

# Reaching 100% Coverage Using Formal



Haifa Verification Conference

Jamil R. Mazzawi

Ziyad Hanna

Jasper Design Automation

# It's Time for 100% Coverage with Formal, on Most Blocks

- Formal verification can deliver 100% coverage
- Capacity bottleneck has dramatically improved
  - ➔ **More blocks can achieve 100% coverage**
- Industry is rapidly adopting formal verification

# Two Main Coverage Measures

- Verification/coverage completeness is assessed by answering these two categories of questions
- Exhaustiveness measure:
  - Did we cover all “important” corner cases?
  - All “interesting” scenarios?
  - And all configurations?
- Checkers completeness measure:
  - Did we write enough checkers?
  - Do all the required outputs and states of the design match the spec or reference model?

# Exhaustiveness Measure

- Dynamic verification

- Exhaustiveness is hard/impossible to reach
- Lots of work and energy is put into achieving or getting close to exhaustiveness using different tools and technologies
- Use functional and code coverage as heuristics to assess exhaustiveness
  - Build functional coverage model
  - The verification grand loop
    - Run many simulations
    - Examine coverage results
    - Write more tests to cover missing corner cases
    - Refine functional coverage model
  - Stop when you feel you are done, you're tired, or it's tape-out time

- Formal verification

- All proven properties are 100% covered
- Exhaustiveness is achieved by definition

# Checker Completeness Measure

- Problem not completely solved, yet
- Dynamic verification
  - Review meetings are the only available “tool”
  - **Mostly manual process**
- Formal verification
  - Since exhaustiveness is achieved, teams and tools have more energy to focus on this problem
  - Design state coverage is used to find areas unchecked by any assertion (property density)
  - **Automated tools used as heuristics in verification review meeting**

# Achieving 100% on Both Measures => 100% Verification/Coverage

Checkers completeness  
measure

100%

100%  
Coverage

- Dynamic :  
Two issues to handle
- Formal:  
One is solved one to go

100% Exhaustiveness measure

# Formal Industry's Dramatic Changes in the Past 10-15 Years

- Past

- Academic exercise
- Used at handful of huge companies, building their own tools
- Used mostly by dedicated “formal experts” with formal-PhD
- User needed to know formal theories to make tools works (white box)
- Very limited design size (capacity bottleneck)
- Used mostly on control blocks

- Present

- Essential tool for verification teams at many chip companies
- Tools used mostly as a black box, no need to know the underlying theories to use them
- Used by the “normal” verification/design engineers
- Verification manager has flexibility to assign more engineers to do formal tasks
- Used on more and more kinds of designs
- Capacity improved orders of magnitude
  - Now formal can handle 100k and 400k flop designs

