Talk for the T&E group

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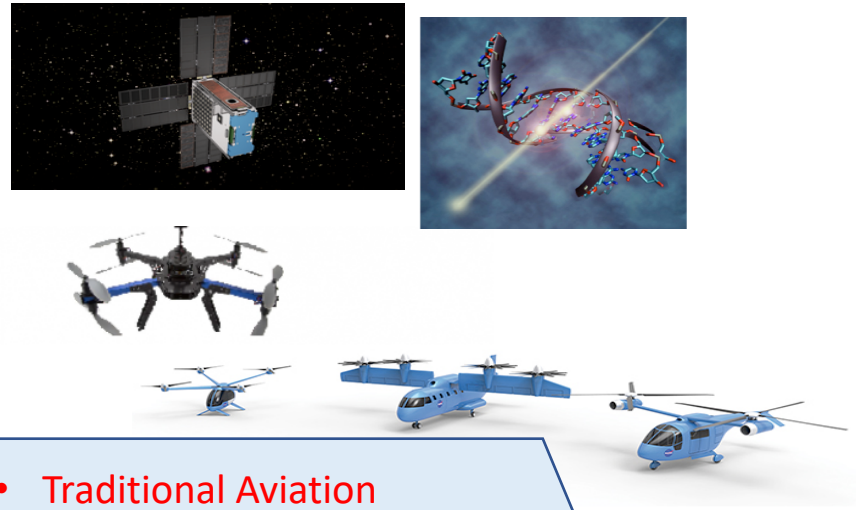
Robust Software Engineering Tech Area

RSE/Ames intro

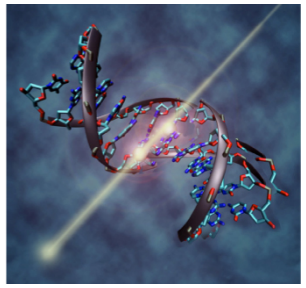
- CAST: Core Avionics and Software Technologies
  - cFS/cFE based FSW
  - Model-based development
  - Swarm simulation
  - Small spacecraft swarm
  - FSW Monitoring & Review
- STMD
  - LCROSS, LADEE
  - BioSentinel
  - Starling, CASAS, DSA
  - RP, VIPER

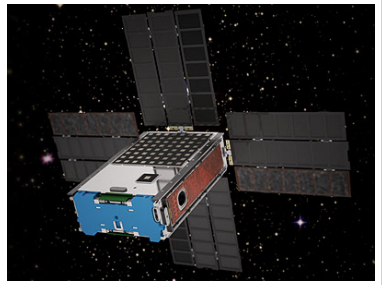


- ASSET: Automated Software & System Engineering Technologies
  - Formal methods
    - Requirement Elicitation/Analysis
    - Design Model Analysis
    - Static Code Analysis
    - Run-Time Analysis
  - Adaptive stress testing
  - Assurance Cases
  - Machine learning V&V
- ARMD
  - AOSP: System-Wide Safety
    - Aviation software assurance
    - Autonomous systems assurance
  - AAM: Automated Flight and Contingency Management
  - Low Boom Flight Demonstrator
- Others
  - Gateway contractors V&V
  - BlueOrigin: ROS 2 V&V
  - DoD Autonomous Systems T&E
- Traditional Aviation
  - US Airframers, OEMs, Airlines
  - FAA, NTSB
  - AFRL
- Emerging Markets
  - Urban Air Mobility
  - Plant inspection, disaster response, precision agriculture, USGS

V&V for Traditional Systems

- Motivation for funding: faster and cheaper Aviation certification through V&V earlier in the lifecycle
  - Focus on flight software





- Applications in our own group working on flight software for small spacecraft
  - Using a model-based, agile process
  - Streamline cost

- Tried it out when “auditing” defense contractors
  - Reluctance to using new methods

V&V for certification

- Motivation for funding: faster and cheaper Aviation certification through V&V earlier in the lifecycle
  - Focus on flight software

DO-178C

- Current standard for getting software certification credits
  - Traceability throughout
  - Track, record, and document

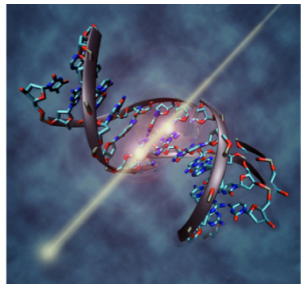
DO-333

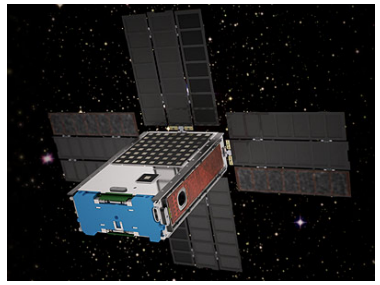
- Formal methods supplement:
  - Model checking
  - Abstract interpretation
  - …

