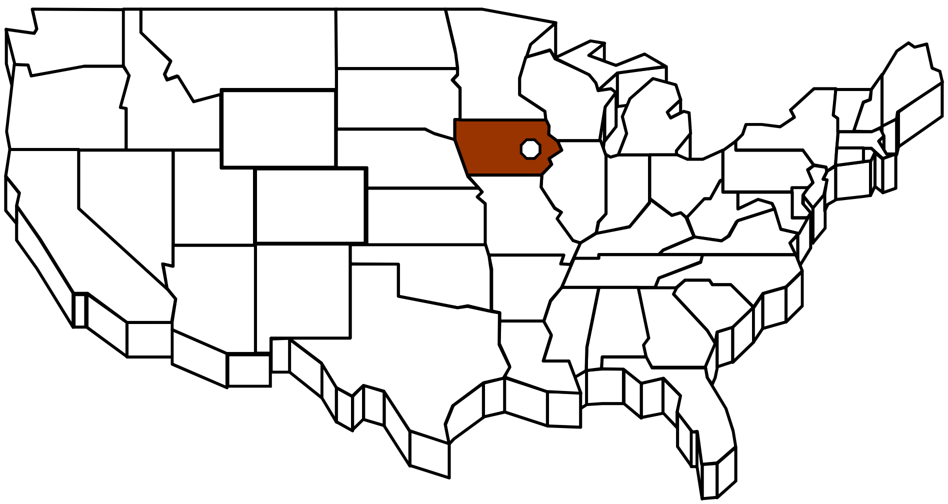
Verification of Avionics Systems

Dr. Steven P. Miller
Advanced Technology Center
Rockwell Collins

- Headquartered in Cedar Rapids, Iowa
- 20,000 Employees Worldwide
- 2010 Sales of $4.7 Billion
- Focus on High Assurance Systems



Domestic

California
Carlsbad
Cypress
Irvine
Los Angeles
Pomona
Poway
San Francisco
San Jose
Tustin
Florida
Melbourne
Miami
Georgia
Atlanta
Warner Robins
Hawaii
Honolulu
Illinois
Chicago
Iowa
Bellevue
Coralville
Decorah
Manchester
Kansas
Wichita
Maryland
White Marsh
Massachusetts
Boston
Michigan
Ann Arbor
Detroit
Minnesota
Minneapolis
Missouri
Kansas City
St. Louis
New York
New York
North Carolina
Charlotte
Raleigh
Oklahoma
Midwest City
Tulsa
Oregon
Portland
Pennsylvania
Philadelphia
Pittsburgh
Texas
Dallas
Fort Worth
Richardson
Utah
Salt Lake City
Virginia
Sterling
Washington
Kirkland
Renton
Seattle
Washington, DC

