



Democratization of Formal Verification with Collective Intelligence

Formal Methods in Computer-Aided Design - Austin, Texas, USA, September 28, 2015

Ziyad Hanna, PhD.
Vice President of R&D
Cadence Design Systems

Software and verification driving SoC project costs

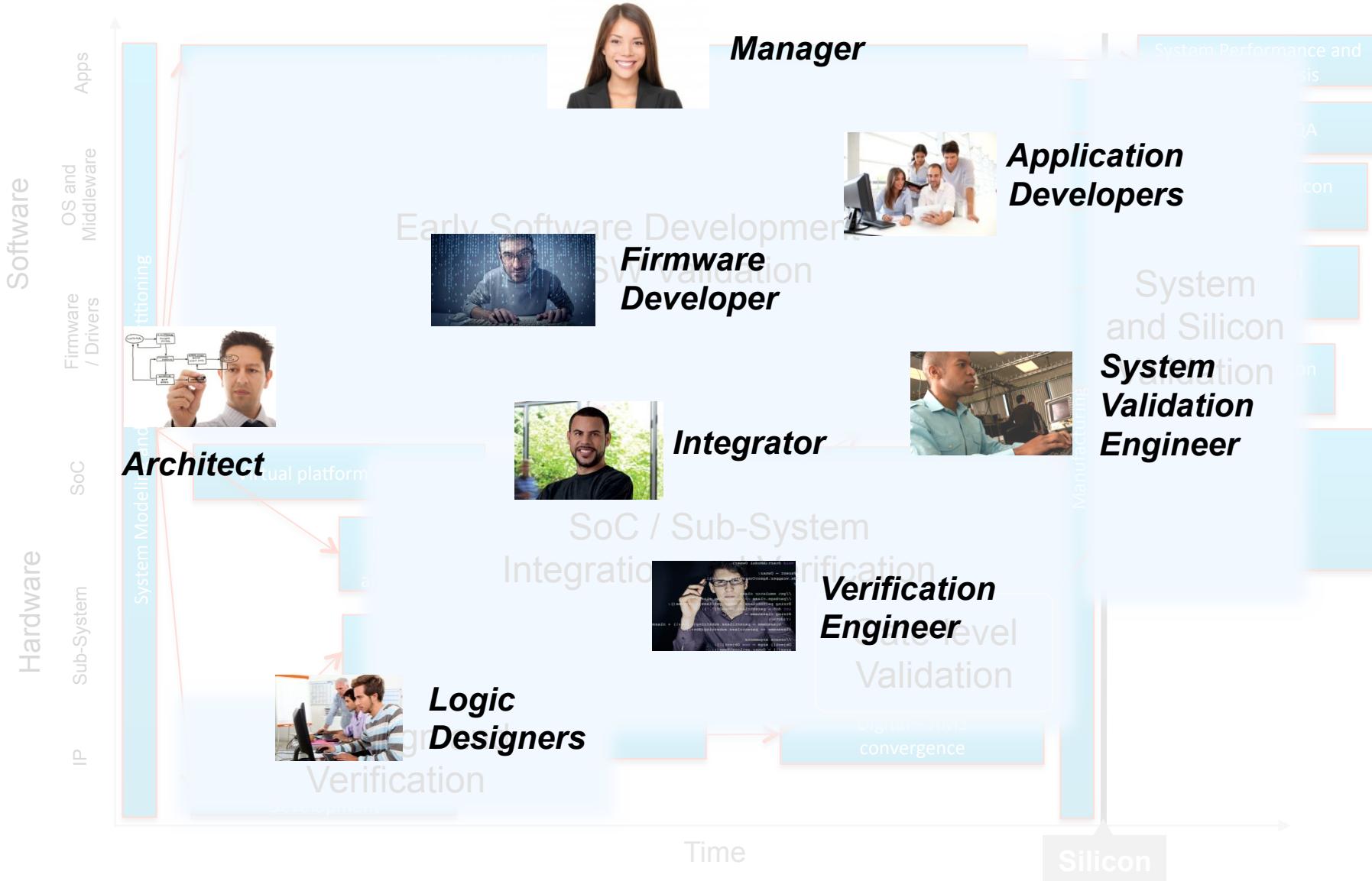
80% of overall development costs, mostly in headcount



Source: IBS July 2013

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Ever-growing system development complexity



Agenda

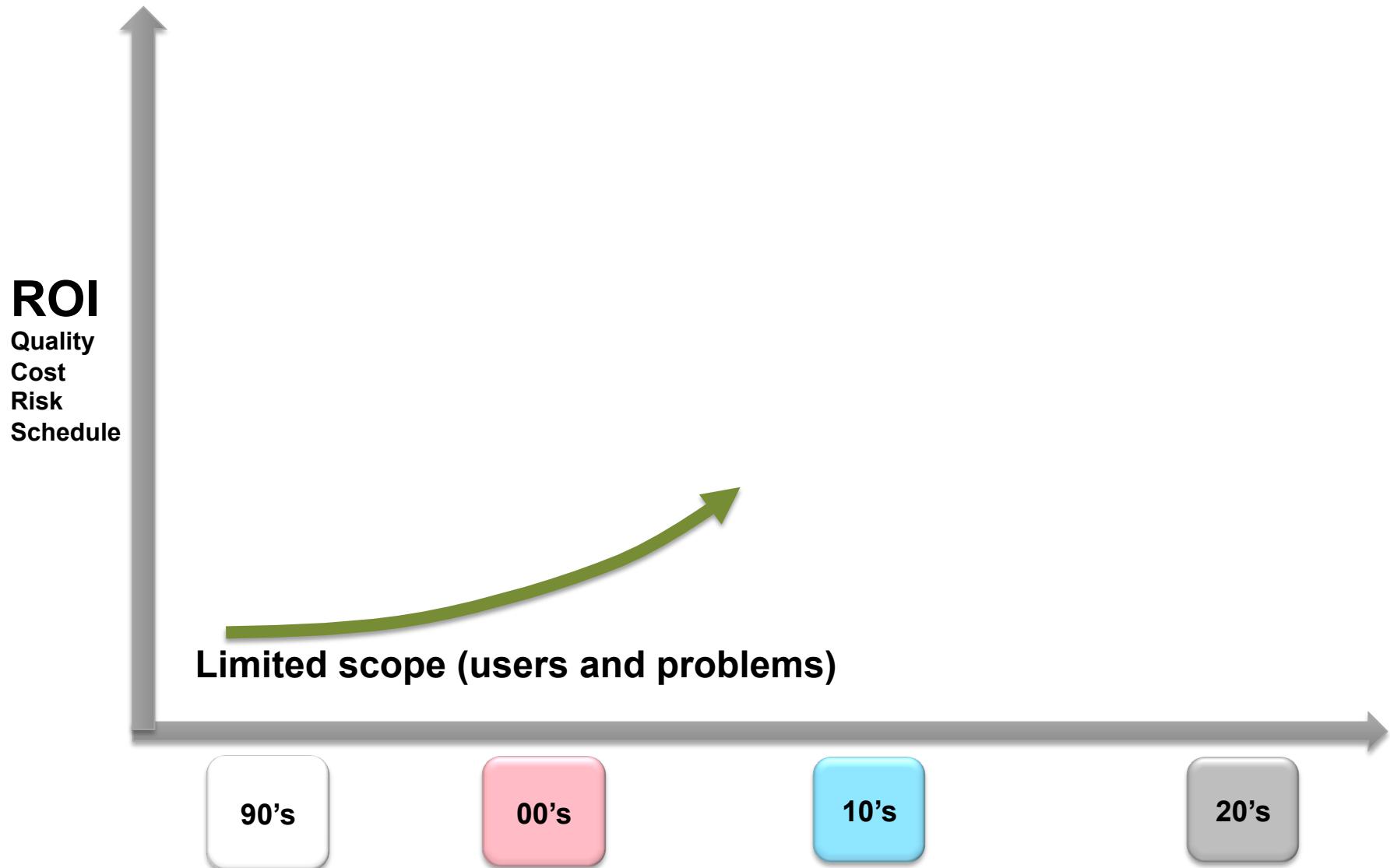
Formal Verification Adoption

Formal Verification Vision

Democratization of Formal

Forward Looking

Disruptive Formal Verification



2007 Turing Award

Groundbreaking work on Model Checking.



Edmund M. Clarke, E. Allen Emerson, Joseph Sifakis

Writing Spec...



