AIGROW: A Feedback-Driven Test Generation Framework for Hardware Model Checkers

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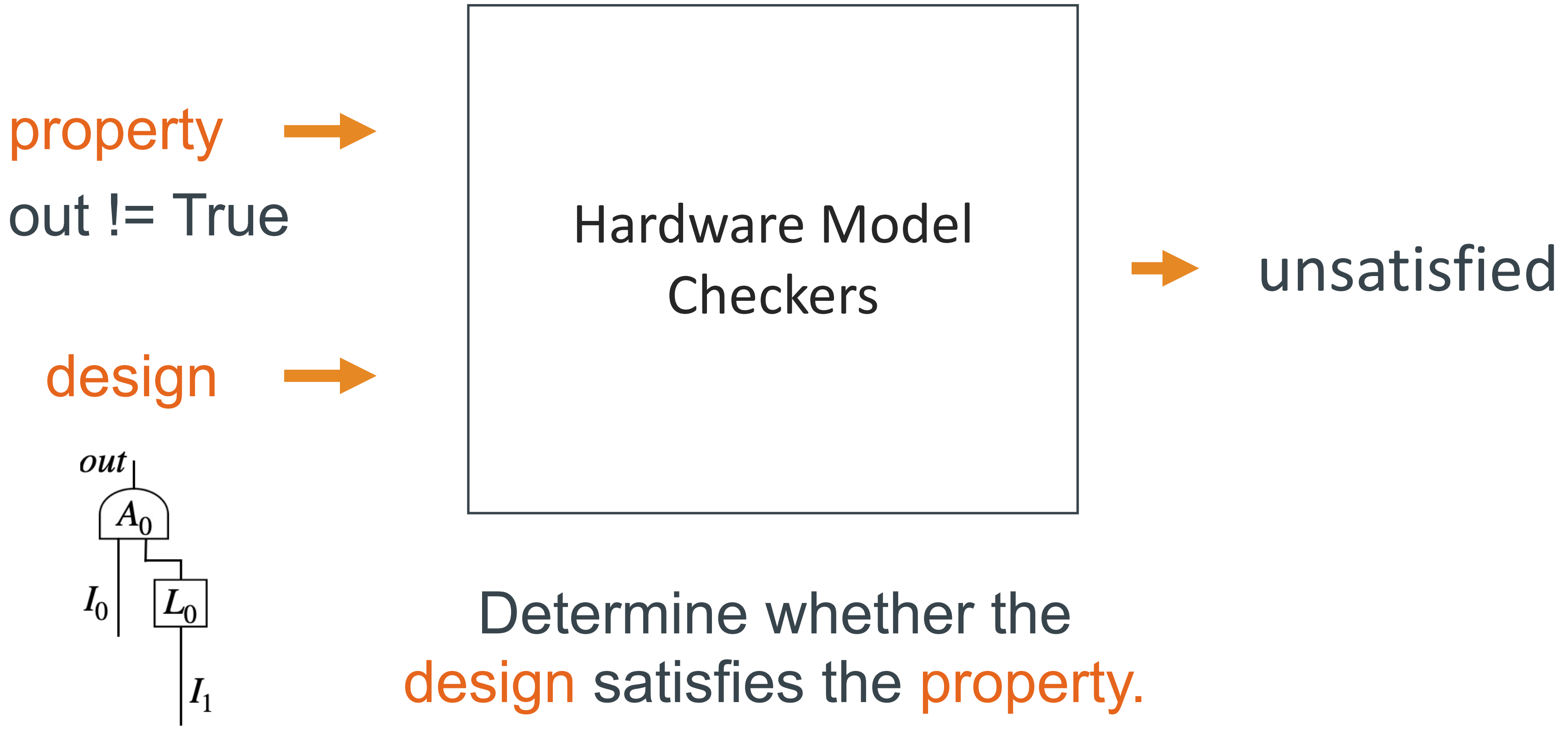
Hardware Model Checkers

the tools for validating the implementation of hardware designs



property

out != True

design

Hardware Model Checkers

unsatisfied

Determine whether the design satisfies the property.