International

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Asia
Bangkok, Thailand
Beijing, China
Hong Kong
Kuala Lumpur, Malaysia
Manila, Philippines
Moscow, Russia
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Shanghai, China
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Frankfurt, Germany
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Manchester, England
Paris, France
Reading, England
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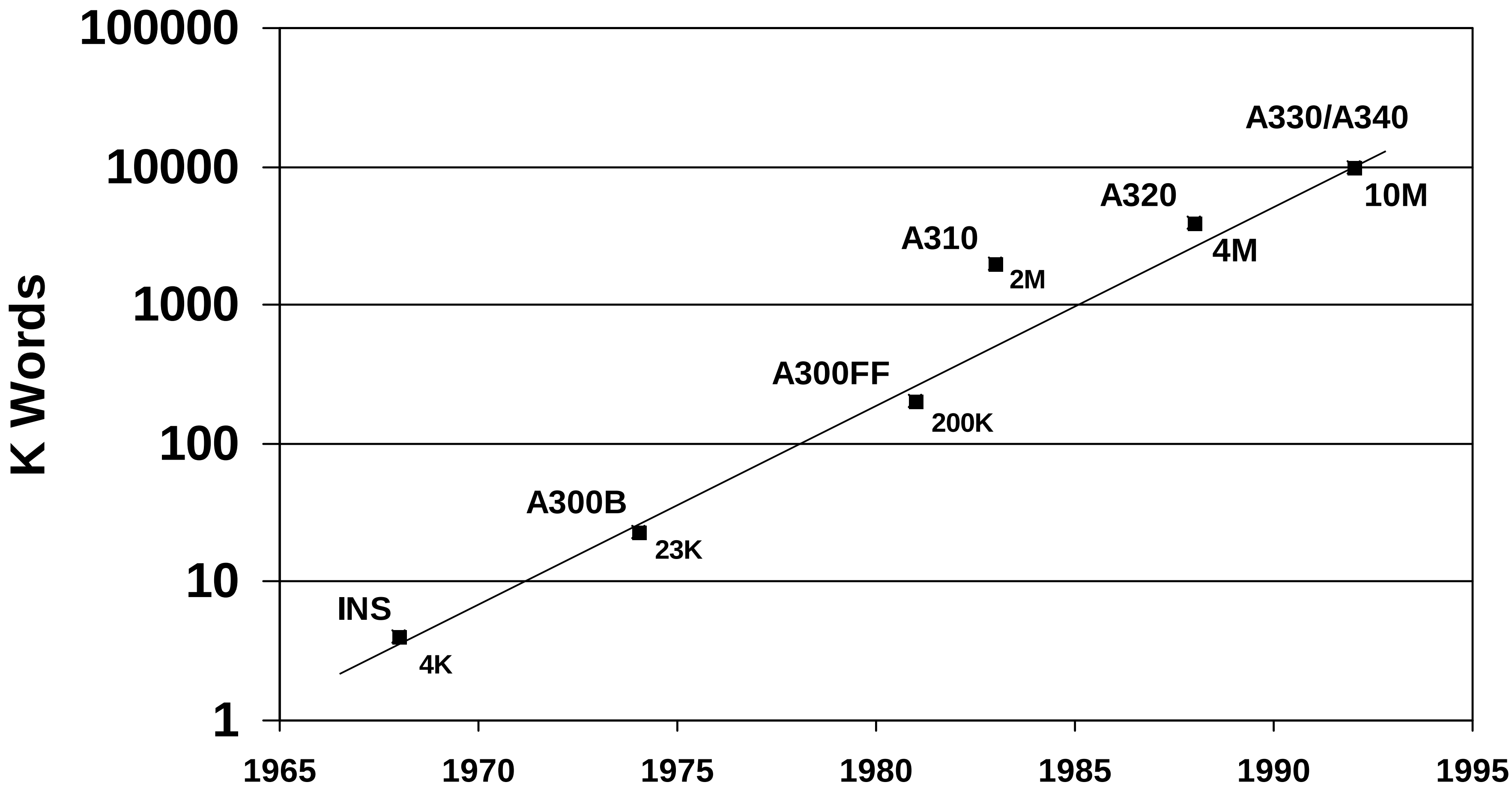
Mexico
Mexicali
South America
Santiago, Chile
Sao Jose dos Campos, Brazil
Sao Paulo, Brazil

Rockwell Collins' core business is based on the delivery of *High Assurance* Systems

- Commercial/Military Avionics Systems
- Communications
- Navigation & Landing Systems
- Flight Control
- Displays

*"Working together creating **the <u>most trusted source</u>** of communication and aviation electronic solutions"*

Airborne Software Doubles Every Two Years

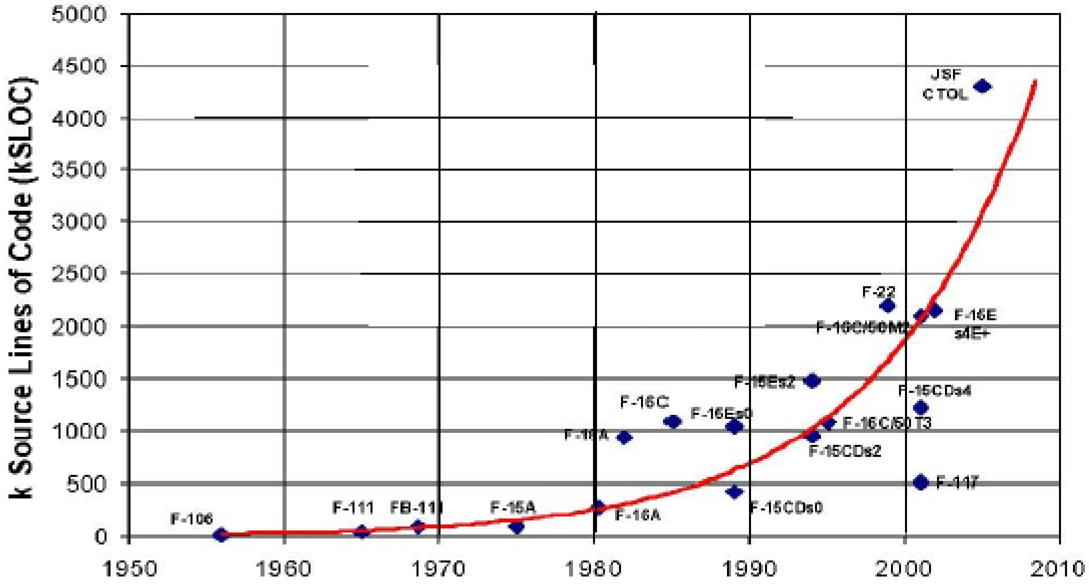


J.P. Potocki De Montalk, Computer Software in Civil Aircraft, Sixth Annual Conference on Computer Assurance (COMPASS '91), Gaithersberg, MD, June 24-27, 1991.