V&V for certification

NPR-7150.2c

NASA-STD-8379.8a





- Applications in our own group working on flight software for small spacecraft
  - Using a model-based, agile process
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- Current standard for getting software certification credits
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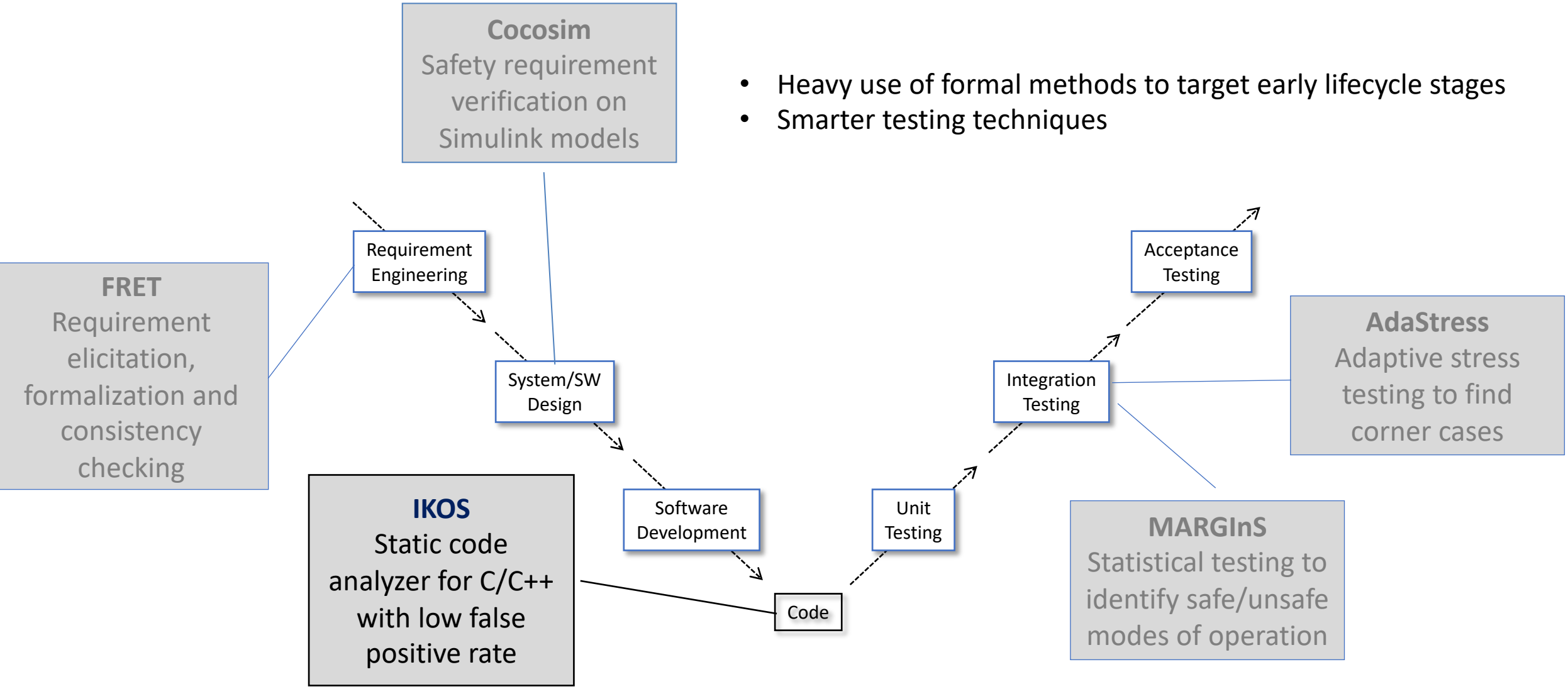
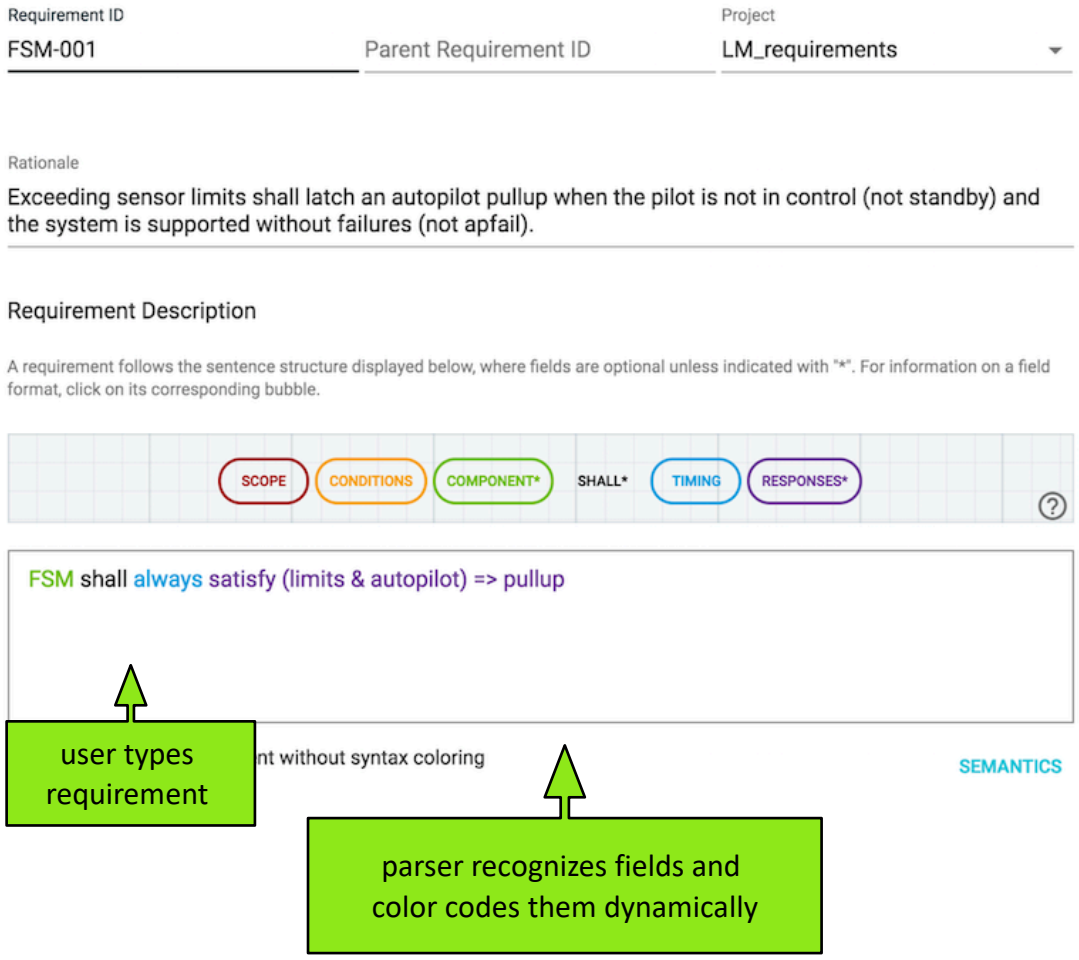
- Analysis available as a V&V means
  - Model checking
  - Abstract interpretation
  - …