IEEE STANDARDS ASSOCIATION



IEEE Standard for SystemVerilog— Unified Hardware Design, Specification, and Verification Language

IEEE Computer Society
and the
IEEE Standards Association Corporate Advisory Group

Sponsored by the
Design Automation Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

21 February 2013

IEEE Std 1800™-2012
(Revision of
IEEE Std 1800-2009)

Big Companies Pioneered Formal

“Replacing Testing with Formal Verification in Intel® Core™ i7 Processor Execution Engine Validation” – CAV 2009

Roope Kaivola, Rajnish Ghughal, Naren Narasimhan, Amber Telfer, Jesse Whittemore, Sudhindra Pandav, Anna Slobodová, Christopher Taylor, Vladimir Frolov, Erik Reeber, Armaghan Naik

“Automatic Verification of Floating Point Units” at IBM – DAC 14

Udo Krautz, Viresh Paruthi, Anand Arunagiri, Sujeet Kumar, Shweta Pujar, Tina Babinsky

“Seqver : A Sequential Equivalence Verifier for Hardware Designs”,at Intel – ICCD 2006

Ziyad Hanna, Daher Kaiss, Silvian Goldenburg

And many more ...

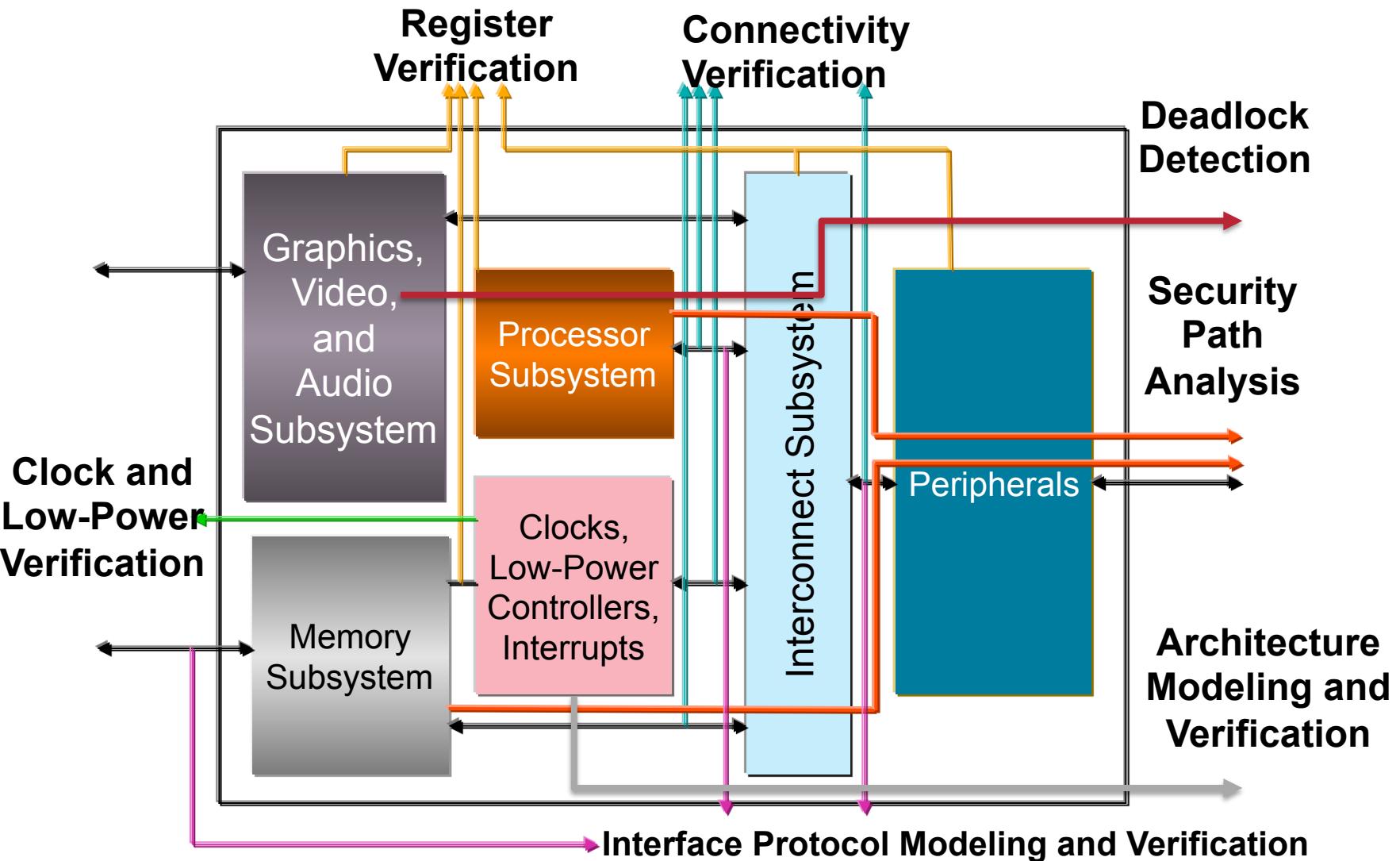
Good Candidates for Formal Verification

- Arbiters
- On-chip bus bridges
- Power management units
- Memory and DMA controllers
- Host bus interface unit
- Scheduler, implementing multiple threads
- Virtual channels for QoS
- IEEE floating point arithmetic
- Interrupt controller
- Token generators
- Cache coherency
- Credit manager blocks
- Standard interface (ARM AMBA protocol, DDR, etc.)
- Proprietary interfaces
- Clock disable units

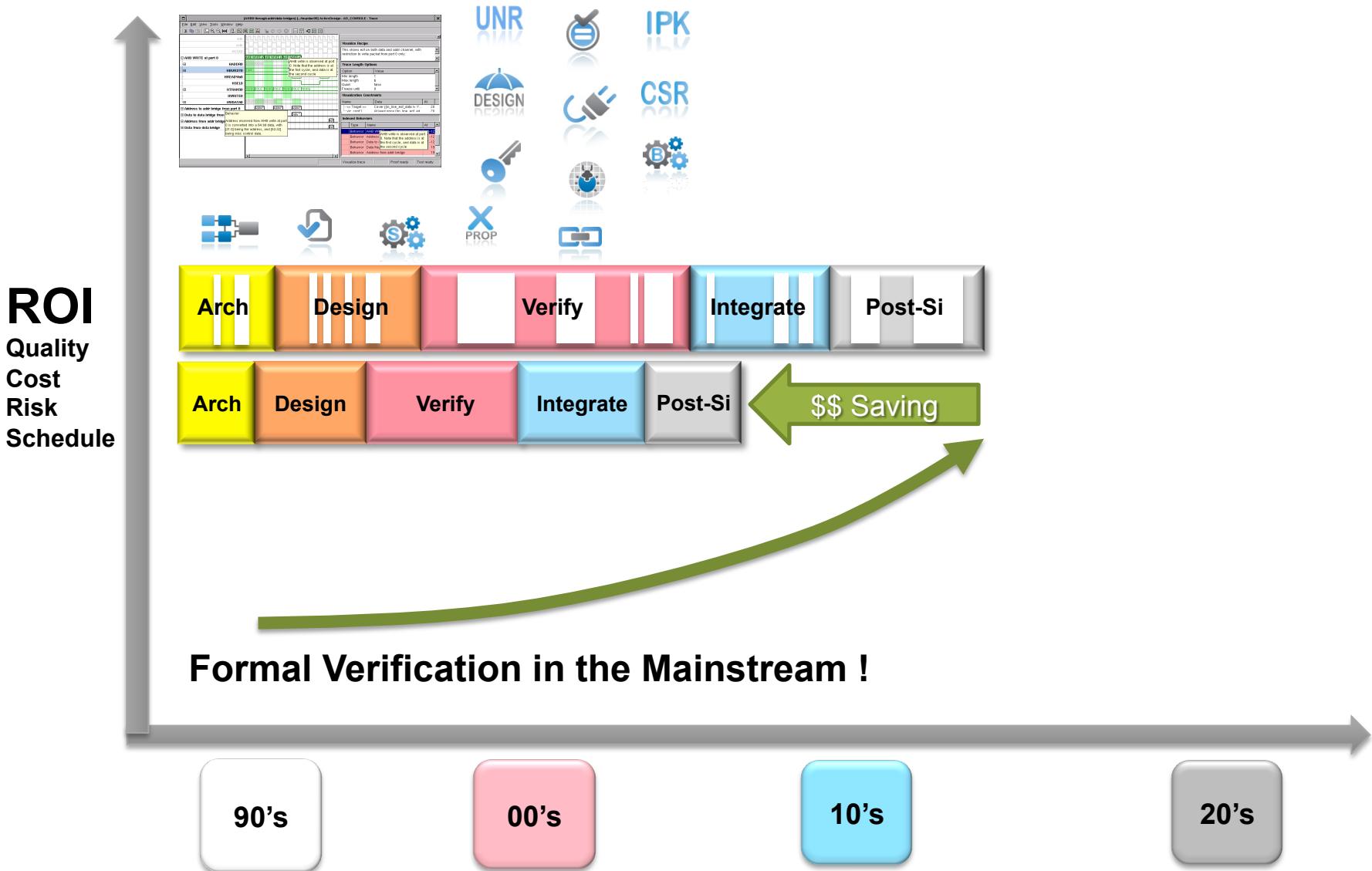
IP and subsystem-level design and verification solutions (Apps)

- Formal property verification
- Sequential equivalence checking
- Structural property synthesis - Superlint
- Behavioral property synthesis
- X propagation checking
- Coverage analysis and measurement
- Post-silicon debug (PSD)
- Clock glitch analysis and debug
- Functional Safety – ISO26262
- ...