DoD software is growing in size and complexity

U.S. AIR FORCE

Total Onboard Computer Capacity (OFP)



Source: "Avionics Acquisition, Production, and Sustainment: Lessons Learned -- The Hard Way", NDIA Systems Engineering Conference, Mr. D. Gary Van Oss, October 2002.

Robert Gold, OSD

Software Aspects of Certification for Civil Aircraft

- Certification – Legal recognition by the certification authority that a product, service, organization or person complies with the requirements.
- Software is not actually certified, but certification of an aircraft does include the "software aspects" of certification.
- DO-178 – Software Considerations in Airborne Systems
  - DO-178 (1982) – best practices
  - DO-178A (1985) – 3 levels
    specified development & verification processes
  - DO-178B (1992) – 5 levels
    specified objectives, activities, and evidence
  - DO-178C (2012) – similar to DO-178B
    but with supplements for new technologies

DO-178C Formal Methods Supplement

- Calls Out Formal Methods as an Accepted Means of Compliance
  - Not just an alternate means of compliance as in DO-178B
- Defines Formal Methods
  - Mathematically-based techniques for the specification, development, and verification of software aspects of digital systems
  - Formal logic, discrete mathematics, and computer readable languages
- Allows Partial Use of Formal Methods
  - Enables evolutionary rather than revolutionary adoption
- Describes How Formal Methods Can be Used to Meet Objectives
- Formal Analysis Tools Must Satisfy Tool Qualification Supplement
  - Only if used to meet DO-178C objectives
- Clearly States that Testing Cannot be Completely Eliminated
  - Functional tests executed on target hardware are still required
  - Formal methods can be used to reduce amount of testing