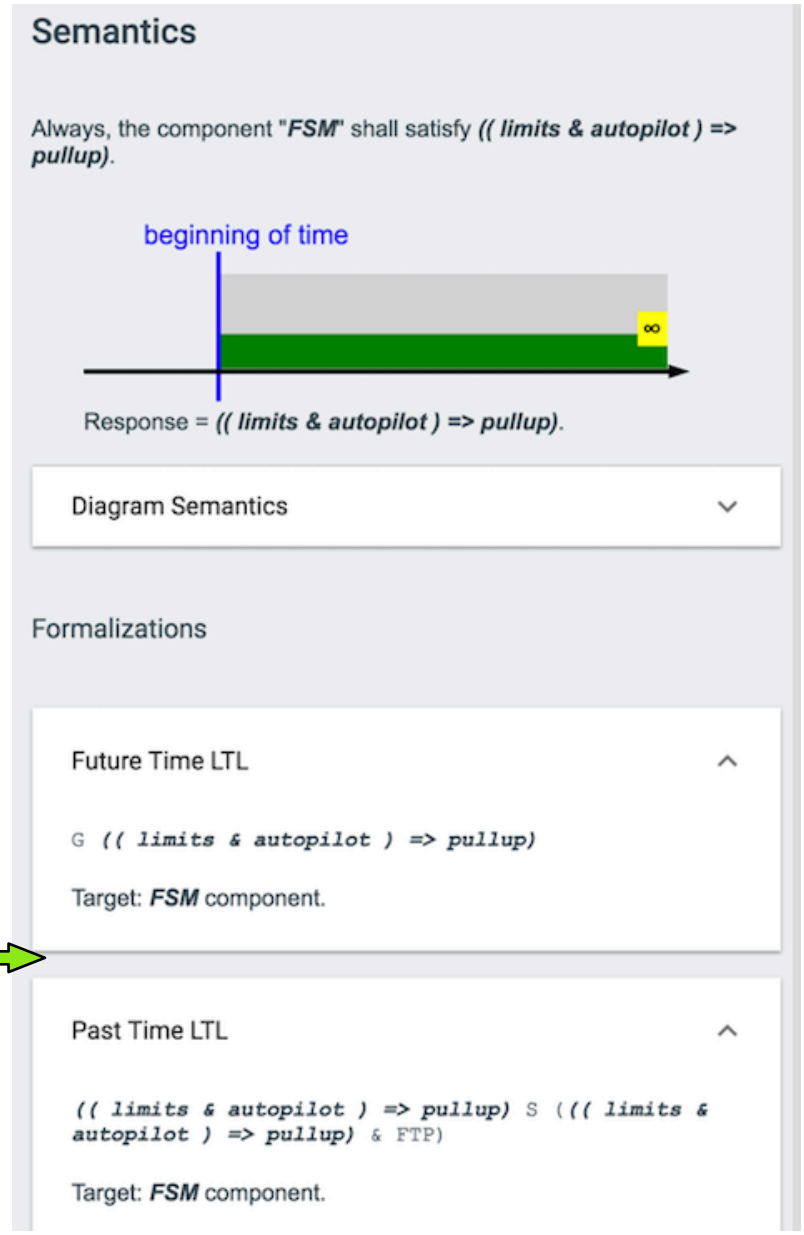
V&V Strategy

- Heavy use of formal methods to target early lifecycle stages
- Smarter testing techniques



FRET at a Glance

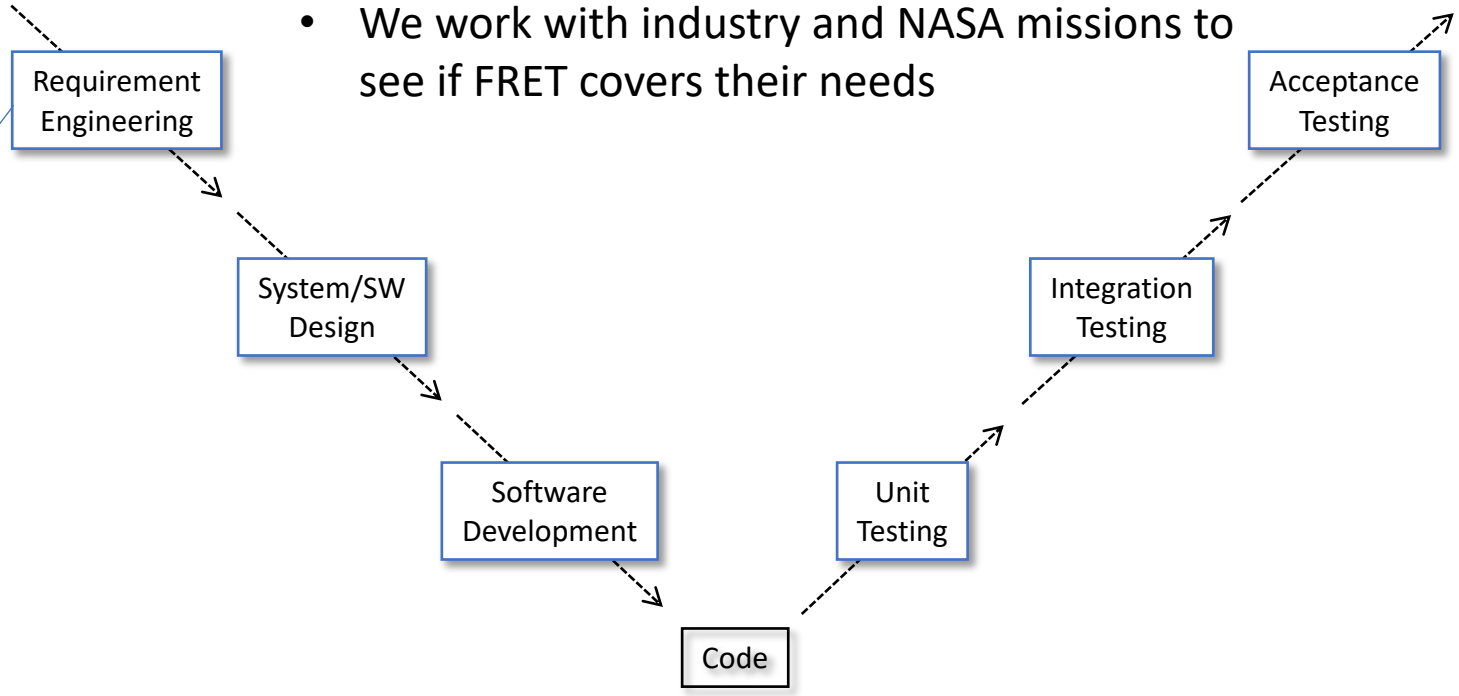




Lessons Learned: FRET

- Going from natural English to formal logic is hard
  - FRET uses English patterns/modes
- Having enough patterns to cover most requirements possible is hard
  - We work with industry and NASA missions to see if FRET covers their needs