SoC-level Formal Verification



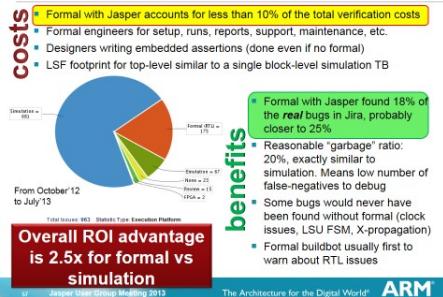
Spectrum of Formal Verification Solutions



ROI is proven by industry leaders

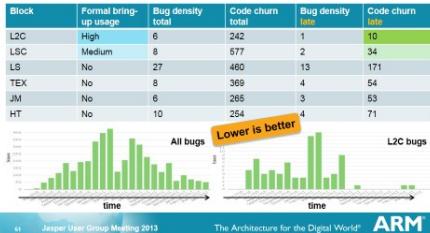
Highlights from Jasper User Group in 2012-2013

Cortex® A12 formal verification results



Design bring-up benefits

- Another GPU example:
- Not more, not less bugs, but the bugs are found much earlier
- So less RTL changes (code churn), especially late



2.5X better ROI than simulation



"At QUALCOMM we've seen three aspects of ROI from our use of JasperGold: engineering efficiency, functional coverage and time-to-market."

EFFICIENCY

"Regarding engineering efficiency, we've observed cases of a 3x-4x productivity gain where we've applied JasperGold, compared to performing the same tasks with simulation."

QUALITY

"Our use of JasperGold increases functional coverage, and thereby chip quality, by exposing bugs earlier during chip development."

TIME-TO-MARKET

"We've seen that JasperGold accelerates time-to-market in certain cases by enabling us to reach verification closure on late-stage changes in a day, versus a week."

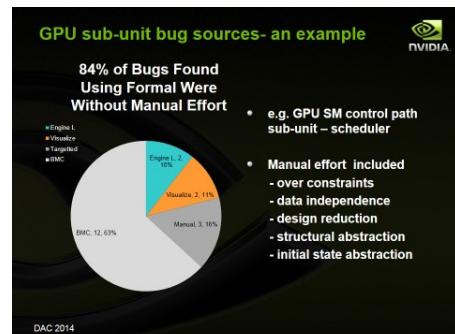
J. Scott Runner, QUALCOMM

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Late-change verification in a day vs. a week



Bugs found earlier: 82% code churn reduction



84% of bugs found automatically



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JUG 2014: focus on proliferation of proven ROI

Formal Plans – NextGen

- Well-staffed formal team – 4 engineers (3 experienced + 1 graduate)
- Formal team part of early design arch reviews
- Designers expected to thoroughly document interfaces
 - Comments in Verilog – properties ok too
 - Relationships, valid qualifiers, legal field values, etc.
 - Early reviews with stakeholders
- Interface property modules for all unit pairs +
 - Cooperation between designers and formal team
 - Used in simulation and formal – assume guarantee – already working
- Designers to create/review embedded asserts during code bring-up
- 10+ formal TBs targeting all units
 - 0-6 "light"-only
 - 4-10 "focused"

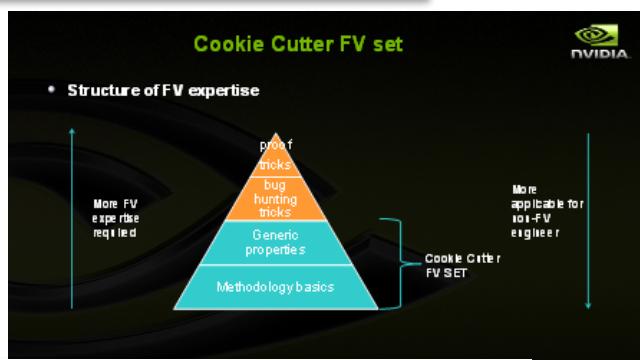


Cortex-A15 → Cortex-A57 → CurGen → NextGen → ...

9

ARM

Formal experts enabling
designers to use FV, with
focus on properties that are
hard to verify with simulation



FVC: status

- Developed successfully on ARM® CORTEX®-A17 processor
- Saves time
- High configurability
- Easier to use than the "usual" way
- Adds no performance overhead onto the JasperGold usage
- Now used in production on our current projects

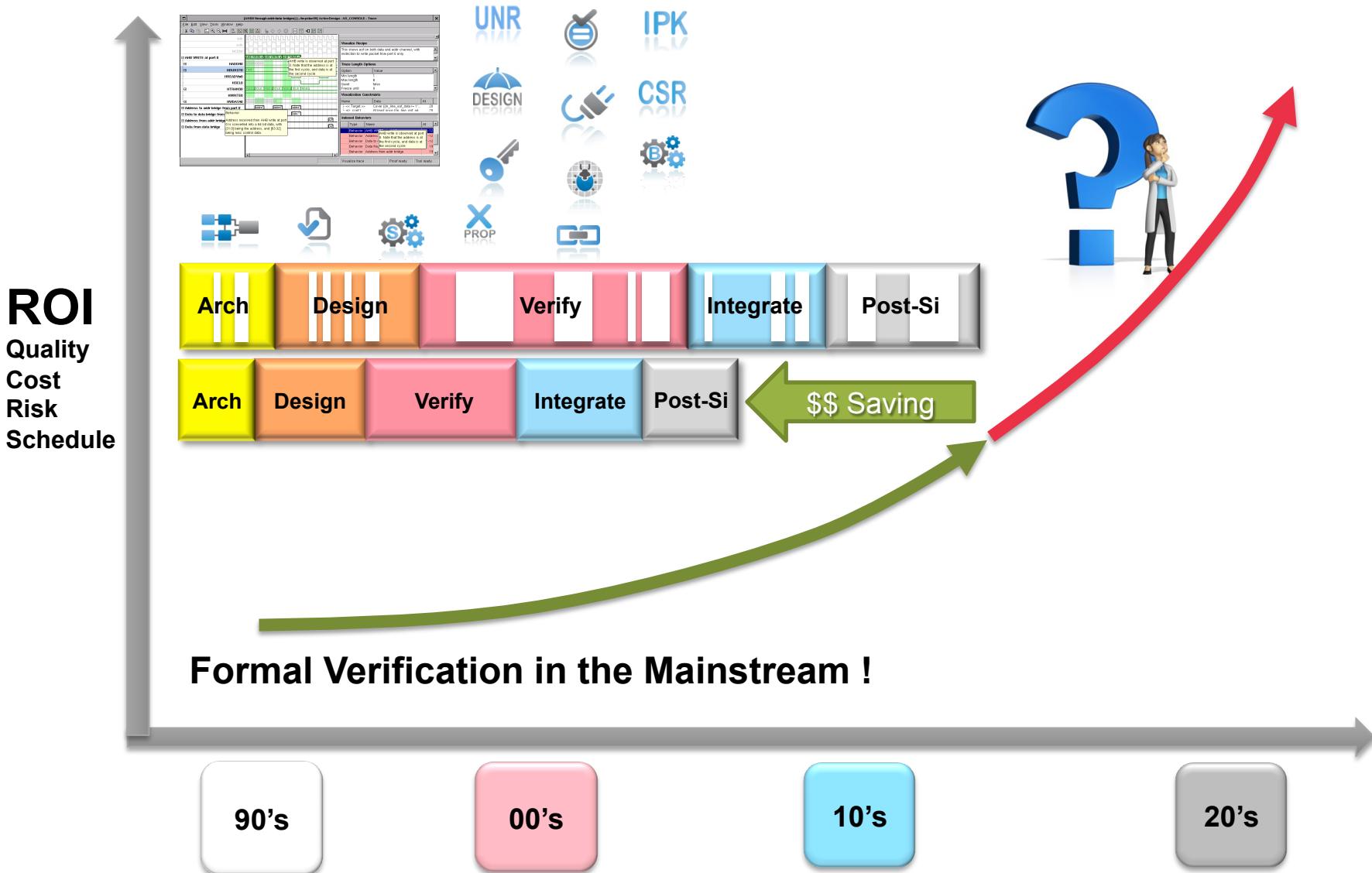


ARM

Formal verification
configuration (FVC)
helps proliferate formal
flows to non-experts