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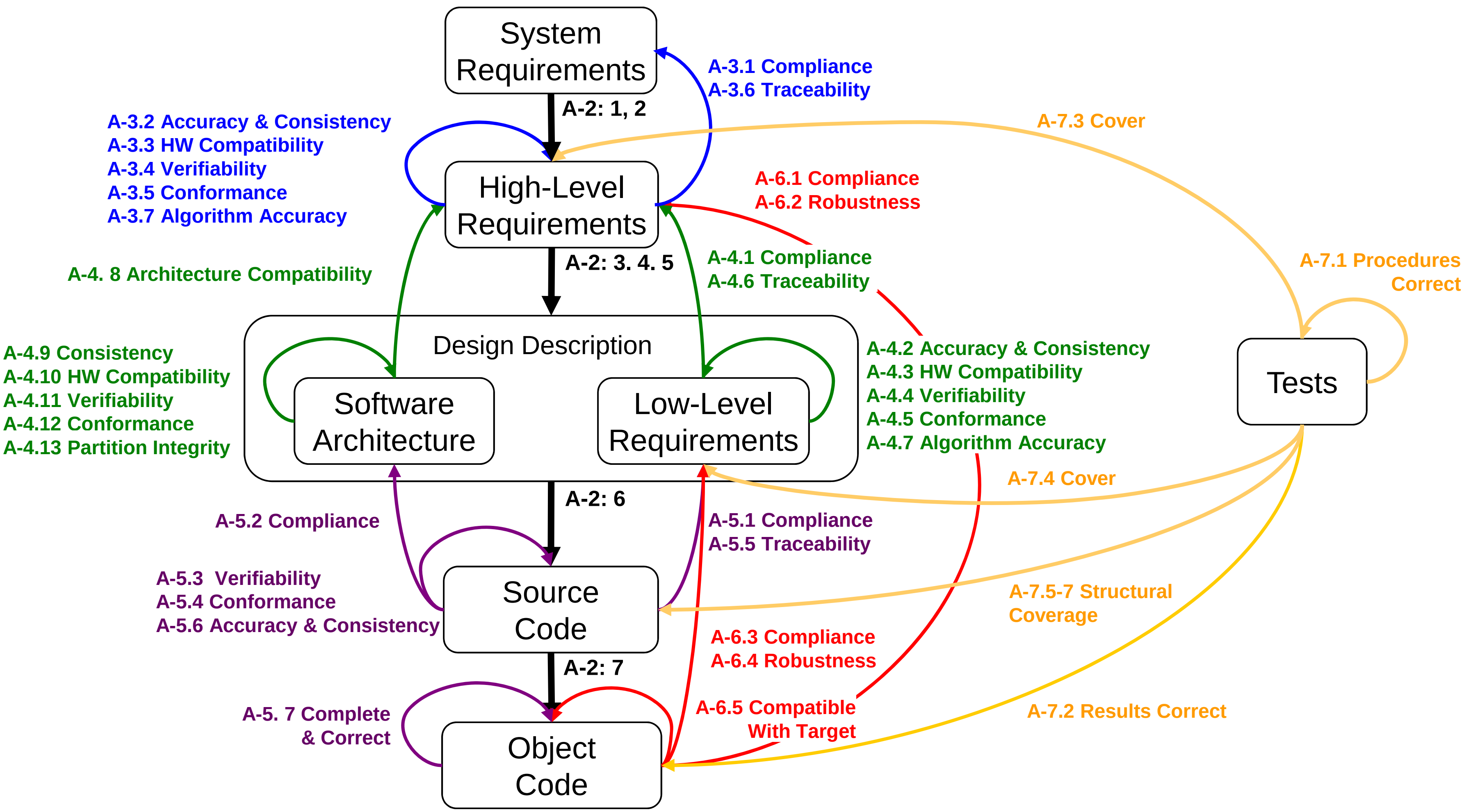
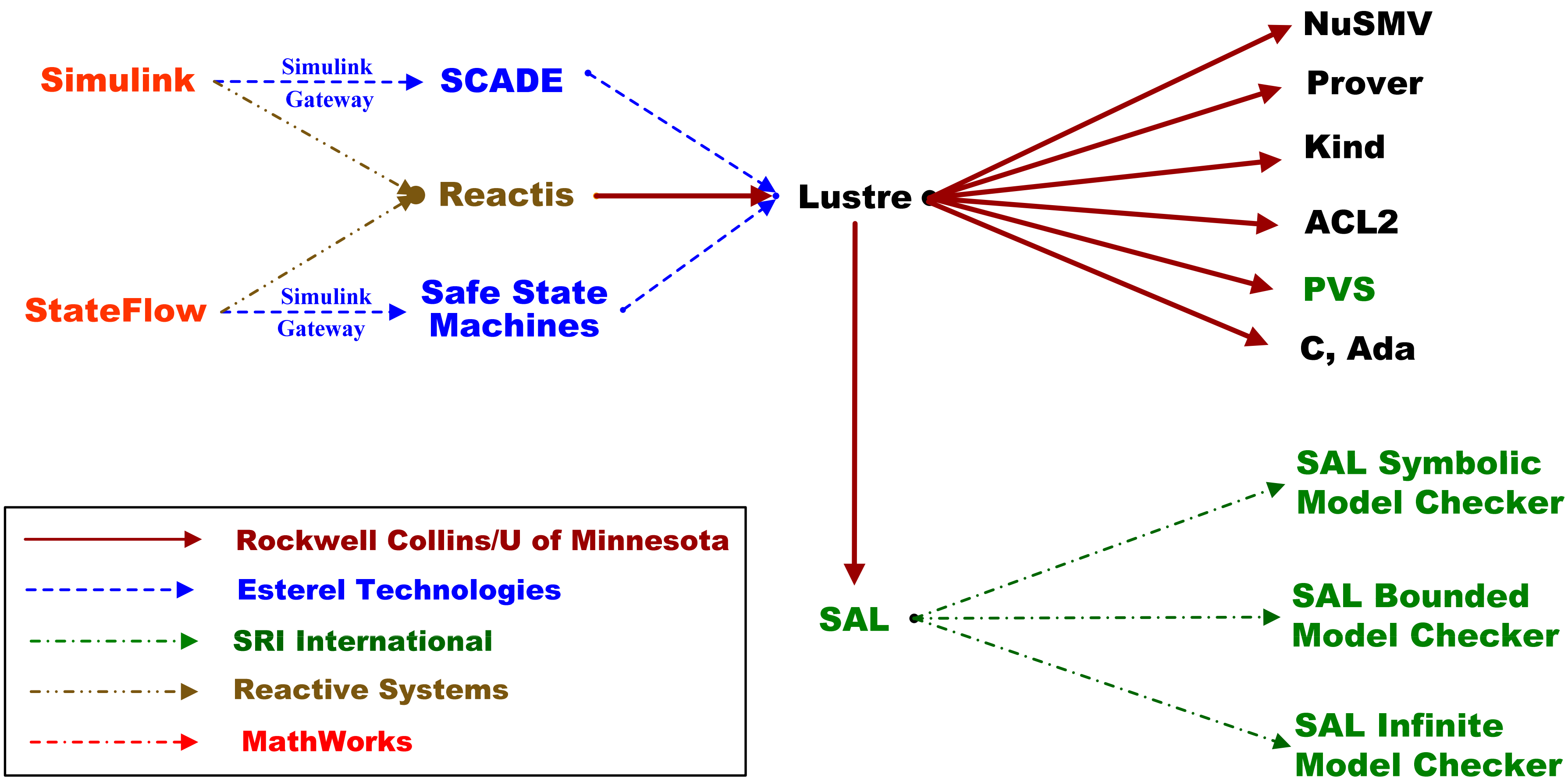
DO-178B at a Glance