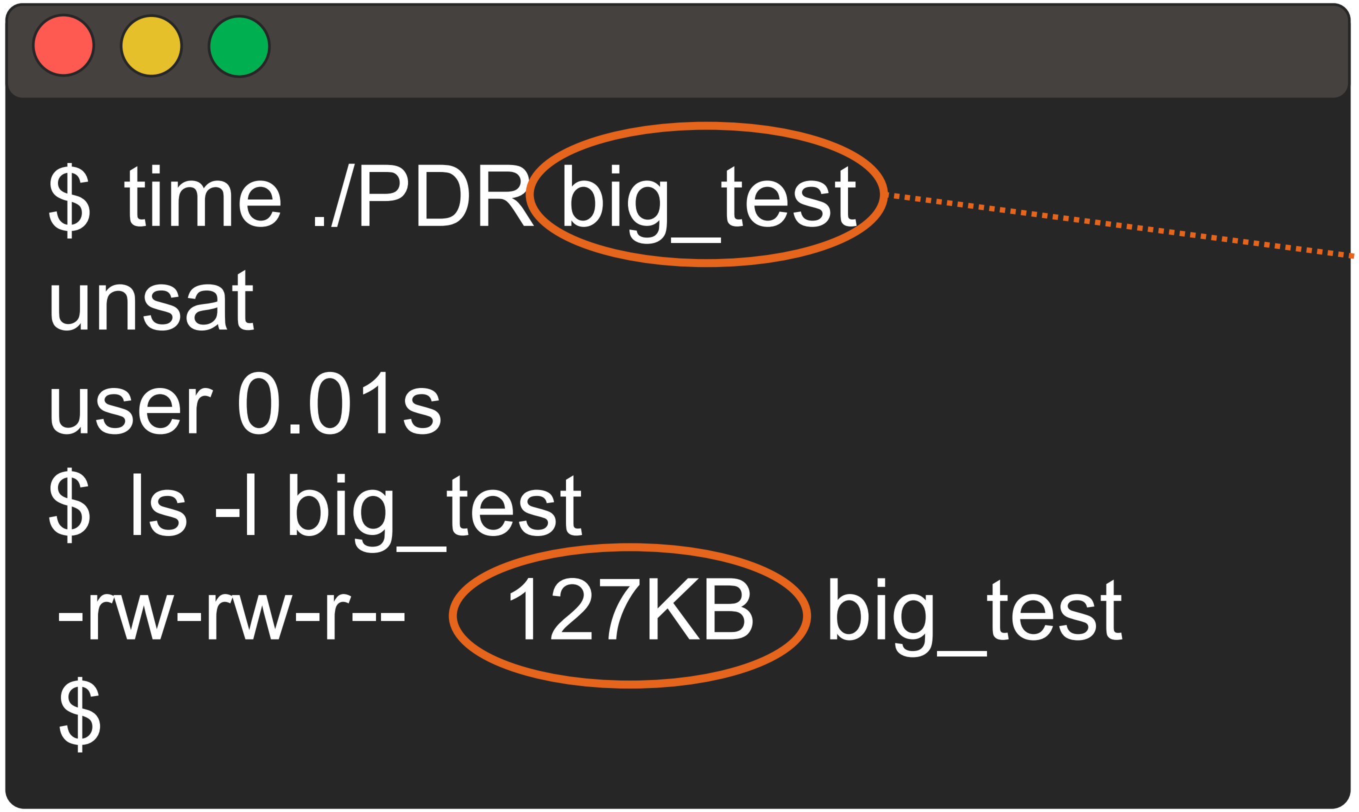
Hardware Model Checkers

the tools for validating the implementation of hardware designs

They should be intensively **evaluated!**

Hardware Model Checkers

PDR: a mature hardware model checker

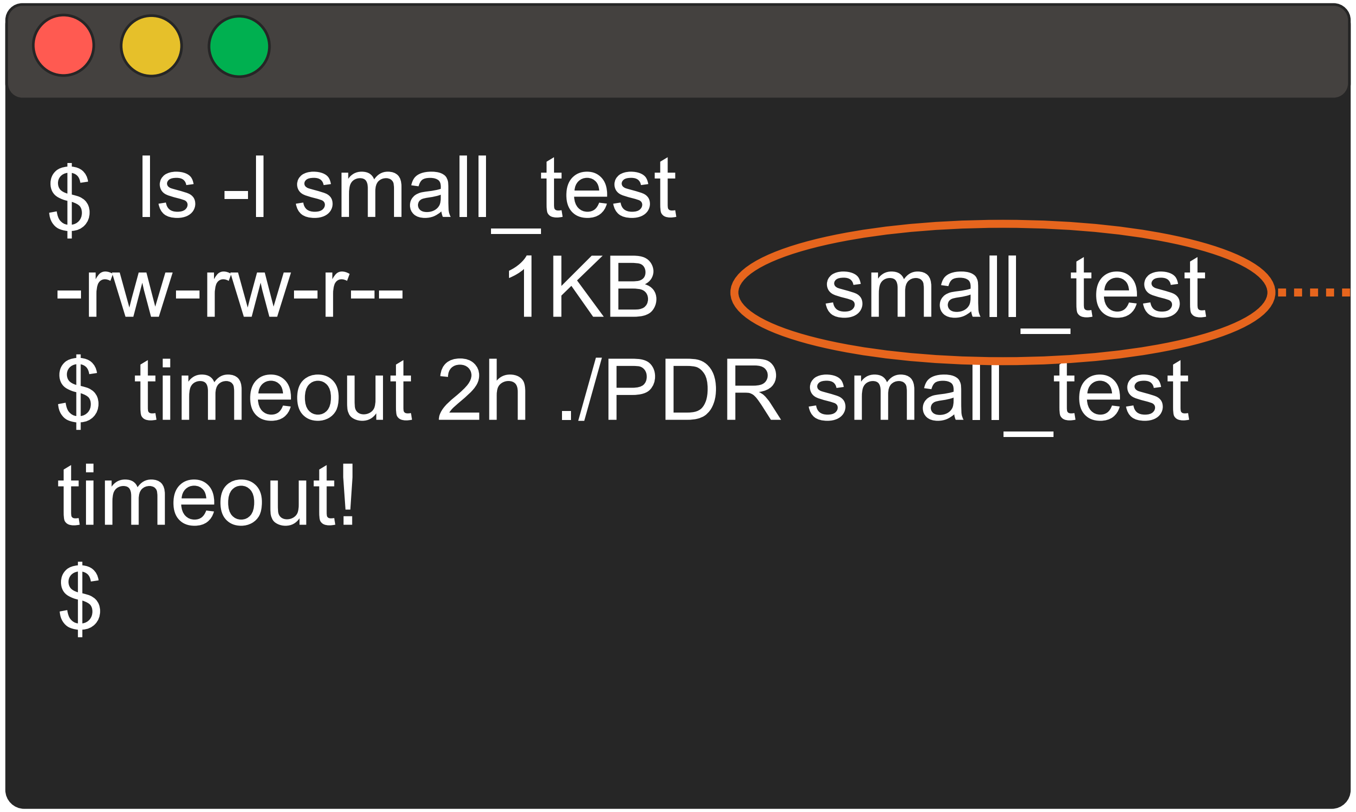


```
$ time ./PDR big_test
unsat
user 0.01s
$ ls -l big_test
 -rw-rw-r--   127KB  big_test
 $
```

From Intel.zip

Hardware Model Checkers

PDR: a mature hardware model checker



```
$  ls -l small_test
-rw-rw-r--    1KB    small_test
$ timeout 2h ./PDR small_test
timeout!
$
```

High-quality test

Difficult

Small size

Diverse

Hard to obtain!

Introduction

Why high-quality tests are hard to obtain?

Source of Tests	Availability	Difficulty	Avg. size	Diversity
Real world benchmarks	no	**yes**	large	**high**
generation tools				
Our approach				

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AIGEN[1]				
AIGFUZZ[2]				
Our approach				

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Our approach	**yes**	**yes**	**small**	**high**

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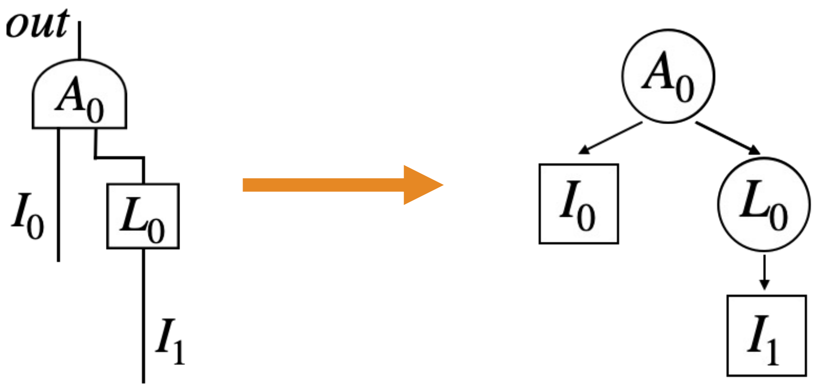
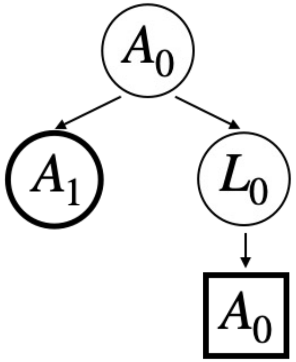
Our approach is to **incrementally generate** tests with **feedback**.