Spectrum of Formal Verification Solutions



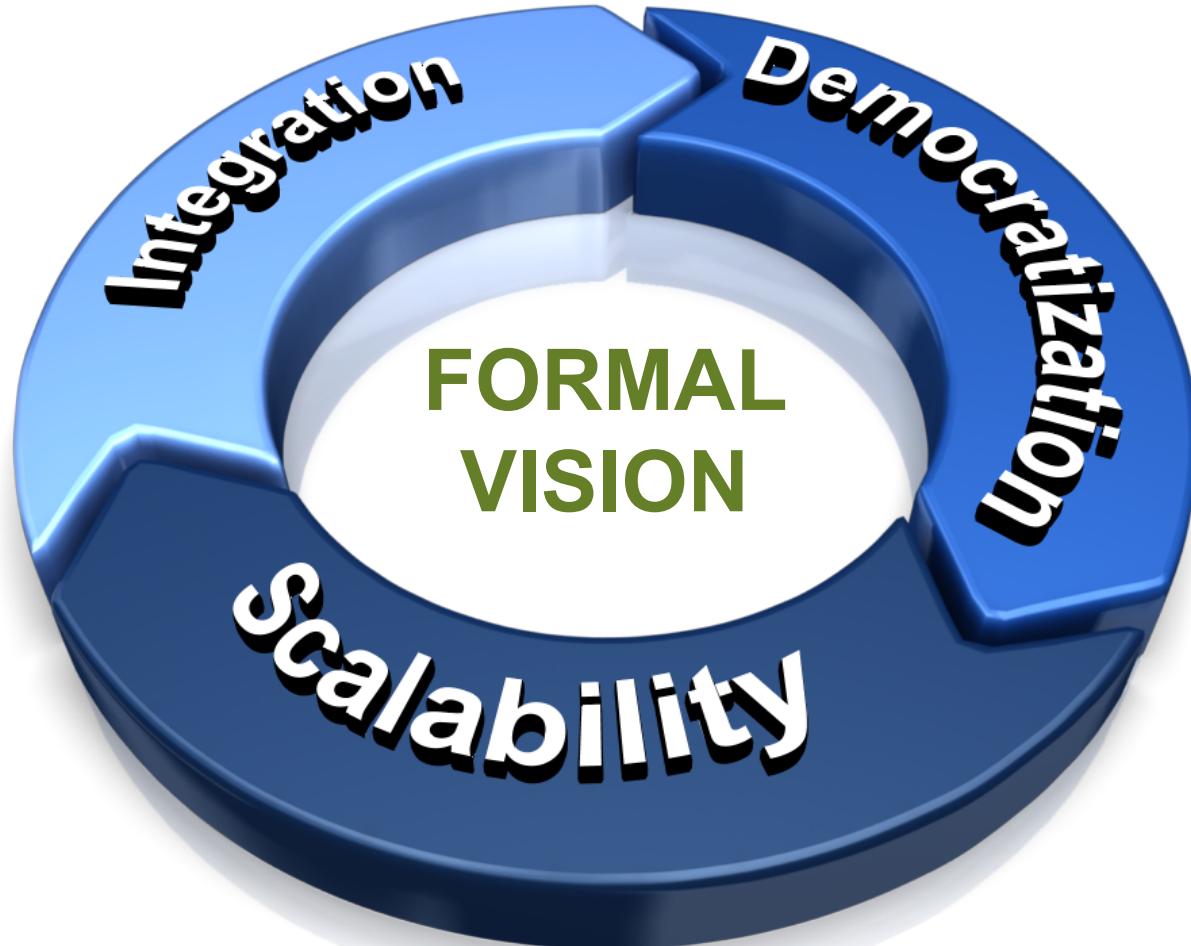
Agenda

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Formal Verification Vision

Democratization of Formal

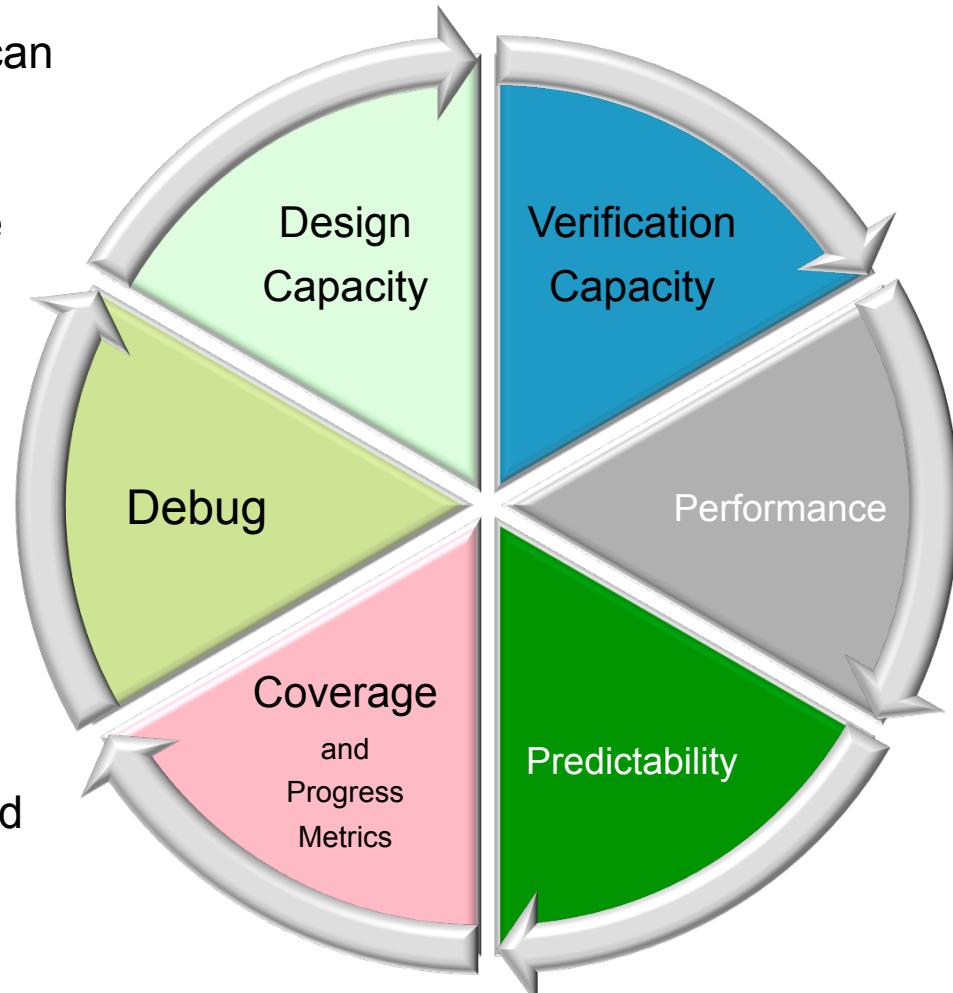
Forward Looking



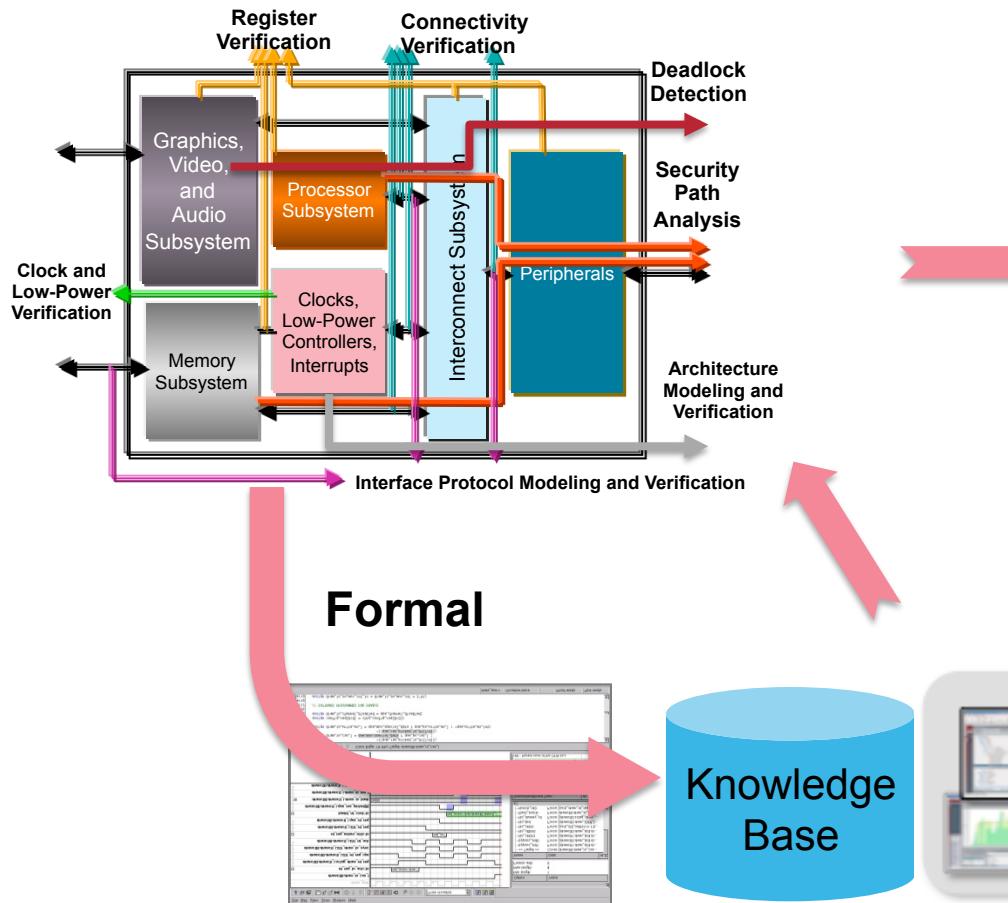
The primary verification method for systems !!

Formal Verification Scalability Factors

- **Design capacity:** Size of designs that can be read and elaborated
- **Verification capacity:** Measured by the number of state variables in pruned models that FV engines can verify
- **Performance:** CPU run time needed to complete a verification task
- **Debugging:** Measured by human effort spent to complete a verification task
- **Predictability:** Where can FV be applied
- **Coverage and progress metrics**



Formal and Simulation Interoperability for System Integration and Verification



Verification & Analysis Results

Simulation/ Emulation

Boost and Offload Simulation !

Agenda

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Democratization of Formal

Forward Looking

Democratization of technology refers to an ongoing process by which access to technology rapidly continues to become more **accessible to more people**. New technologies and **improved user experiences** have empowered those outside of the technical industry to access and use technological products and services. At an **increasing scale**, consumers have **greater access to use and purchase technologically sophisticated products**, as well as to **participate** meaningfully in the development of these products. Industry innovation and user demand have been associated with **more affordable, user-friendly products**.

http://en.wikipedia.org/wiki/Democratization_of_technology

The Industry Believes in it ...

*“Democratization of Formal beyond
the formal experts ...”*

Bob Bentley (Former Intel Validation Director)
Jasper® Users Group 2012

*“Formal for Everyone, Challenges in
Achievable Multicore Design and
Verification”*

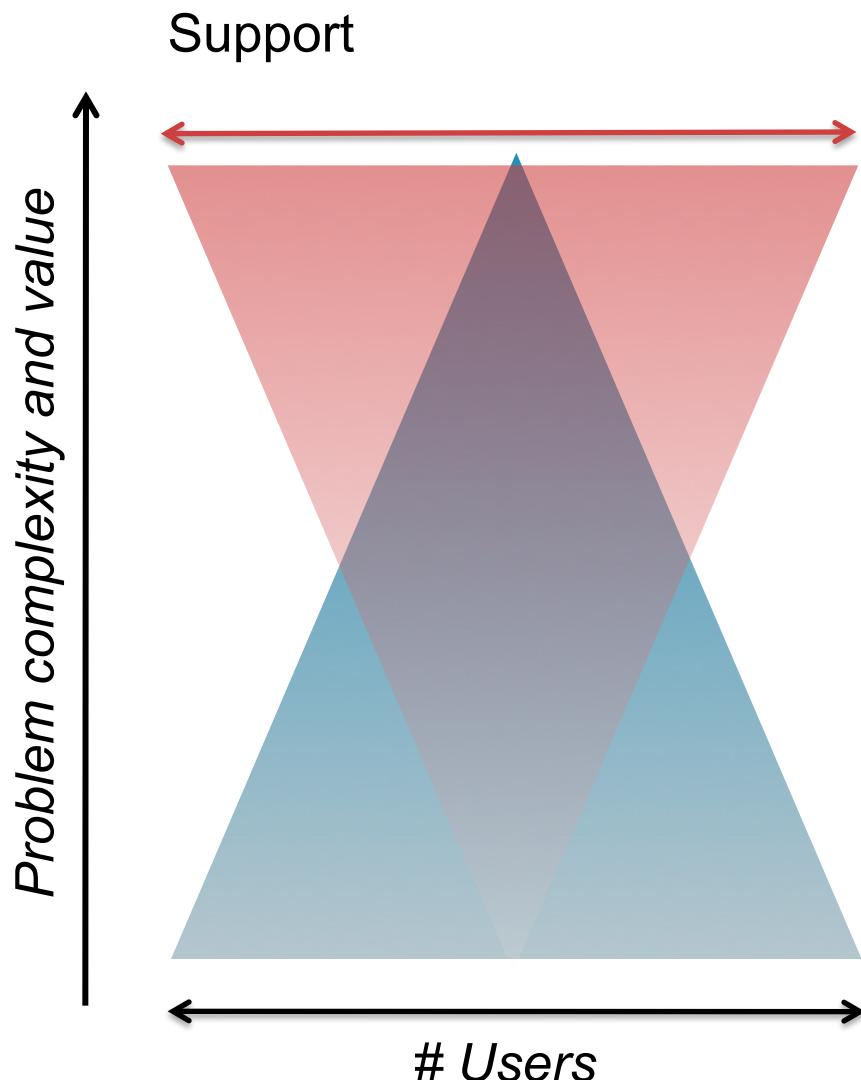
Daryl Stewart (Research Engineer at ARM)
Formal Methods in CAD 2012

Democratization of Formal for Design Community – Why?

- They are the creators of the implementation
- Poor quality design rolled out to downstream
 - process cause costly iterative design effort
- Design knowledge poorly communicated
- Main verification starts after RTL creation process
- Verification is costly and not effective



Democratization Challenges – Support and Enablement !!