Rockwell Collins Translation Framework



ADGS-2100 Adaptive Display & Guidance System

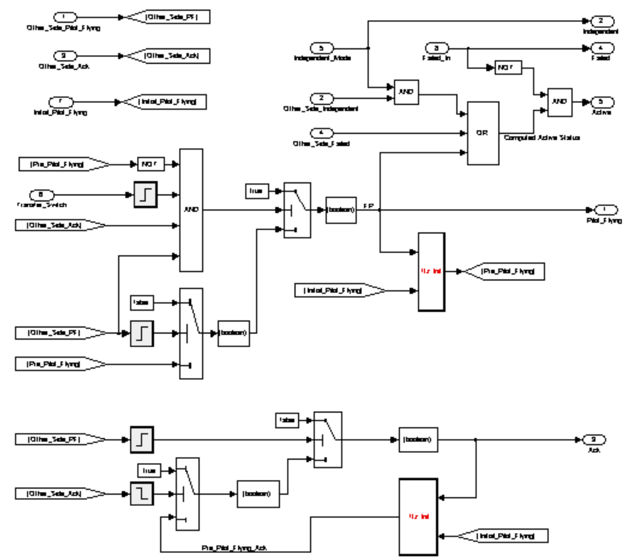
- Modeled in Simulink
- Translated to NuSMV
- 4,295 Subsystems
- 16,117 Simulink Blocks
- Over 10^{37} Reachable States

Example Requirement:

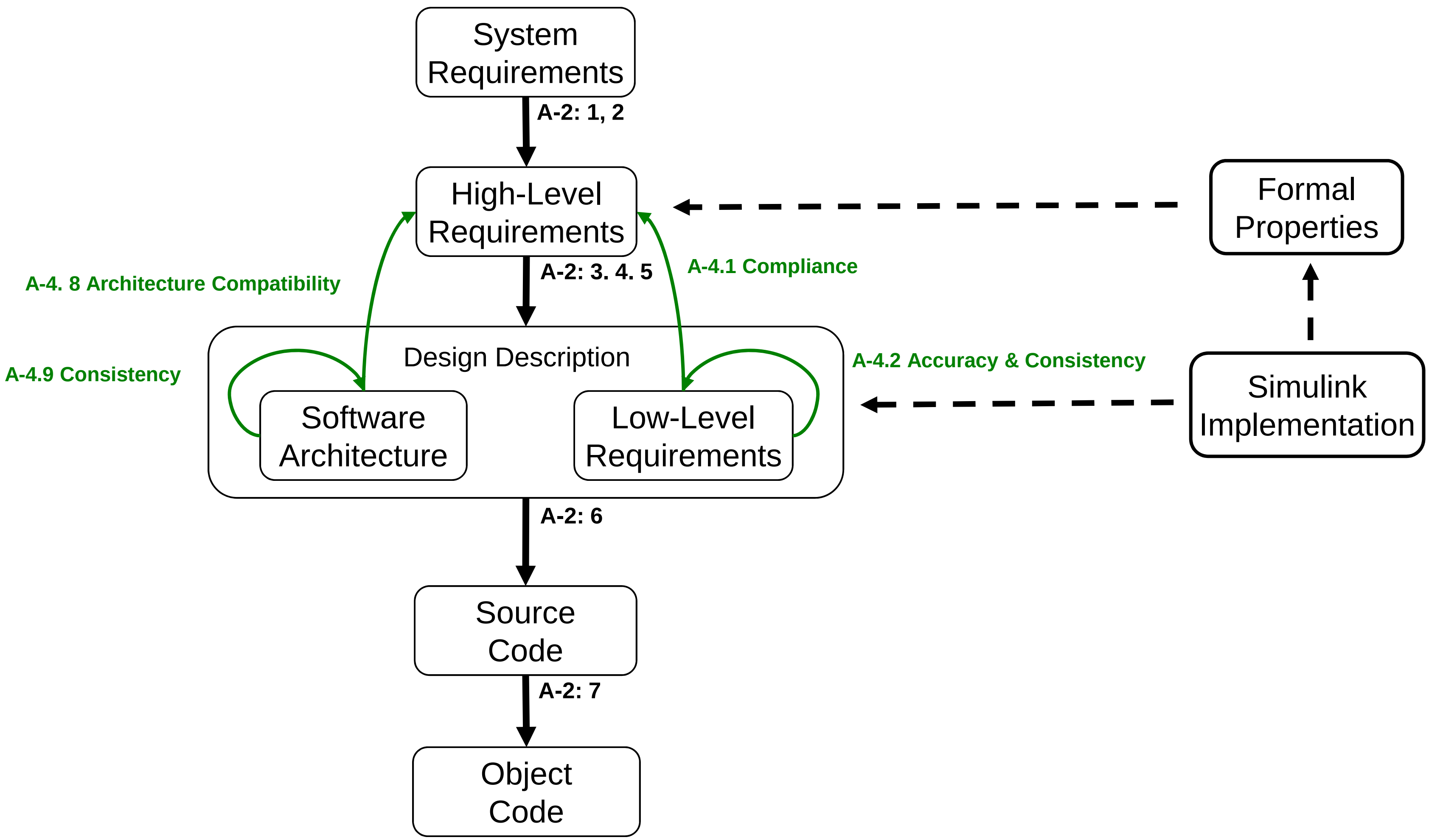
The Cursor Shall Never be Positioned on an Inactive Display

