The Challenge of Evolutionary Verification

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The Four-Color Theorem

- **<u>1852</u>**: Guthrie ***conjectured***

  Every planar map is four-colorable

- **<u>1976</u>**: Appel & Haken ***proved*** the theorem using an assembly program on a IBM 370-168 computer
- **<u>2004</u>**: Gonthier ***verified*** the proof of the theorem using the Coq proof checker
- **<u>2005</u>**: Devlin [Math. Assoc. America] ***announced***

  Last doubts removed

  about the proof of the Four Color Theorem

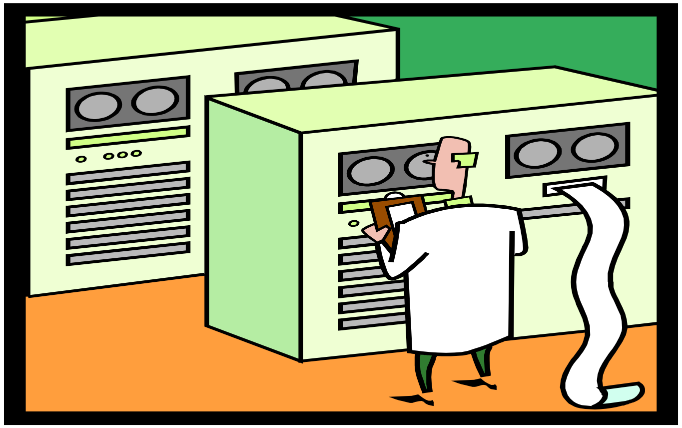
- **<u>2006</u>**: Harrison ***partially verified*** HOL light, the logical kernel of Coq, using HOL light itself
- …

Even for most non-typically well defined problem - math, formalization and verification are not so easily attainable

A Different Aspect of Uncertainty

1976 layers

- Assembly program
- Assembler
- Operating system (with VM!)
- Mainframe



2004 layers

- Data: proof
- Application: proof-checker
- Compiler(s)
- Operating system ***+ updates***
- Dual-core system
- ***Network connection***

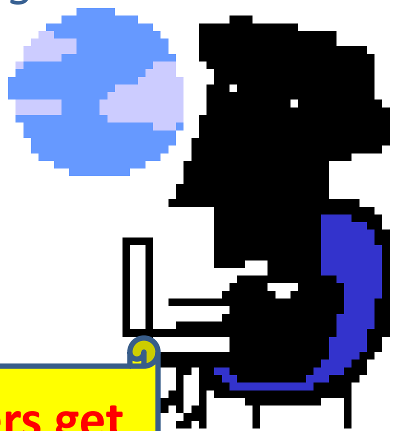
A Typical Application

2010 layers

- Data
- Application
- Compiler(s)
- Operating system(s)
- Virtualization layer(s)
- Multi core / multi processor
- Heterogeneous network

Dynamic aspects

- *Runtime downloadable data / scripts*
- *Dynamic libraries*
- *Dynamic compilation*
- *Online SW updates*
- *Anti virus at the background*
- *Viruses*
- *OS patches*
- *Virtualization layer*
- *Cloud computing*
- *…*



The interfaces *between* abstraction layers as well as *inside* layers get more *complex*, *dynamic* and *unstable* – more reasons for doubts!!!

Outline

- Motivation and conception of an "evolutionary" approach for verification
- Supporting examples
- Initial thoughts about potential directions

Motivation

- ***Verification task*** refers to a single, isolated transition
  - Given model, system, assumptions, specification
  - Apply an algorithmic verification process
  - Desired correctness outcome: once proved - done forever
- Modern systems are of a more progressive nature
  - Systems evolve, assumptions change
  - Underlying models adapt, correctness criteria get refined
  - Verification methods improve, adjust
  - Correctness concerns are never fully satisfied
- **Hypothesis**
  - System's fast evolution and complexity make it increasingly inefficient / impossible to target system time-snapshots by isolated verification tasks

Proposal: Evolutionary Verification

Challenge: *Extend the scope of formal-methods research from* ***(isolated) verification tasks*** *to the context of* ***(evolutionary) verification process***