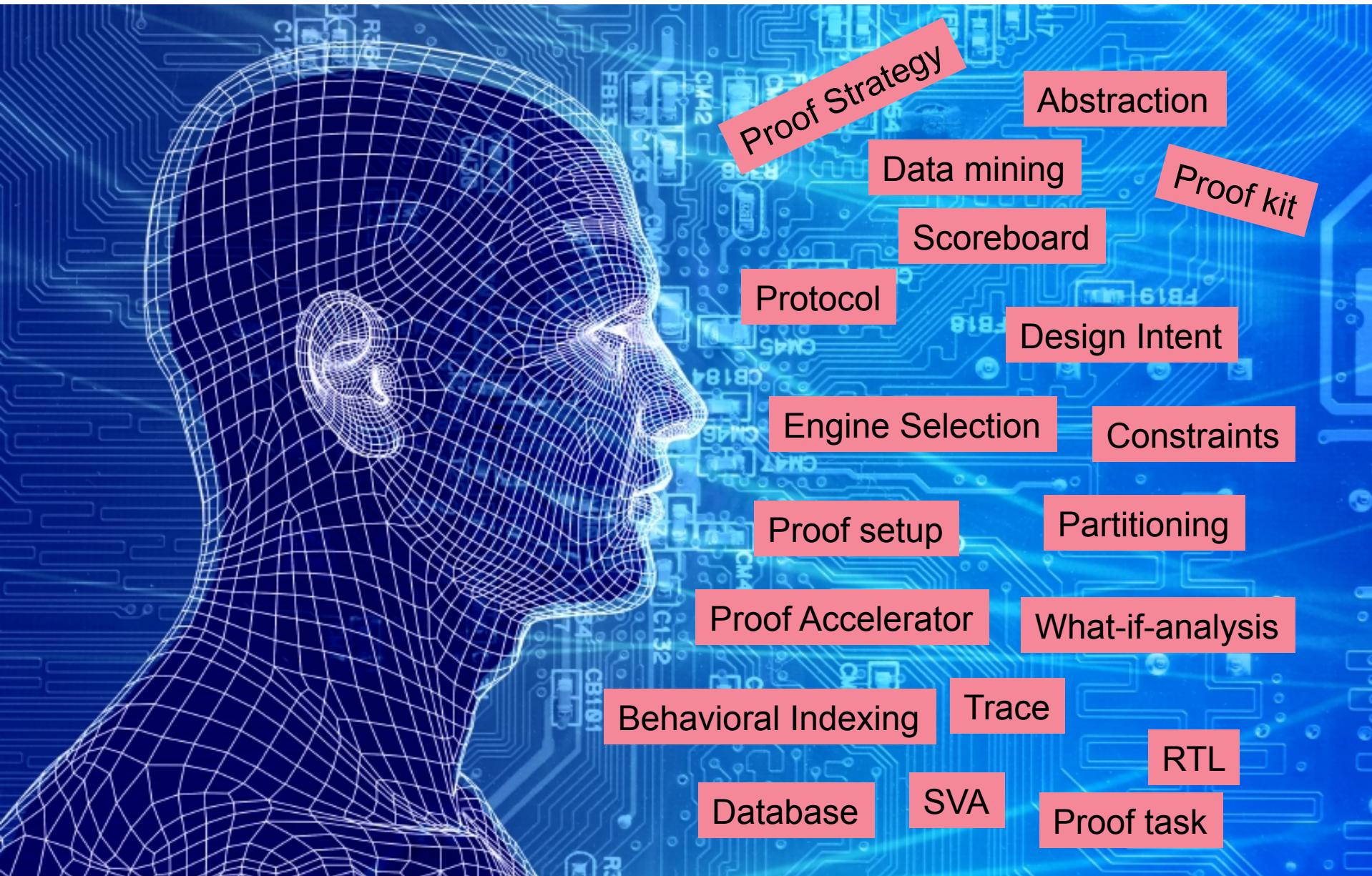
- Low-end solutions are useful for debugging and easy problems, however have limited ROI
- Formal applicability is evolving rapidly, but is still gated by capacity limitations, and therefore needs more automation
- Support and expertise is required to train initial users:
 - ✓ How to convert spec to properties
 - ✓ How to develop proper constraints
 - ✓ How to manage complexity

How do we train/support users today?

- Dedicated help and training (by EDA and Expert Users)
- Reference materials to search and read



Innovation – Exploiting Human Intelligence and Technology

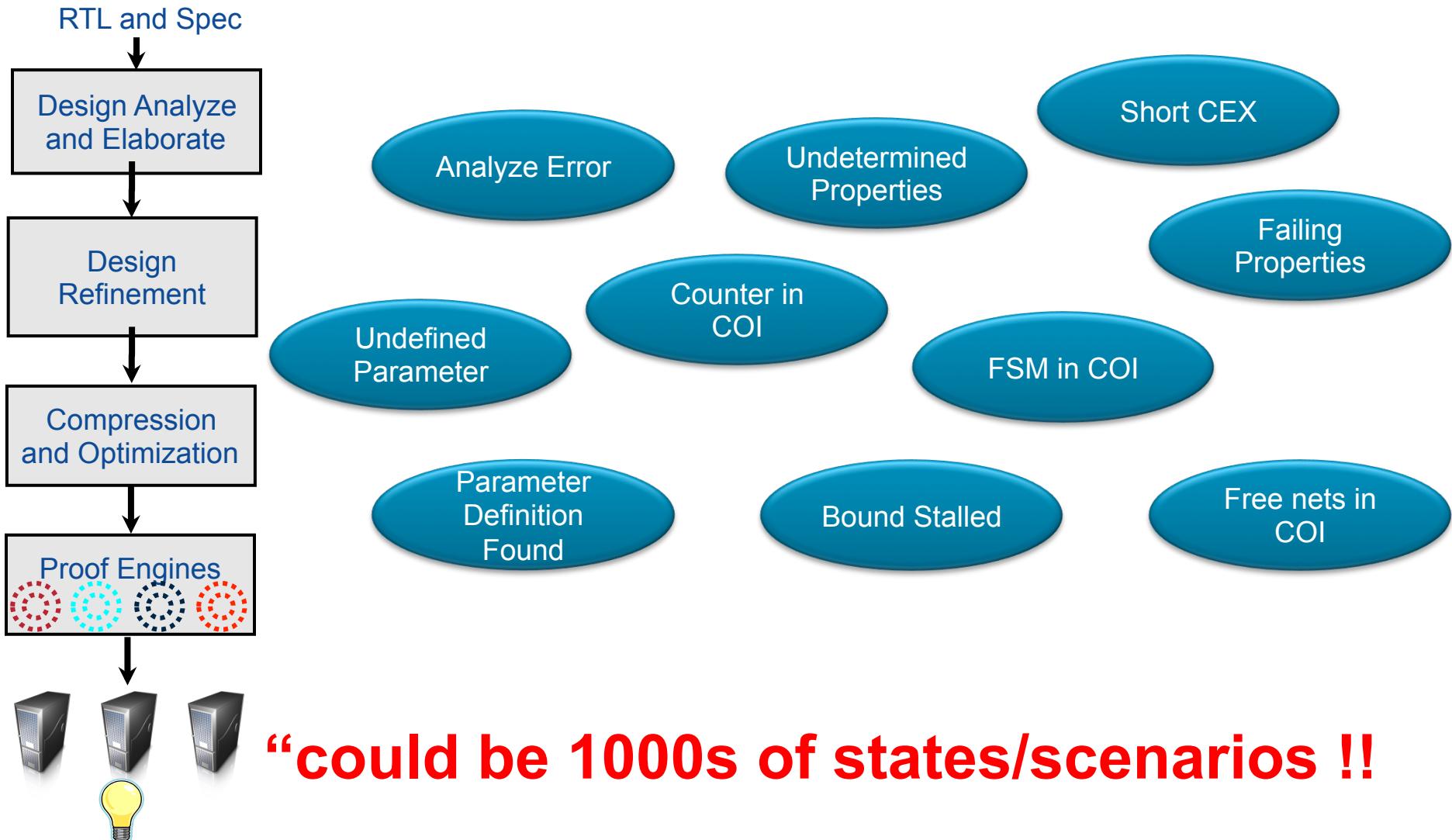


What if we knew...

- When is a user struggling?
 - Did they give up?
- What problem is the user trying to solve?
- What stage of the verification effort is it
 - early, late, ...?
- Is there an opportunity for other App(s)?
- What information could we use to improve the tool?
- What design components/complexity are bogging down the tool?
- When is a task finished?
 - What was the ROI?



“Formal Tool State” !



“could be 1000s of states/scenarios !!



Collective Intelligence

Users



Users



Champion

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Work Flows
Methodologies
Algorithm Choices
Tuning
Optimizations
Custom Scripts