Our Approach: Incremental Generation



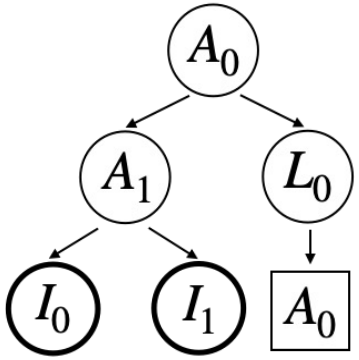
Remove Inputs

Our Approach: Incremental Generation



Add Nodes

Our Approach: Incremental Generation



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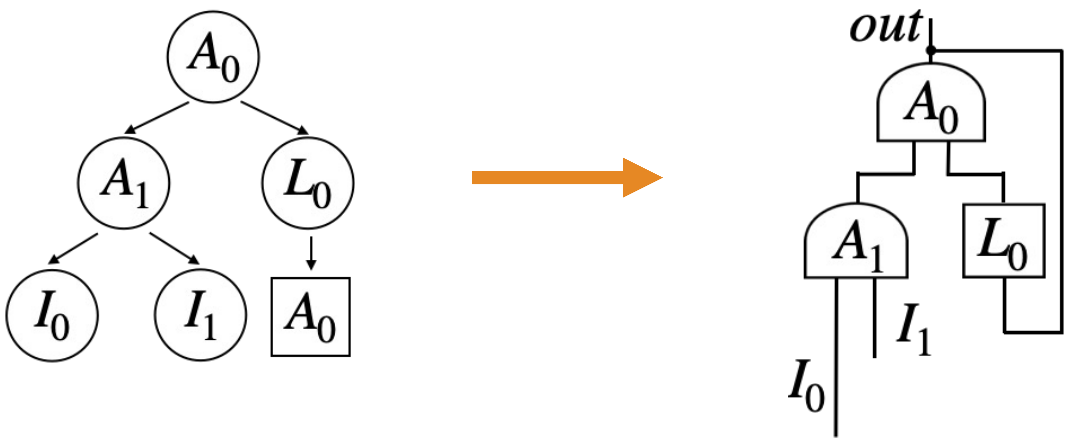
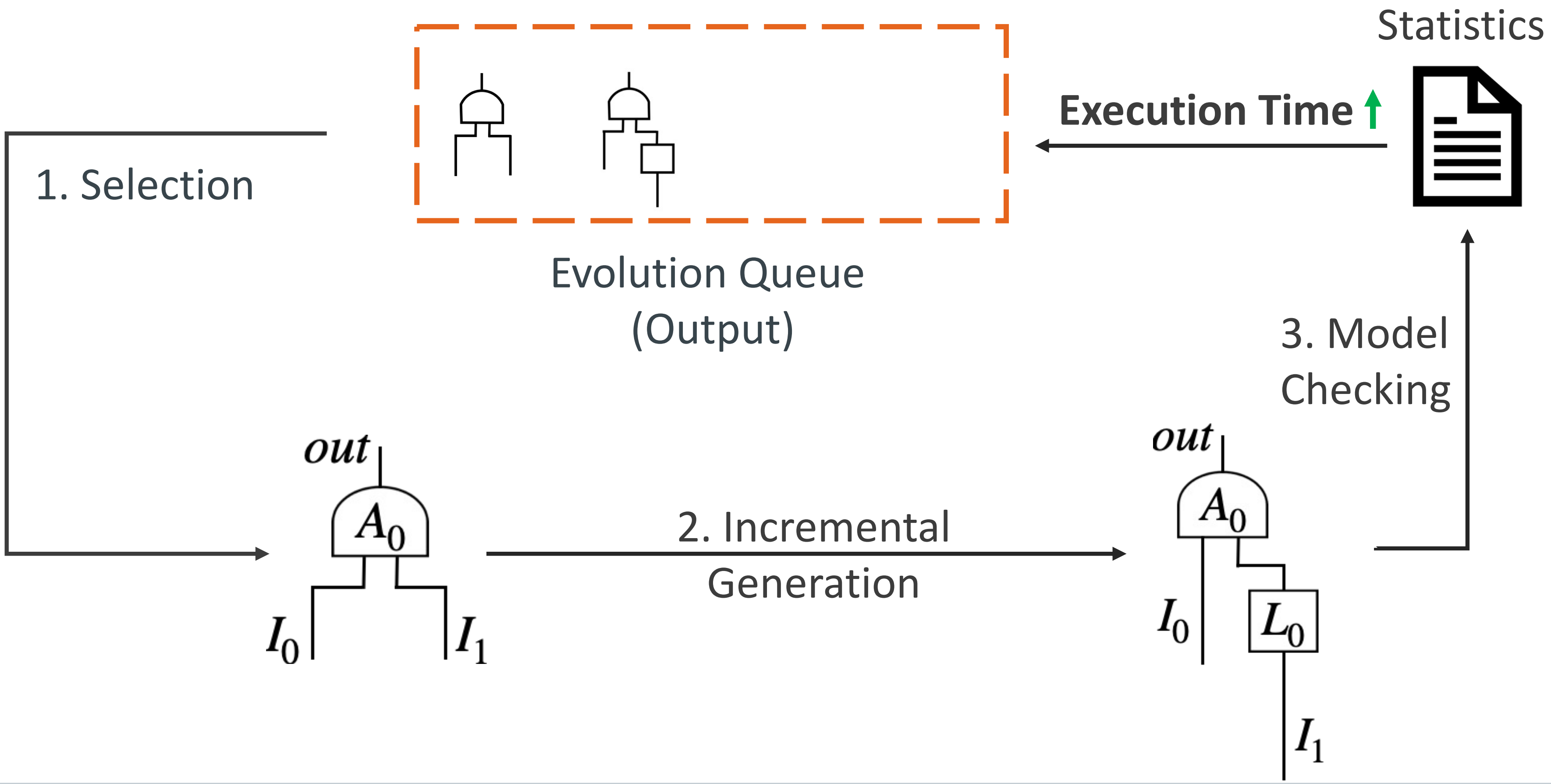