FRET
Requirement elicitation, formalization and consistency checking

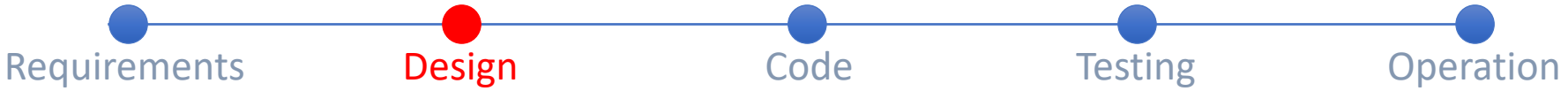


CoCoSim at a glance

- Integrated verification framework for Simulink models
- Fully automated analysis framework
- Shown effective in avionics applications

Limitations and future work

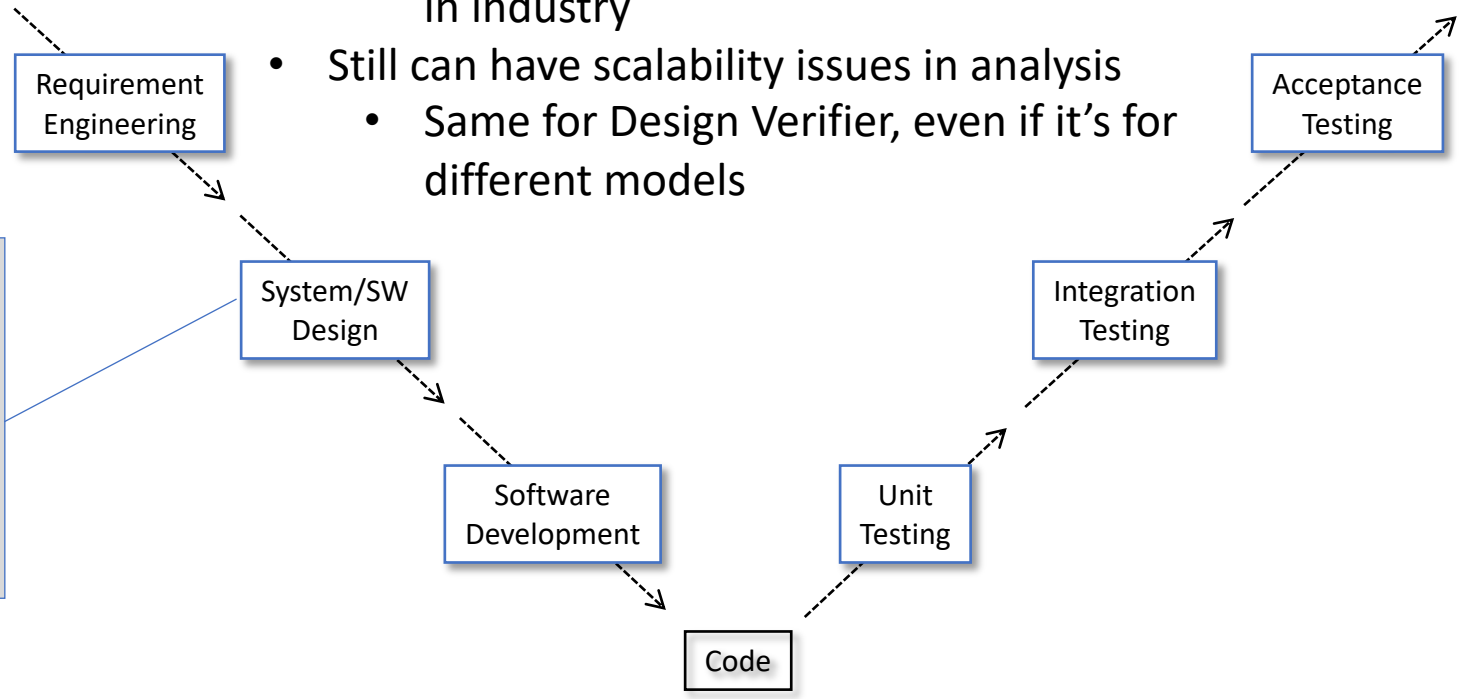
- Currently supports a subset of Simulink models described here **https://github.com/coco-team/cocoSim**
- Uses Z3 constraint solver – plan to integrate other solvers to extend the constraints that can be handled, for example trigonometric constraints
- Does support Stateflow but not embedded matlab