Counterexample Found in 5 Seconds

Checked 563 Properties - Found and Corrected 98 Errors in Early Design Models



ADGS-2100 Adaptive Display & Guidance System



CerTA FCS Phase I

- Sponsored by the Air Force Research Labs
  - Air Vehicles (RB) Directorate - Wright Patterson
- Investigate Roles of Testing and Formal Verification
  - Can formal verification complement or replace some testing?
- Example Model – Lockheed Martin Adaptive UAV Flight Control System
  - Redundancy Management Logic in the Operational Flight Program (OFP)
  - Well suited for verification using the NuSMV model-checker

Lockheed Martin Aero

- Based on Testing
- Enhanced During CerTA FCS
  - Graphical Viewer of Test Cases
  - Support for XML/XSLT Test Cases
  - Added C++ Oracle Framework
- Developed Tests from Requirements
- Executed Tests Cases on Test Rig

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- Based on Model-Checking
- Enhanced During CerTA FCS
  - Support for Simulink blocks
  - Support for Stateflow
  - Support for Prover model-checker
- Developed Properties from Requirements
- Proved Properties using Model-Checking

CerTA FCS Phase I – Errors Found

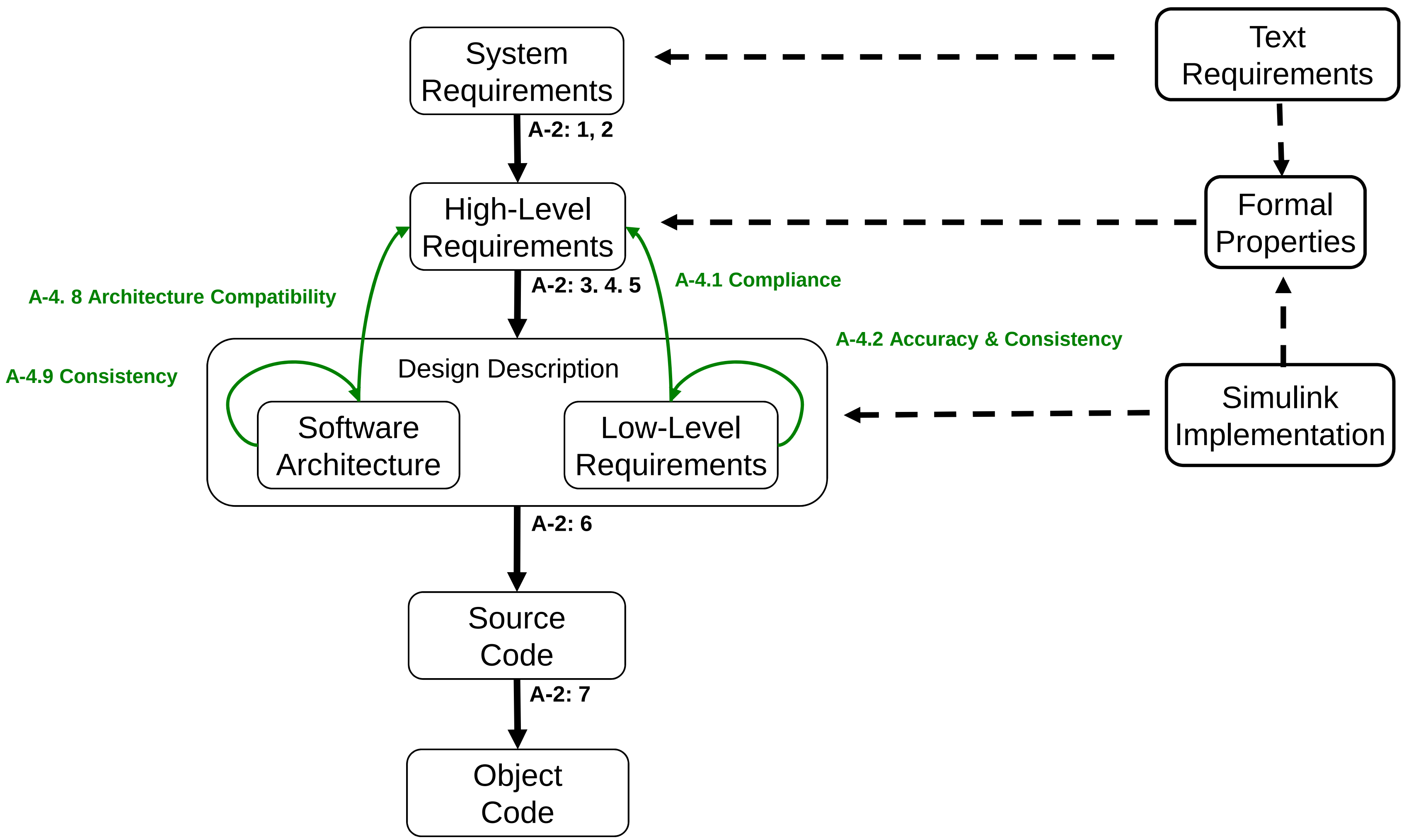
Errors Found in Redundancy Manager

	Model Checking	Testing
Triplex Voter	5	0
Failure Processing	3	0
Reset Manager	4	0
Total	12	0

- Model-Checking Found 12 Errors that Testing Missed
- Spent More Time on Testing than Model-Checking
  - 60% of total on testing vs. 40% on model-checking

Model-checking was more <u>cost effective</u> than testing at finding <u>design</u> errors.

CerTA FCS Phase I



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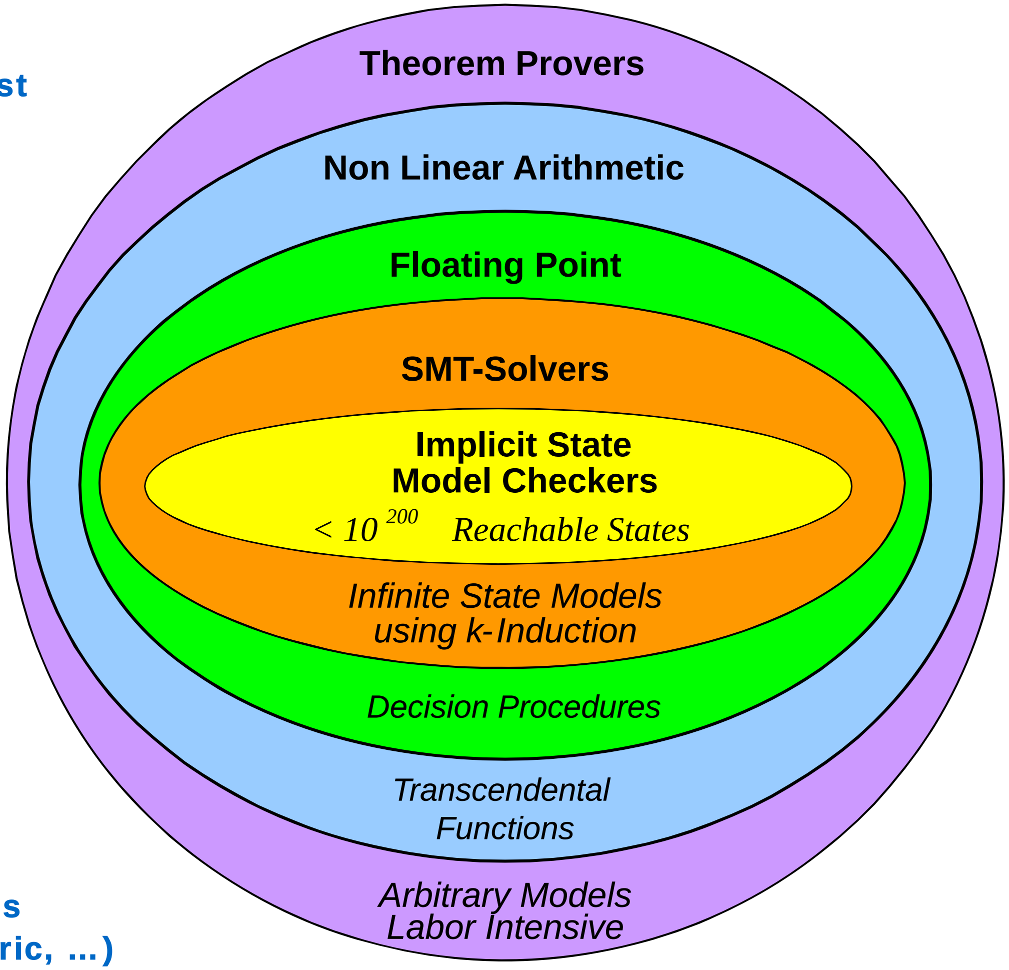
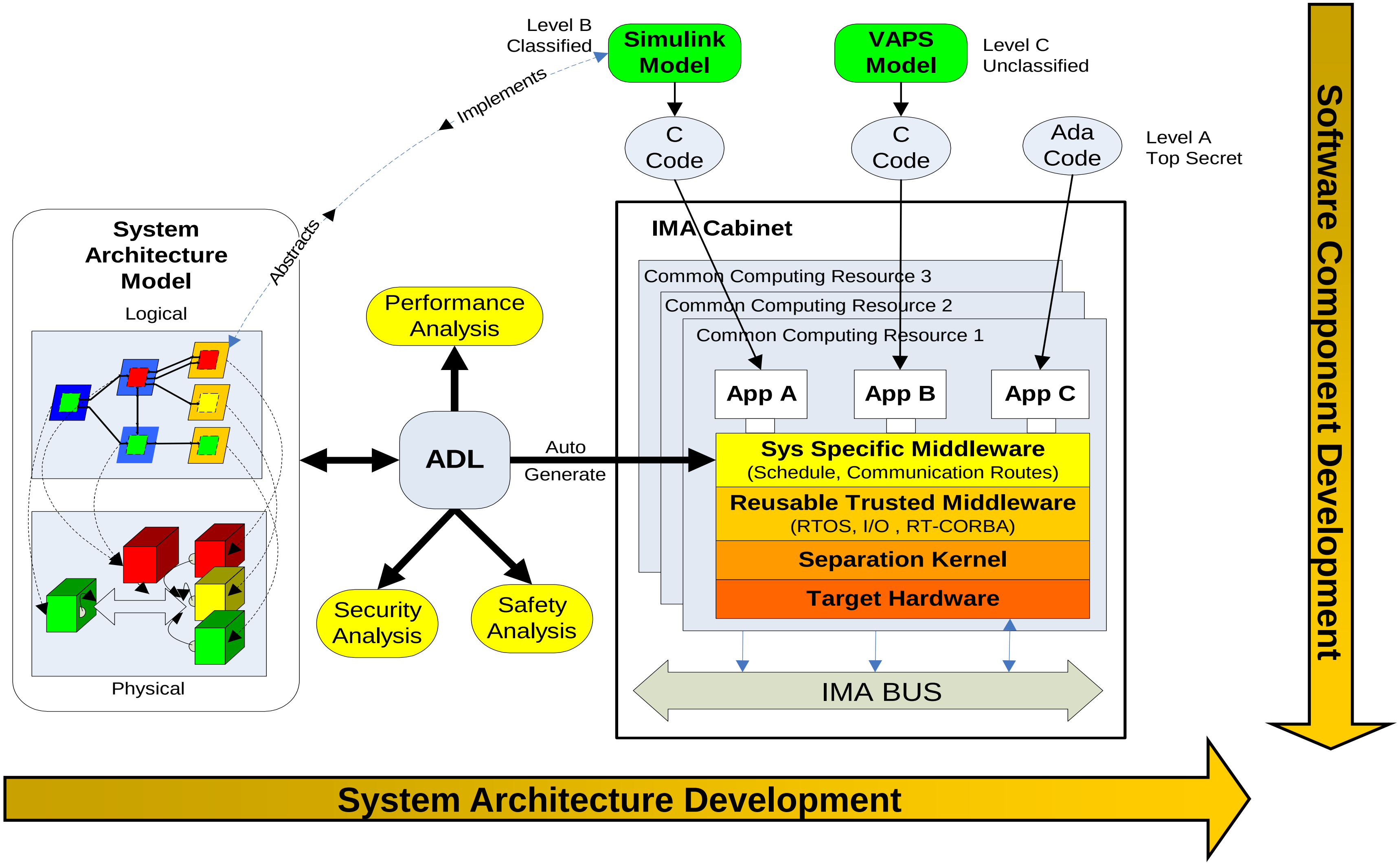
Extending the Verification Domain