Our Feedback-Driven Framework: AIGROW



Statistics

Execution Time ↑

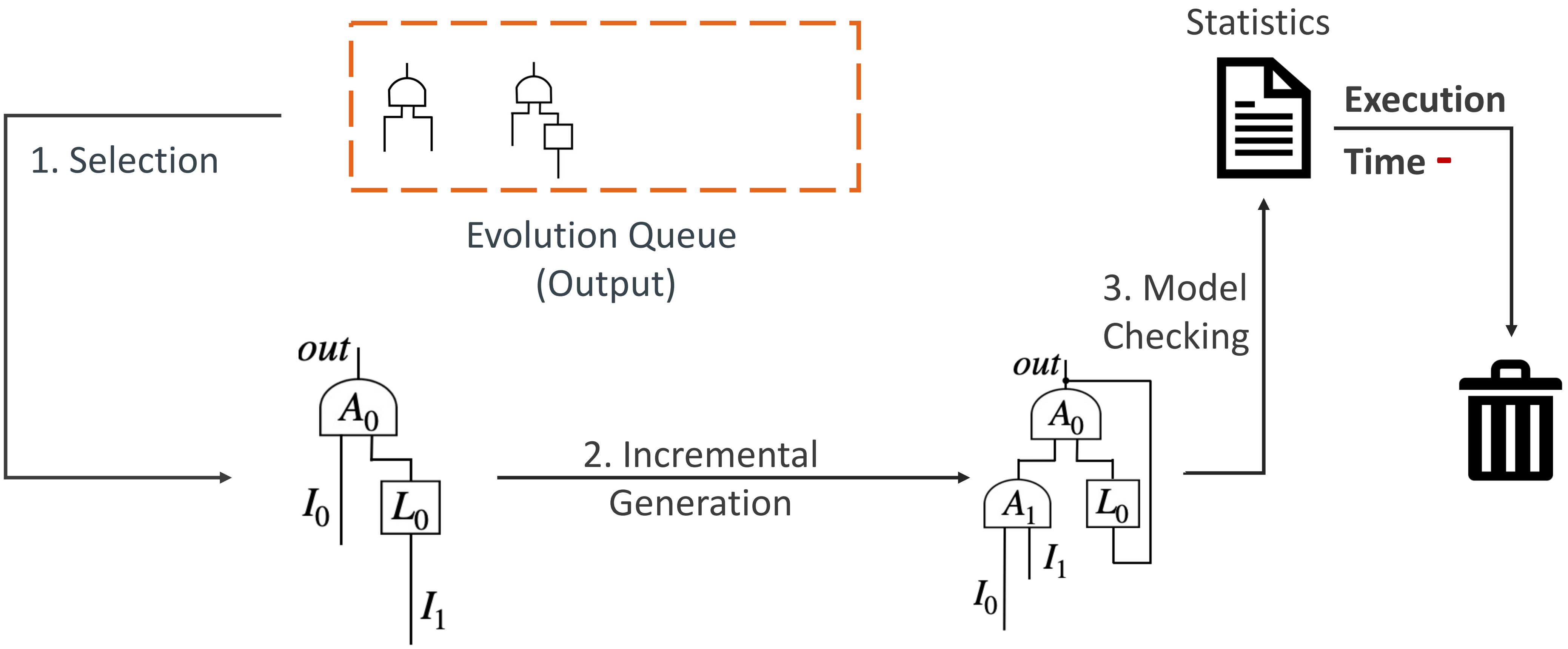
1. Selection

Evolution Queue (Output)

2. Incremental Generation

3. Model Checking

Our Feedback-Driven Framework: AIGROW



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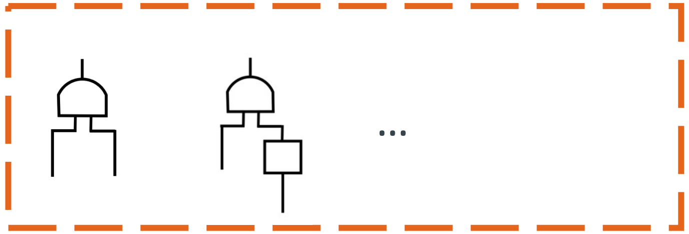


Evolution Queue
(Output)