Lessons Learned: CoCoSim

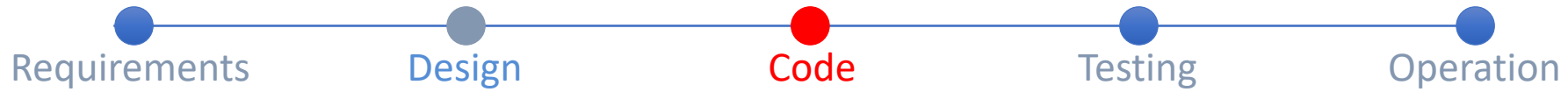
- Formalizing properties is hard but we solved the problem by coupling with FRET.
- Covering all possible Simulink block is impossible
  - We are falling short of covering all blocks used in industry
- Still can have scalability issues in analysis
  - Same for Design Verifier, even if it's for different models

Cocosim
Safety requirement verification on Simulink models



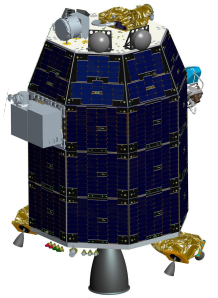
IKOS at a Glance

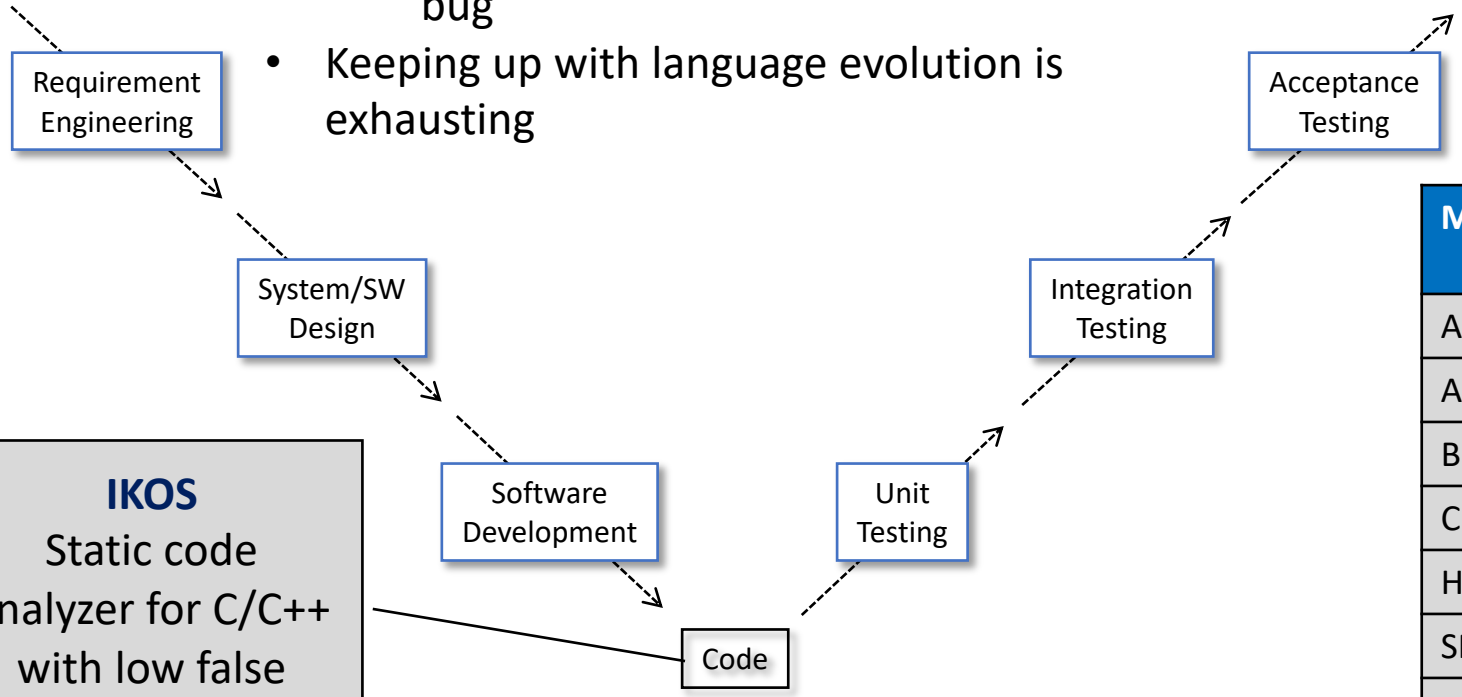
- Analyzes C code and C++ code
  - using the LLVM frontend
  - limited support for C++
- The code does not need to execute:
  - Libraries are not required, but knowledge on the environment and libraries is needed on a per case basis
- Available analyses:
  - Buffer overflow errors, Division by Zero, null pointer de-references, use of uninitialized variables
- No size restriction, but so far applied to 500 KLOC max