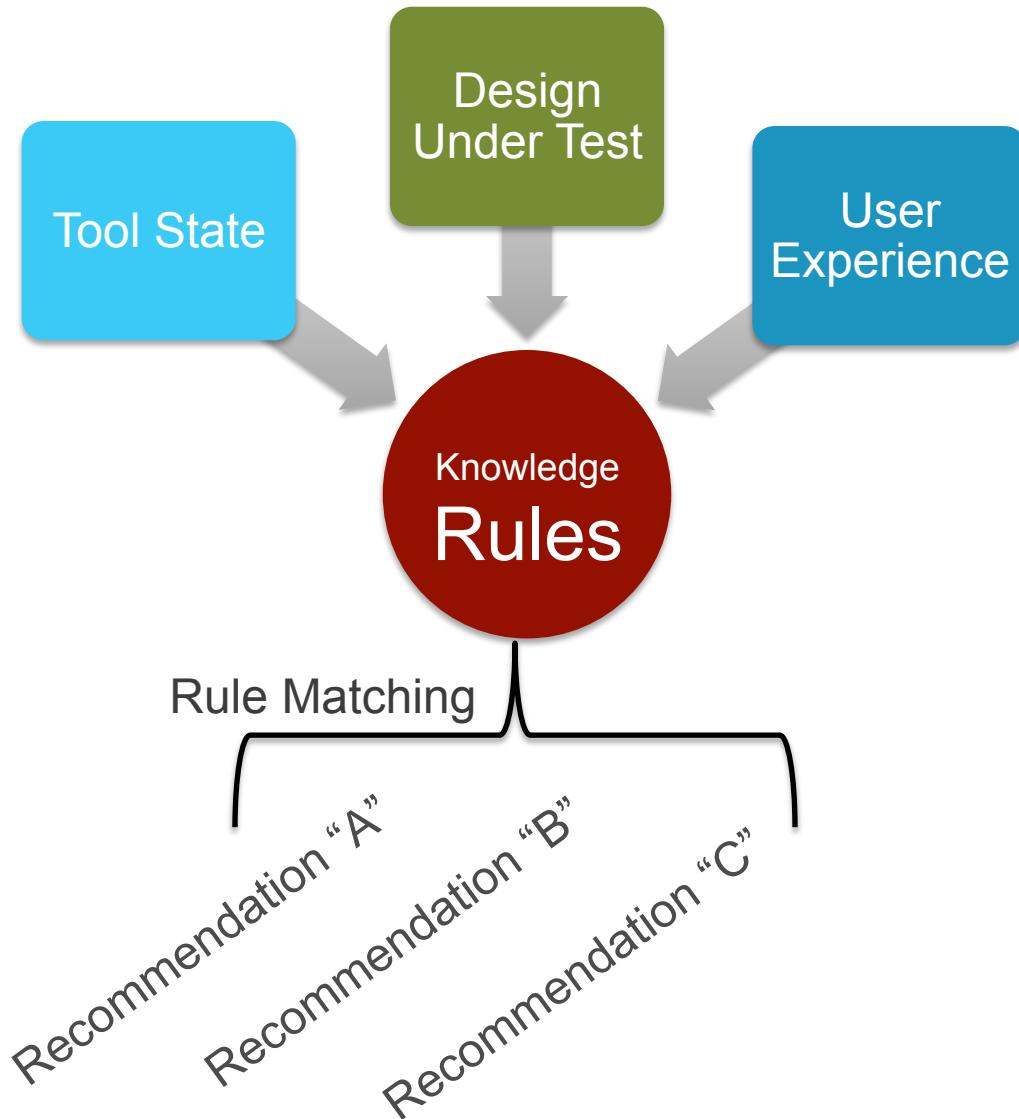
Technologies:

Engines
Abstraction
Scoreboard
Database
Debug
Reports
...

Formal Expert System !

- A revolutionary new approach to user guidance. It is a knowledge-based system, that **recommends decisions specific to the user's experience, design under verification** in the context of **tool state**.
- It leverages everything the tool can detect, and then asks the user for additional information.
- Under the hood, decision leverages a versatile **expert knowledge rules** captured by experts
- Provides live monitoring and alerts from the FV tool to a **web server**. The web server collects usage data from runs.