Evaluation Setting

Testing targets

PDR: a mature hardware model checker

IC3ref: a reference implementation of IC3 algorithm

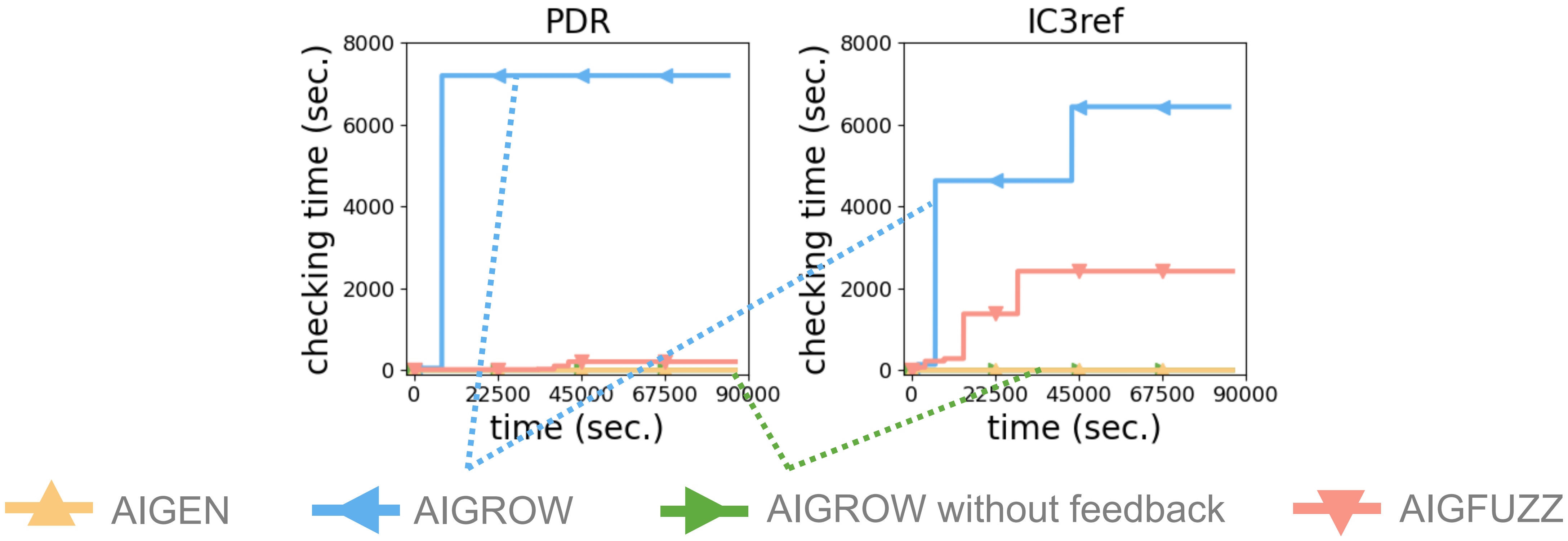
Evaluation metrics

Difficulty: checking time (sec.)

Size: #units

Diversity: line coverage (%)

Result: Difficulty



AIGROW generates **more difficult** tests.

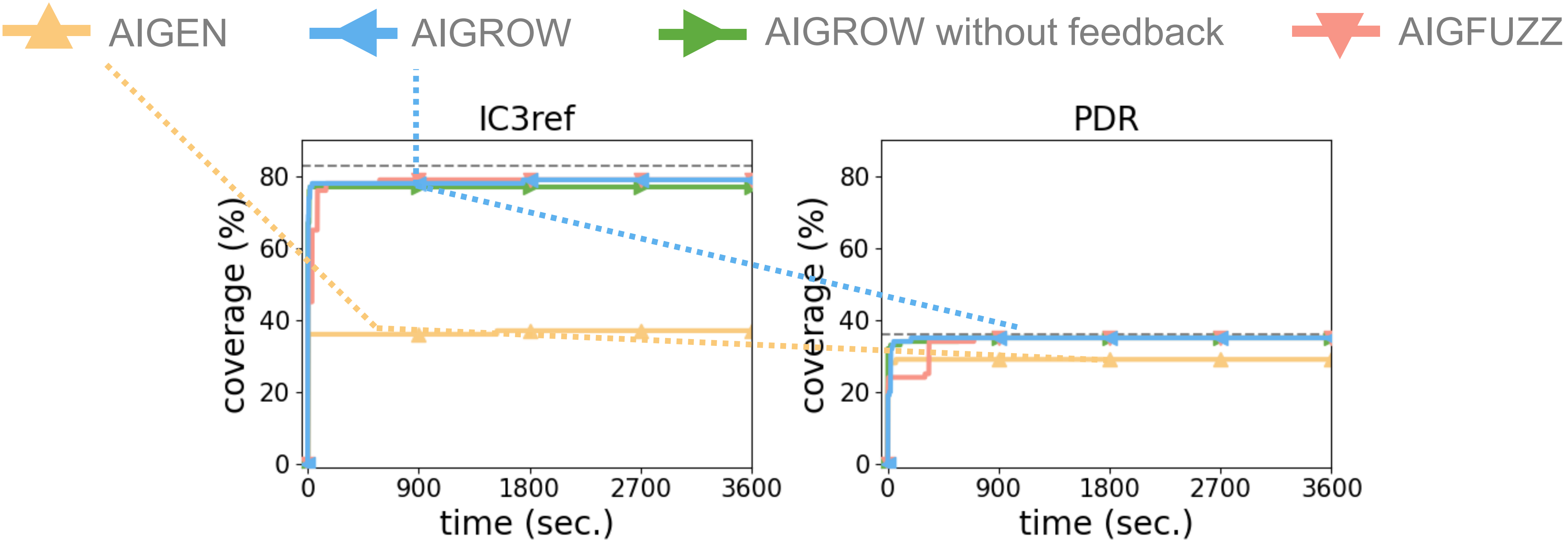
Feedback strategy make difference in generating difficult tests.

Result: Avg. Size (#units)

Hardware Model Checker	AIGROW	AIGEN	AIGFUZZ
PDR	**109**	6,871	1,910
IC3ref	**40**	6,867	1,940

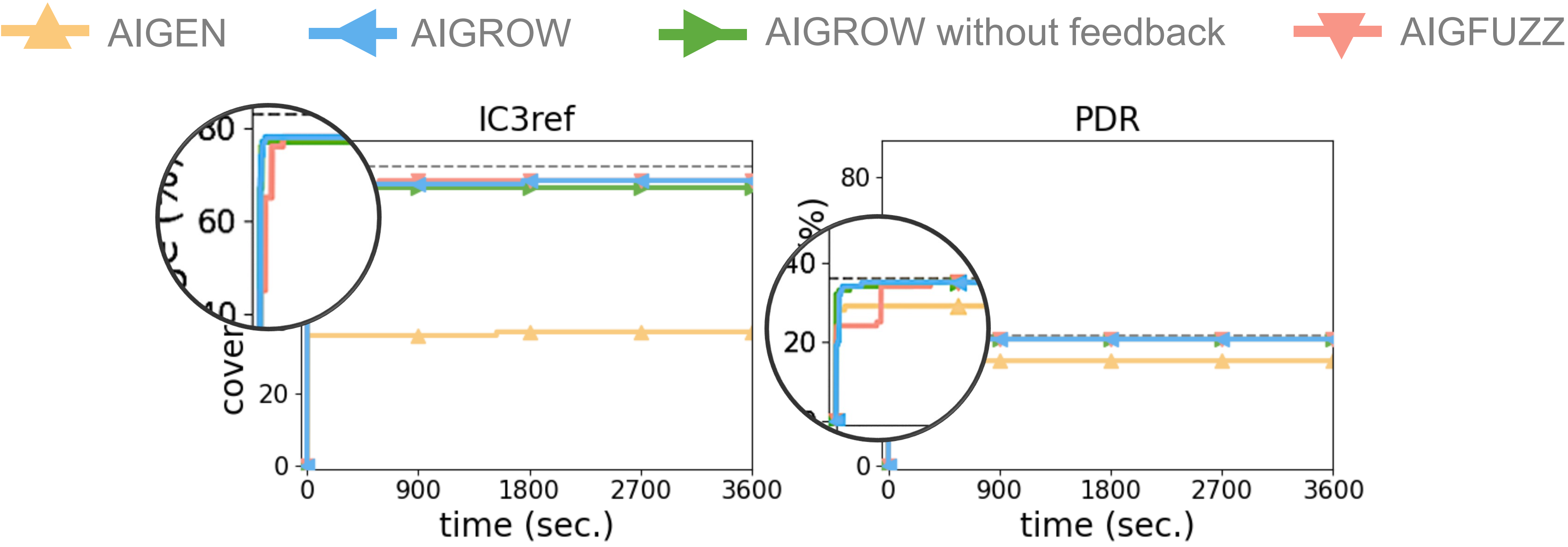
The avg. size of the tests generated by AIGROW is **10x smaller** than AIGEN and AIGFUZZ

