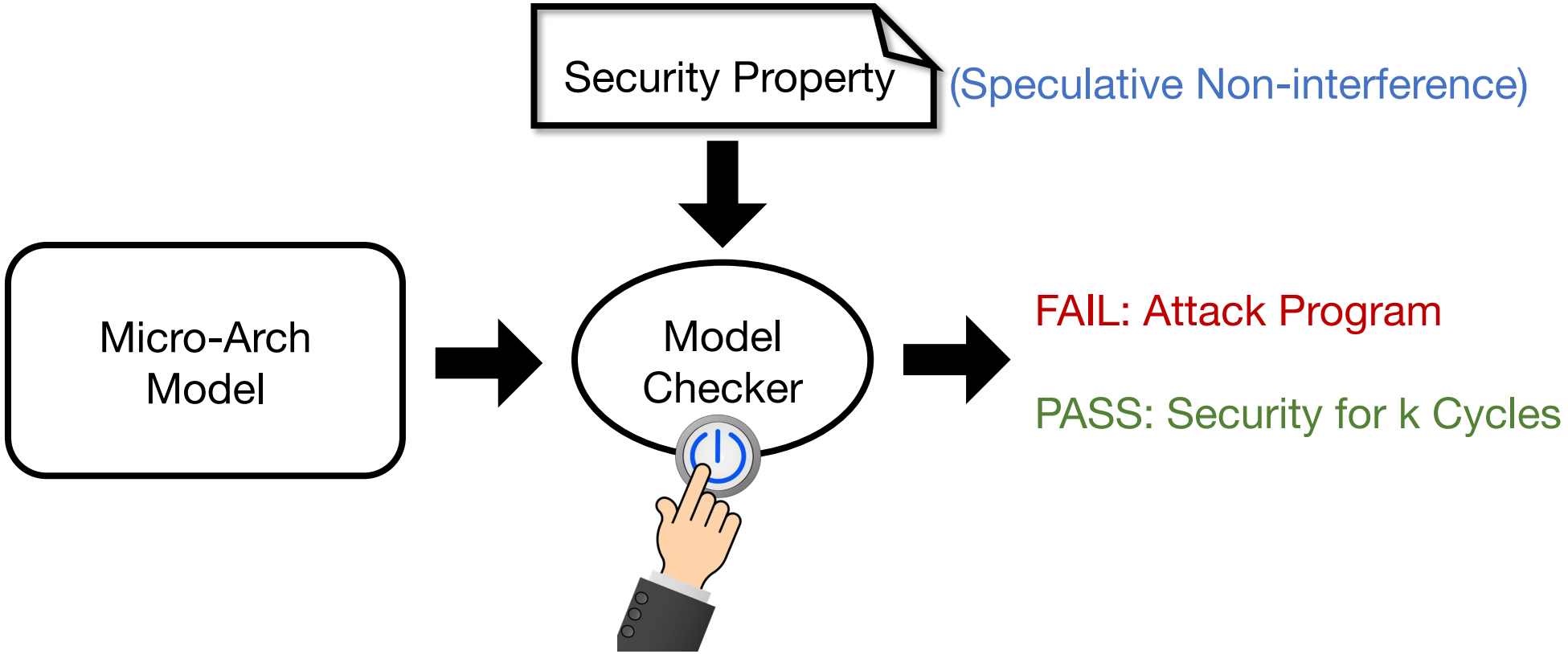
Pensieve can use **simple** models to cover
space of microarchitectures with **complex** timing behaviors

Pensieve Modeling

- Decouple timing and functionality using the hand-shaking interface
- Represent a space of timing behavior with uninterpreted functions



Pensieve Security Evaluation Framework



Pensieve finds **unknown** security vulnerabilities in the latest speculative execution defense, i.e., GhostMinion [2021]

New Attack on GhostMinion Summary

Takeaway: Manual evaluation can easily be unsound, we need Pensieve, a trustworthy evaluation tool