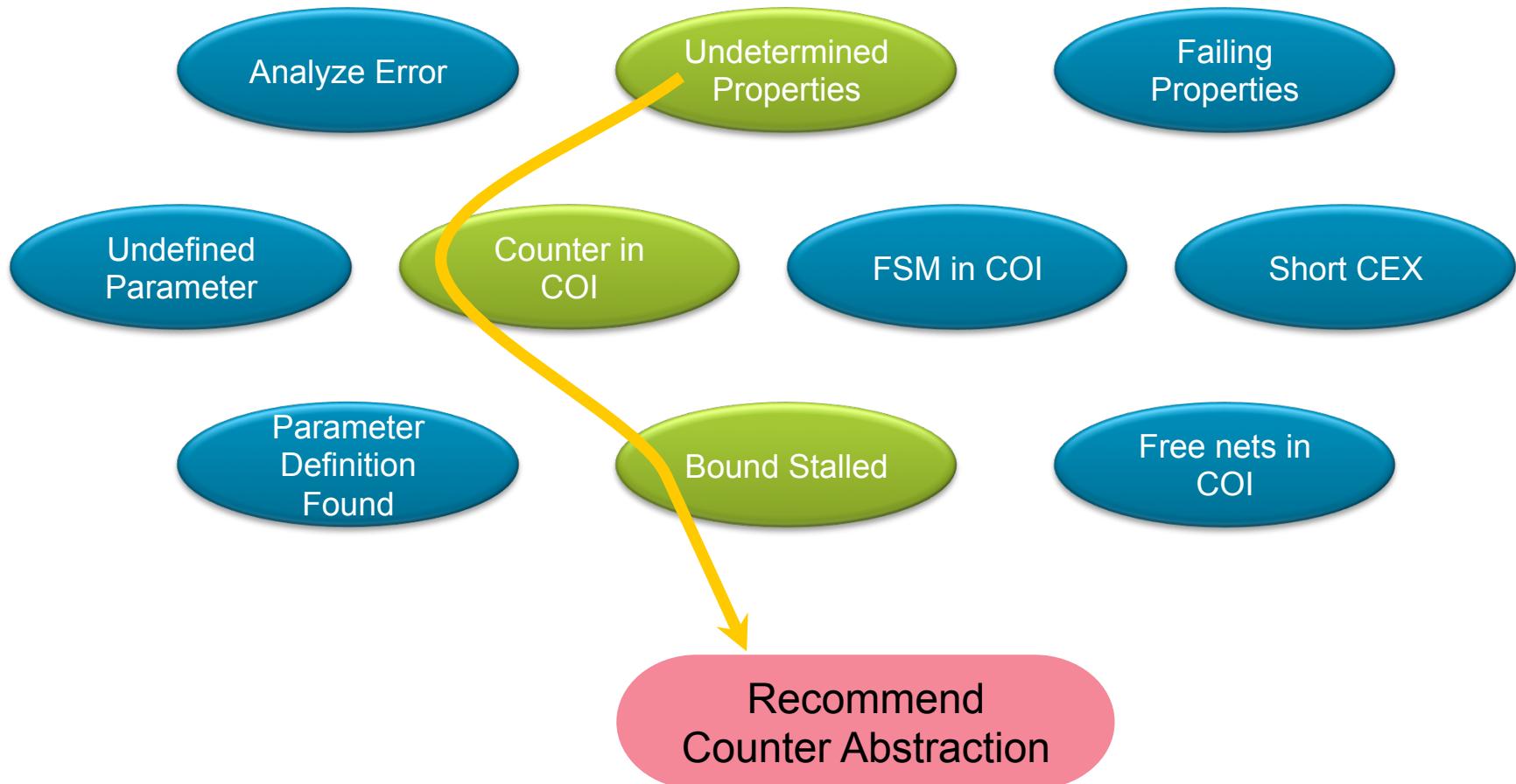
Formal Expert System



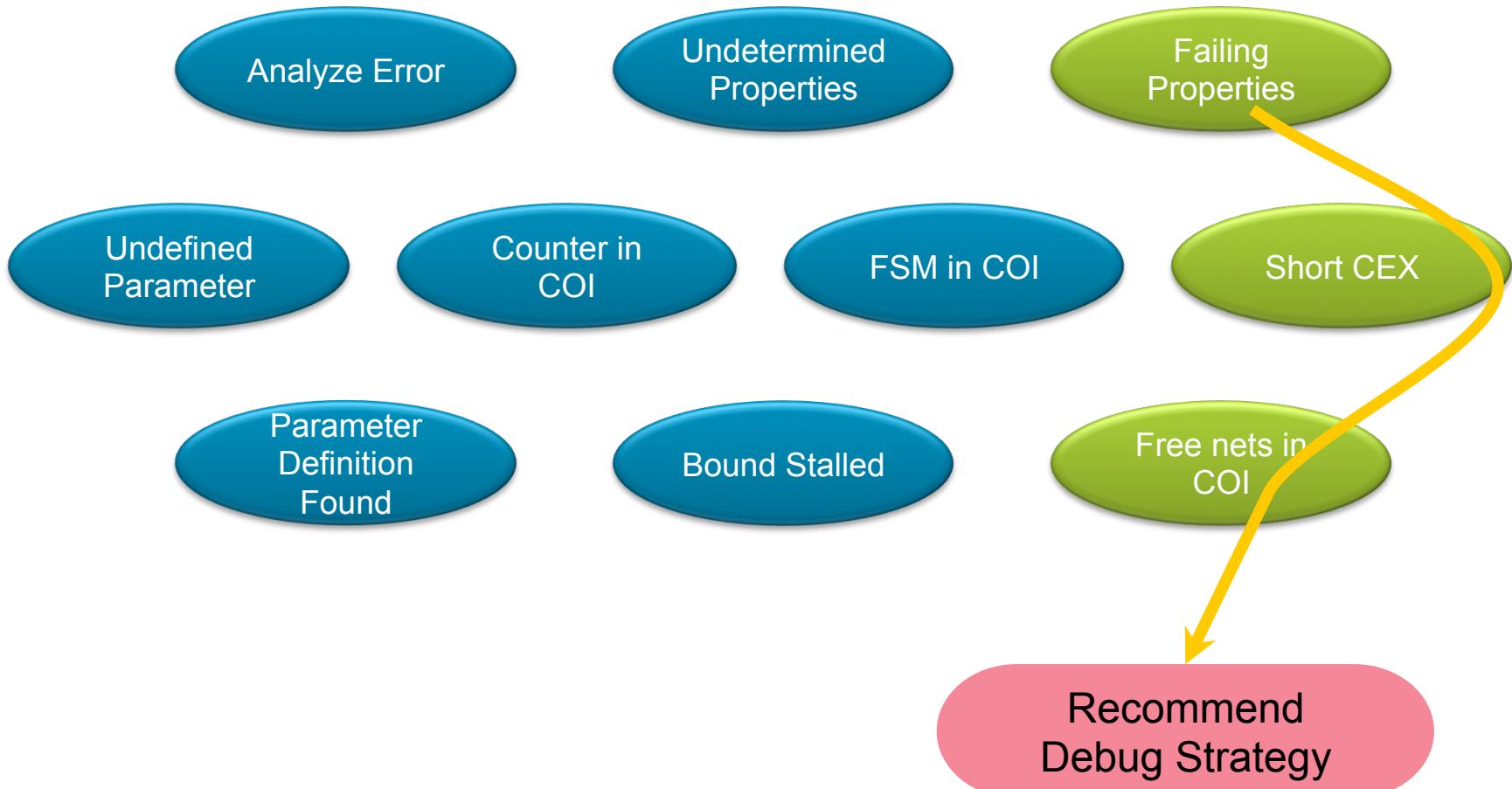
Expert System and Rule Matching



Expert System and Rule Matching



Expert System and Rule Matching



Knowledge Rule Challenges

- How to capture the rules ? How effective are they ?
- How to match the rules, considering the context ?
- How to sort the rules and recommendations based on user experience and skill set?
- Apply the recommendations and undo/redo, history ?
- Frequency of the recommendation, in same or different sessions ?
- Capturing user feedback and sharing !
- Fast processing ... all happens on-the-fly !

Known Recommendation systems: Amazon, eBay, Google, Google, Netflix, LinkedIn, ...

All ▾ Model Checking 

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Google Recommendation systems 

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Recommender systems or recommendation systems (sometimes replacing "system" with a synonym such as platform or engine) are a subclass of information filtering system that seek to predict the 'rating' or 'preference' that a user would give to an item.

Recommender system - Wikipedia, the free encyclopedia
https://en.wikipedia.org/wiki/Recommender_system

More about Recommender system 

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Overview - Approaches - Beyond Accuracy - Mobile Recommender Systems

Introduction to Recommender Systems - University of ...
<https://www.coursera.org/learn/recommender-systems>

Introduction to Recommender Systems from University of Minnesota. Recommender systems have changed the way people find products, information, and even ...

Introduction to Recommender ... - Certificate Available For ... - The Course

[PDF] Recommendation Systems - The Stanford University I...
infolab.stanford.edu/~ullman/mmds/ch9.pdf

Collaborative filtering systems recommend items based on similarity measures between users and/or items. The items recommended to a user are those preferred by similar users.

Recommender systems, Part 1: Introduction to approaches ...