Result: Coverage



AIGROW achieves **higher coverage** than AIGEN.

Result: Coverage



AIGROW achieves **higher coverage** than AIGEN.

AIGROW achieves the maximum coverage **faster** than AIGFUZZ.

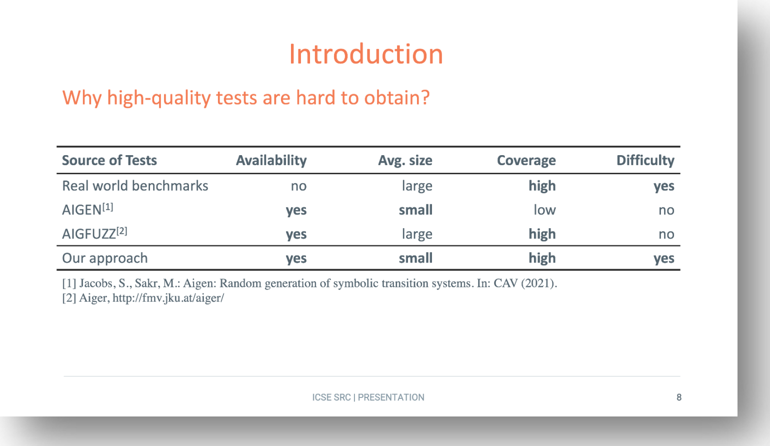
Future Work

- Apply this approach to test other **model-based design tools.**

SIMULINK VIVADO™

- Our preliminary investigation found **21 critical bugs** in the model-based design tool of our industry partner.

Conclusion



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Our approach	**yes**	**small**	**high**	**yes**

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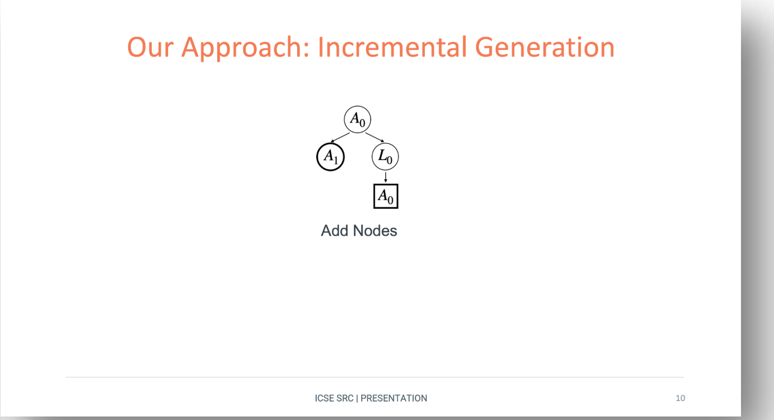
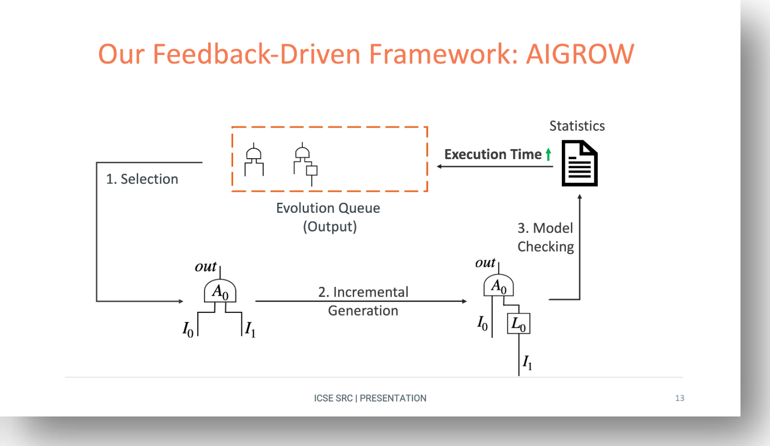
ICSE SRC | PRESENTATION 8