Lessons Learned: IKOS

- IKOS works/scales better for C than C++
- Possible to achieve less than 1% warnings
- Some users won't believe the results
  - Need better explanations on why a bug is a bug
- Keeping up with language evolution is exhausting





IKOS
Static code analyzer for C/C++ with low false positive rate

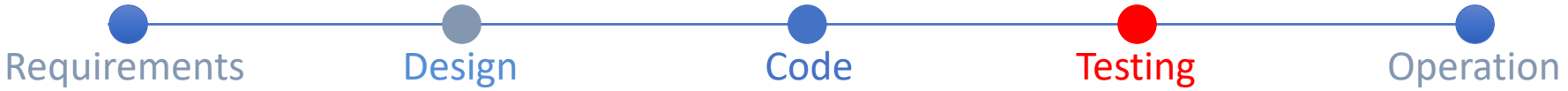
Module	Analysis Time	Precision
ACS	37mn	97%
ACT	35mn	99%
BCS	108mn	97%
CMP	89mn	99%
HIO	7mn	98%
SMC	37mn	98%
TCS	103mn	99%

MARGInS at a Glance

- Is an advanced test generation and test analysis toolset
- Implemented in MATLAB, C, and R – also runs in Octave
- Used for large and small scale space applications (Pad Abort, EFT-1, LADEE)