- Formal technology has improved in two ways

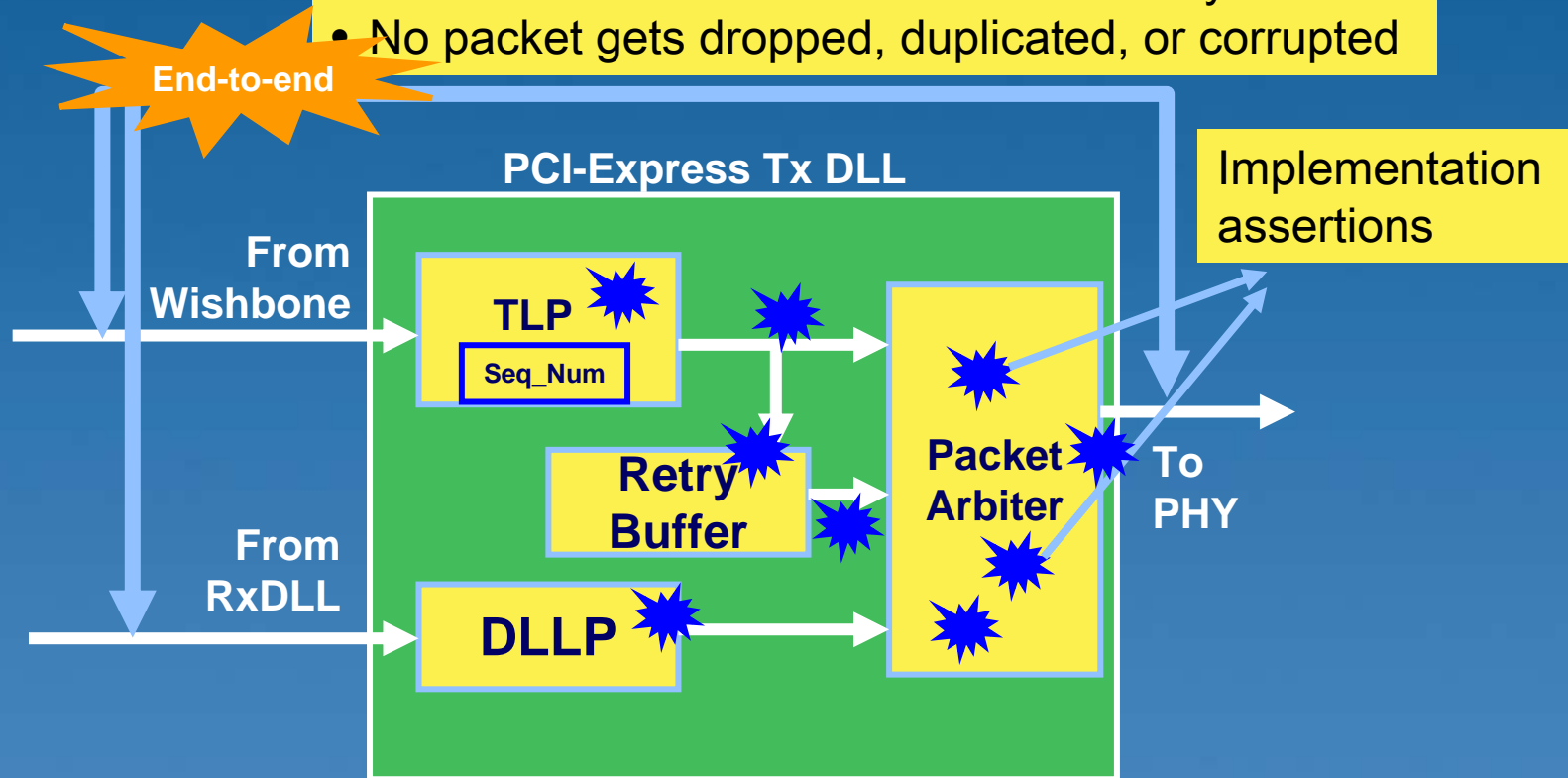
- Formal engine technology advancement (under the hood)
- Methodology advancement (over the hood)



# Capacity Improvements Allow End-to-End Properties

- Past: Formal users had to write many small, implementation-level properties
- Now: We can do end-to-end properties
  - Complete block-level verification of micro-architecture properties

- Packets must exit in the same order they came in
- No packet gets dropped, duplicated, or corrupted





# End-to-End Properties Make It Easier to Reach 100% Coverage

- Exhaustiveness measure:
  - Complete, properties are formally proven
- Checkers measure
  - Much easier to achieve with end-to-end properties

# Summary

- Coverage has two main dimensions or measures
  - Exhaustiveness measure: How well I have exercised my design?
  - Checkers completeness measure: Did I write enough checkers?
- In dynamic verification, most of the focus and energy goes into achieving high level of exhaustiveness
- Formal verification achieves 100% exhaustiveness on all proven checkers by definition, hence more energy (tools, methodologies, and practice) goes to completeness measure
- Dynamic verification industry needs to put more energy and focus on the checker completeness measure (tools, methodologies, and practice)
- Formal technology has dramatically improved in the past years
  - Capacity improvements
  - Formal is used on a wide range of problems
  - End-to-end properties can be proven now
- Capacity improvements in formal allow end-to-end properties to be proven
  - This makes higher achievements easier on the checker-completeness measure, hence high or 100% coverage