Our Approach: Incremental Generation

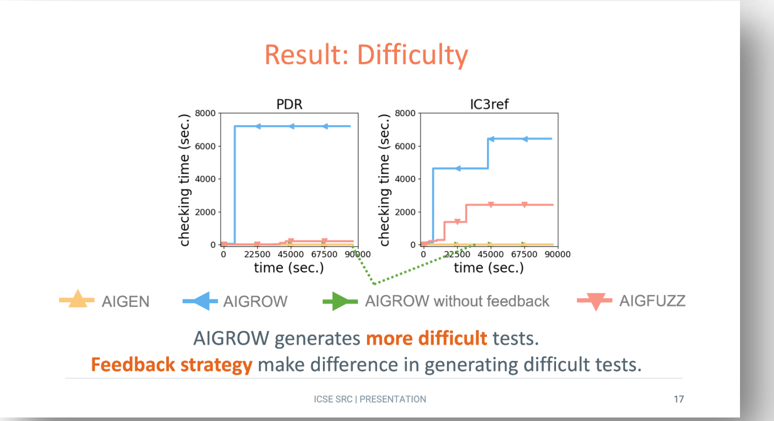
Add Nodes

ICSE SRC | PRESENTATION 10



Our Feedback-Driven Framework: AIGROW

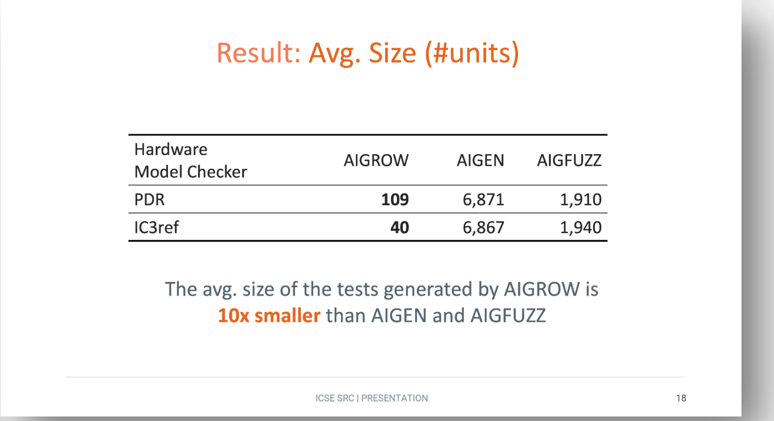
ICSE SRC | PRESENTATION 13



Result: Difficulty

AIGROW generates **more difficult** tests.
Feedback strategy make difference in generating difficult tests.

ICSE SRC | PRESENTATION 17



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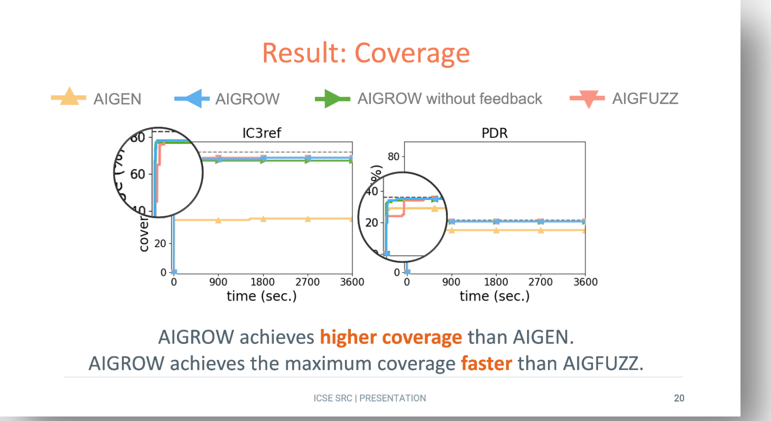
ICSE SRC | PRESENTATION 18



Result: Coverage

AIGROW achieves **higher coverage** than AIGEN.
AIGROW achieves the maximum coverage **faster** than AIGFUZZ.

ICSE SRC | PRESENTATION 20

Take-aways

Approach

- **Incremental generation** guided by **feedback**

Perform better than existing tools

- Generate **more difficult** test cases.
- Achieve maximum coverage **faster.**
- **Fewer redundant units** in a single test.

Introduction

Why high-quality tests are hard to obtain?

Def. High-quality Tests.

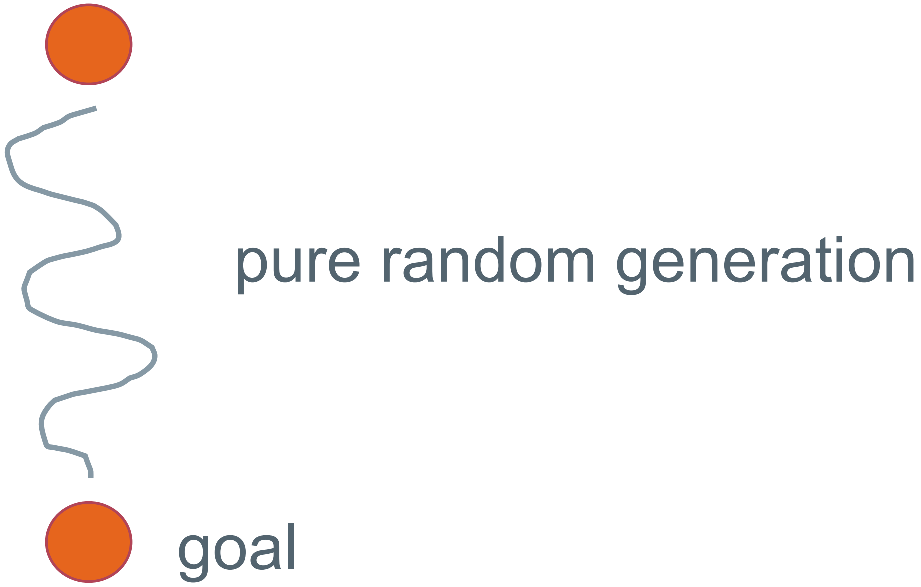
• **Hard to solve**	**Evaluation**
• **Diverse** among tests	**Validation**
• **Fewer redundant units** in a single test	**Debug**

Source of Tests	Always available	Fewer Redundant Units	Diverse	Hard to Solve
Real world	**no**	**no**	**yes**	**yes**
AIGEN	**yes**	**yes**	**no**	**no**
AIGFUZZ	**yes**	**no**	**yes**	**no**

Our Approach avoid these shortcomings.

Approach

Our Approach is to **incrementally** generate tests with **feedback.**



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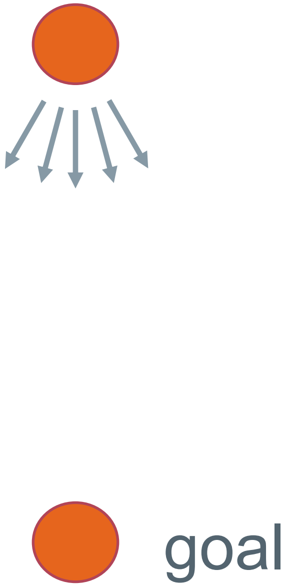

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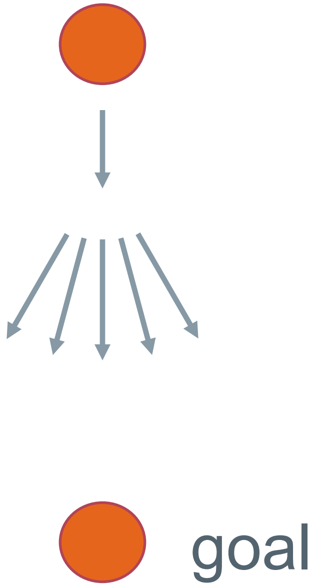