- **Theorem Provers**
  - Deal with arbitrary models
  - Concerns are ease of use and labor cost
- **Large Finite Systems ($<10^{200}$ States)**
  - Implicit state (BDD) model checkers
  - Easy to use and very effective
- **Infinite State Systems**
  - SMT-Solvers
  - Large integers and reals
  - Limited to linear arithmetic
  - Ease of use is a concern
- **Floating Point Arithmetic**
  - Most modeling languages use floating point (not real) numbers
  - Decision procedures
- **Non-Linear Arithmetic**
  - Multiplication / division of real variables
  - Transcendental tunctions (trigonometric, ...)
  - Essential to navigation systems



System Architectural Modeling & Analysis



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Conclusions

- Formal Methods *Are* Practical and *Are* Being Used
  - Model Based Development is the industrial face of formal methods
  - The engineers get to pick the modeling tools!
  - Semantics of some of the commercial tools could be improved

- Formal Verification Tools Are Being Used in Industry
  - Key is to verify the models the engineers are already building
  - Large portions of existing systems can be verified with model checkers
  - DO-178C Formal Methods Supplement opens up new opportunities
  - Tools will need to be qualified

- Directions for the Future Work
  - Making verification tools more powerful and easier to use
  - Floating point arithmetic and non-linear arithmetic
  - Addressing scalability through compositional verification
  - Tool qualification