www.ibm.com/developerworks/library/os-recommender1/

Dec 12, 2013 - Most large-scale commercial and social websites recommend options, such as products or people to connect with, to users. Recommendation ...

RecSys – ACM Recommender Systems
recsys.acm.org/

ACM RecSys 2016. The 10th ACM Recommender Systems Conference will take place in Boston, MA, USA from Sept 15-19, 2016.



9th ACM Conference on Recommender Systems

Vienna, Austria, 16th-20th September 2015

The ACM Recommender Systems conference (RecSys) is the premier international forum for the presentation of new research results, systems and techniques in the broad field of recommender systems. Recommendation is a particular form of information filtering, that exploits past behaviors and user similarities to generate a list of information items that is personally tailored to an end-user's preferences. As RecSys brings together the main international research groups working on recommender systems, along with many of the world's leading e-commerce companies, it has become the most important annual conference for the presentation and discussion of recommender systems research. RecSys 2015, the ninth conference in this series, was held at the TU Wien, Vienna, Austria, from September 16-20, 2015. Participants — in total nearly 500 — came from academia and industry presenting their latest results and identify new trends and challenges in providing recommendation components in a range of innovative application contexts. In addition to the main technical track, RecSys 2015 program featured keynote and invited talks, tutorials covering state-of-the-art in this domain, a workshop program, an industrial track and a doctoral symposium.

RECSYS 2015 (VIENNA)

[About the Conference](#)

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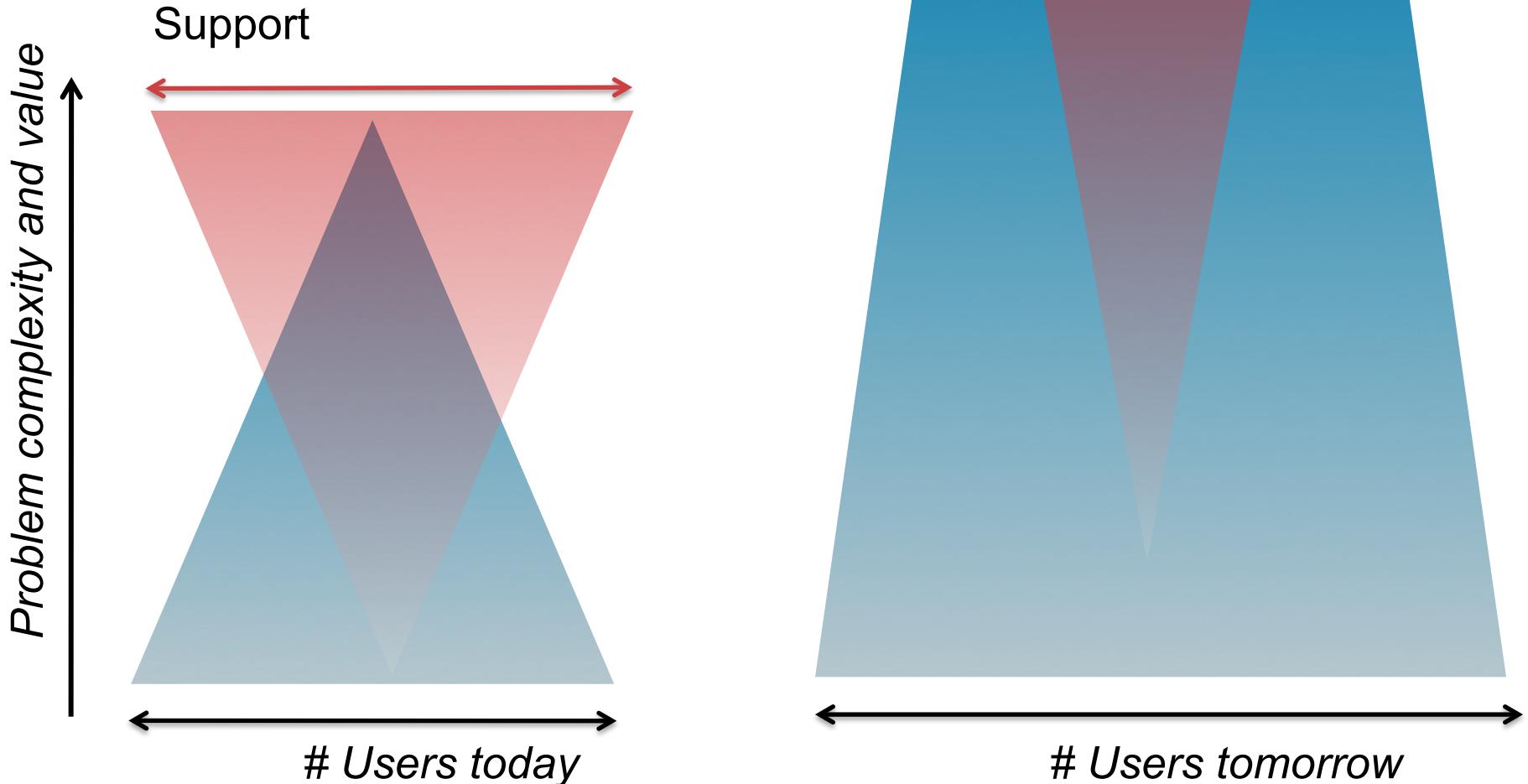
[Keynotes](#)

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Formal Democratization Impact !



Wider usage, higher impact, higher productivity, reduced cost



The primary verification method for systems !!