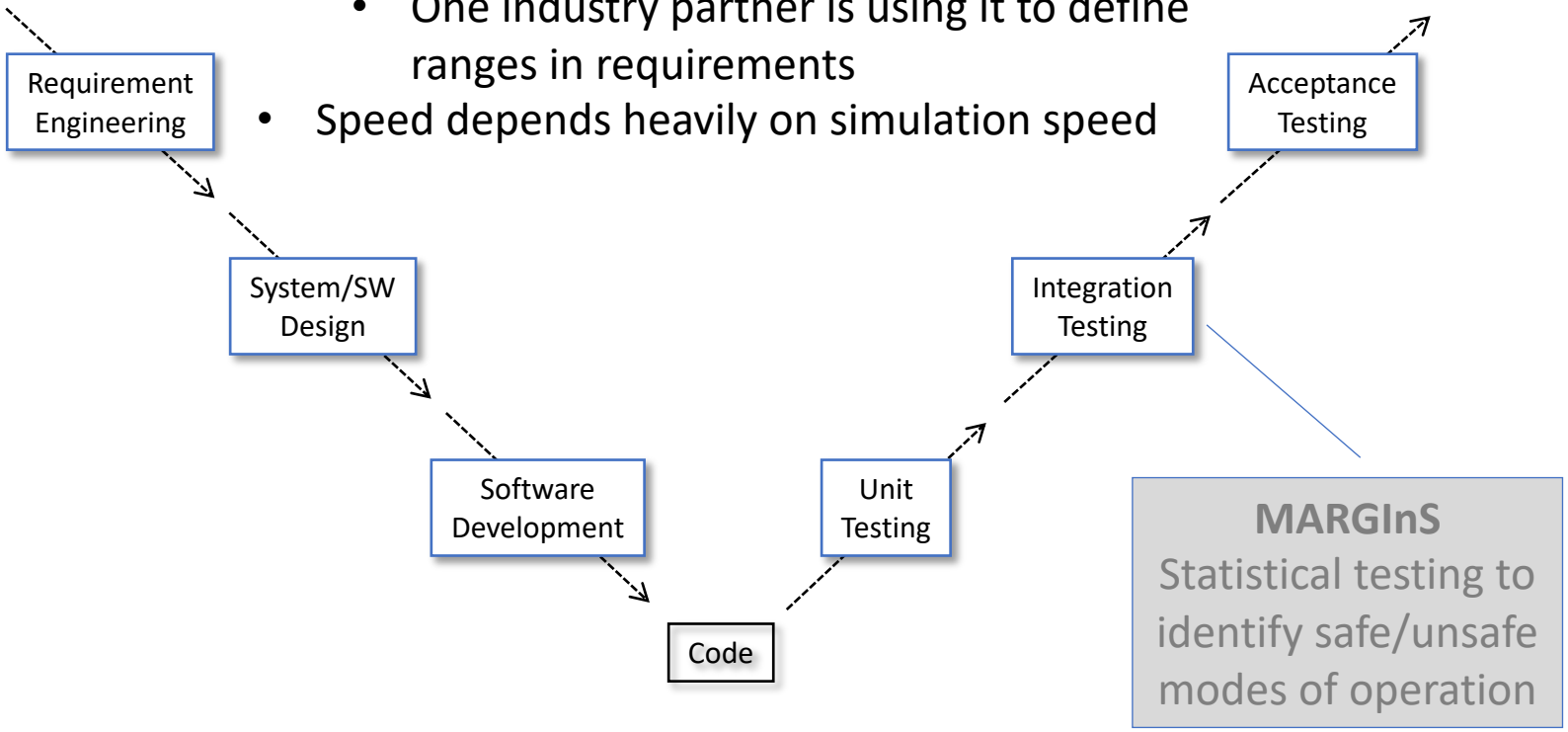
Limitations and future work

- Like any testing tool, MARGInS can increase confidence in the system but cannot guarantee the absence of errors
- Many of the results are visual, and require interpretation from domain experts
- Framework can be extended with additional components such as different machine learning techniques or test case generation schemes.