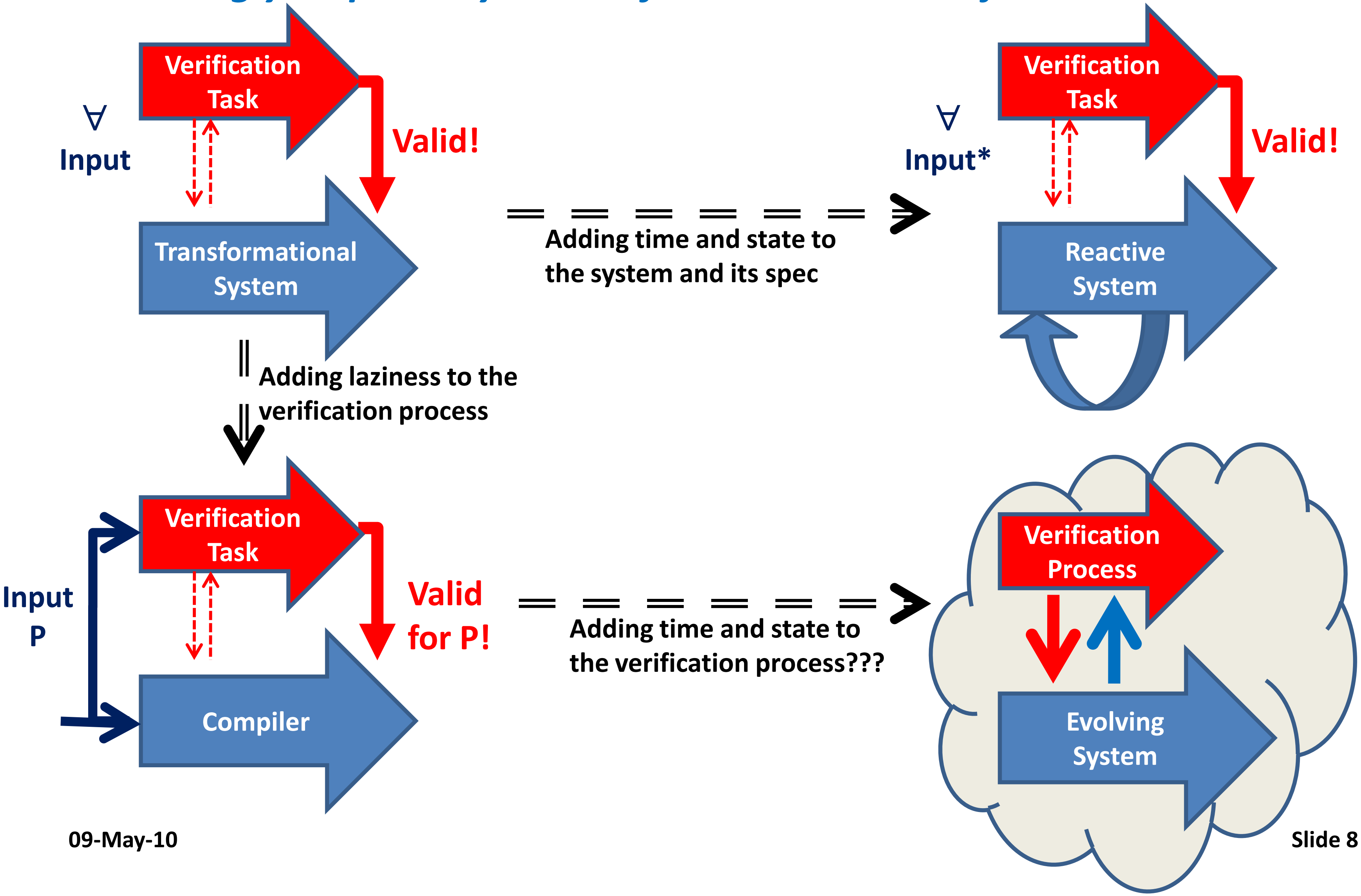
This requires the development of a ***formal framework*** that can ***adapt*** to and express the ***evolution*** of

- Specifications
- Computational/programming model
- Verification methods
- Correctness criteria and metrics
- Methods for handling intermediate, incorrect states

… and their ***ongoing integration*** into the implementation process.

Put into Historical Perspective

Strongly Inspired by some of Amir Pnueli's Major Contributions



Case for Evolution (1) - Racing

- Characteristics
  - Systems are too complex to fully verify in advance
  - System's (at least initial) reaction/output is required earlier than full verification can complete
- Examples
  - Just in time (JIT) compilation
  - Dynamic binary optimizers (DBO)
  - Virtualization layers

Case for Evolution (2) - Unpredictability

- Characteristics
  - System behavior is changing dynamically
  - Modes of operations / usage environments are amorphous / not known in advance
- Examples
  - WEB applications, e.g. Java scripts
  - Viruses and anti viruses
  - Operating systems
  - Server networks
  - Cloud computing

Case for Evolution (3) - Maliciousness

- Characteristics
  - Optimized systems
  - Explicit interfaces (e.g. ISA, programming model) are preserved, yet implicit assumptions of the applications are broken
  - Knowledge of implementation details enables unexpected attacks
- Examples - RSA encryption
  - ***Side channel attack*** on the Secure Socket Layer (SSL) protocol (protecting online transactions)
  - Exploits intimate knowledge of HW optimizations such as caches and branch prediction
  - Exploit intimate knowledge of the algorithmic implementation of the protocol
  - Utilize “innocent” OS features such time sharing to “spy” into the protocol
  - Gain ***observability*** into tiny timing effects uncovering the private key

So How Evolution?

- All three cases (racing, unpredictability, maliciousness) have several characteristics in common
  - Complexity
  - Impossibility to validate in advance
  - A sense of continuous struggle for correctness
  - Need to tolerate intermediate failures
- Can “incessant, lazy-verification” become a more robust evolutionary model?
  - Specification, verification are building blocks of the continuous design process
- While competing for system resources, need to address
  - How to manage the evolving specification, correctness status
  - What to do about incorrect output?
  - How to fix a failing system?
  - How to improve verification over time (learn)?

Why is Evolutionary Verification an "Appropriate" Challenge?

- Interesting? – subjective
- Difficult? – necessary, not sufficient
- Inspired by real world problems
- Has the potential of expanding the scope and outreach of formal methods, by
  – Addressing some fundamental questions about the very nature of formal models
    - *What is a (good) specification?*
    - *What defines the limits and the desired flexibilities of a formal model?*
  – Allowing for better design engineering

Partial List of Related Trends and Potential Directions

- Open Verification Methodology (OVM) intiative
- Subject/aspect oriented programming
  - Separation of concerns
- Self verification
  - Assertions
  - Artificial intelligence methods
  - SHADOWS
- Any method of gradual verification
  - Bounded model checking
- Many relevant ideas I heard in the first day of the symposium

Thank You