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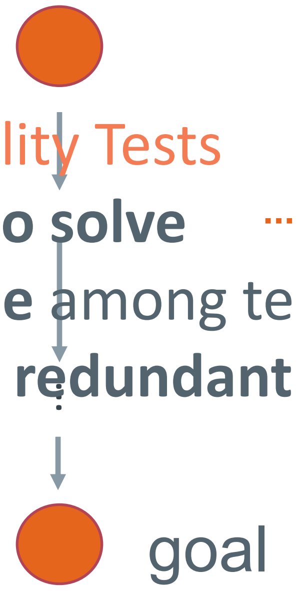


High-quality Tests

- **Hard to solve** .... Solving time
- **Diverse** among tests .... Coverage
- **Fewer redundant units** in a single test

Layout

Background

Introduction

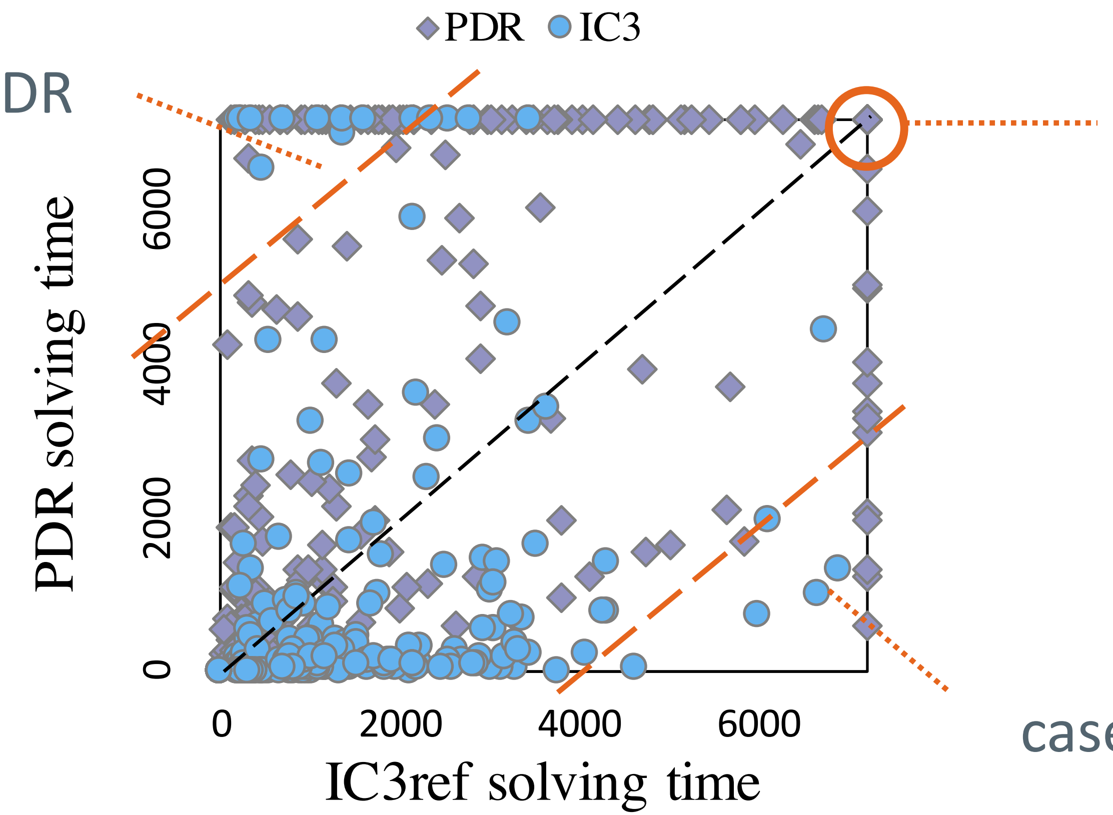
Approach

Result

Take-away

Diversity of Our Benchmarks

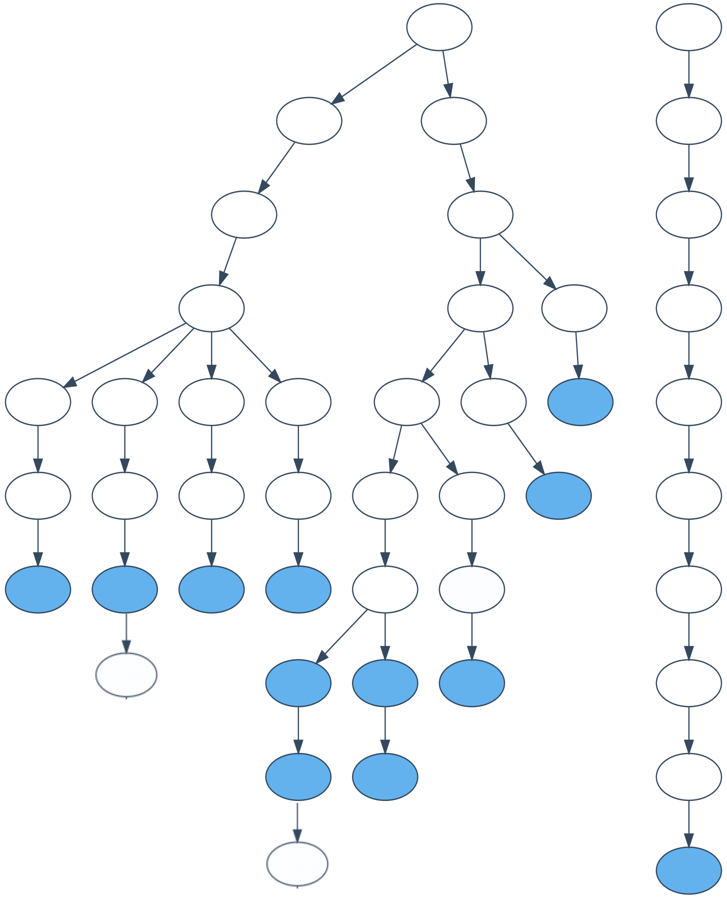
cases: IC3ref << PDR



73 cases: hard to solve for both

cases: IC3ref >> PDR

Generation Process for PDR



Background

Def. Hardware Model Checkers.

The tools for validating the implementation of hardware designs.

Hardware model checkers should be intensively **validated** and **evaluated.**

High-quality tests

hard to obtain!