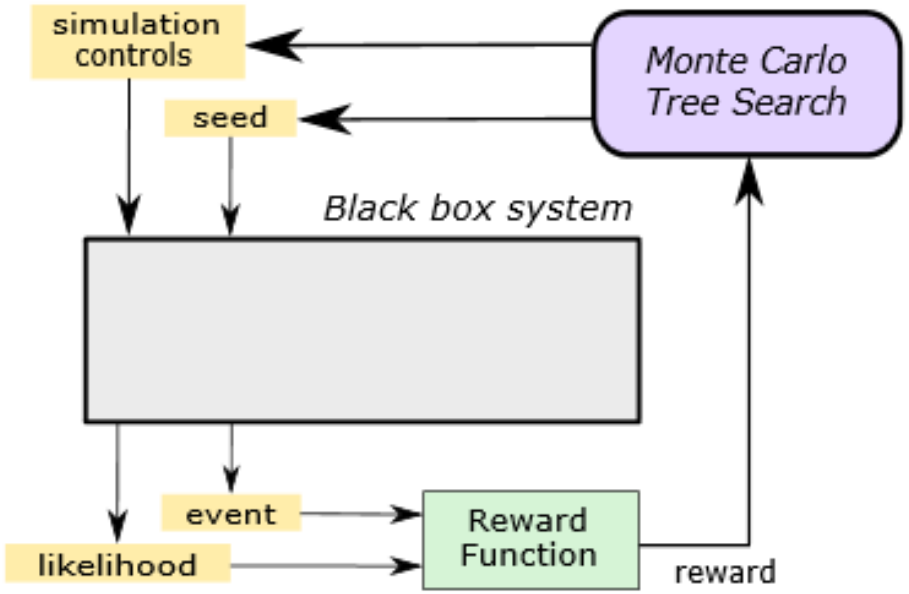
Lessons Learned: MARGInS

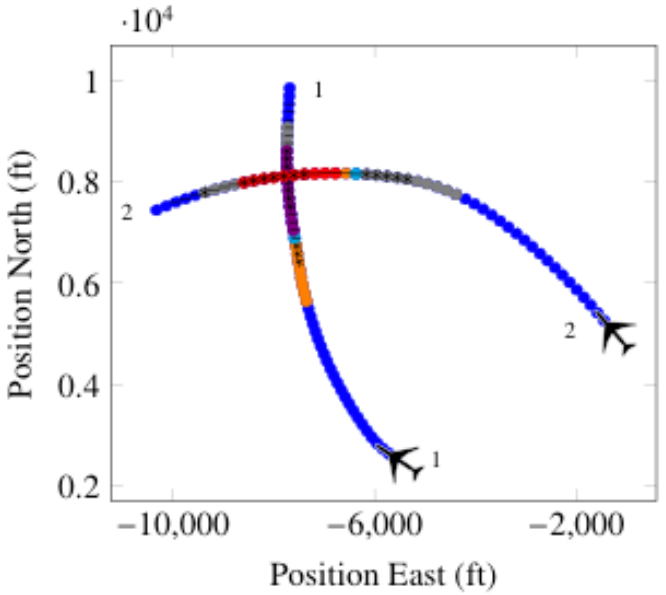
- Not a fully automated process
  - User needs to tell what is a result of interest
- Useful to find boundaries for safe operation
  - One industry partner is using it to define ranges in requirements
- Speed depends heavily on simulation speed

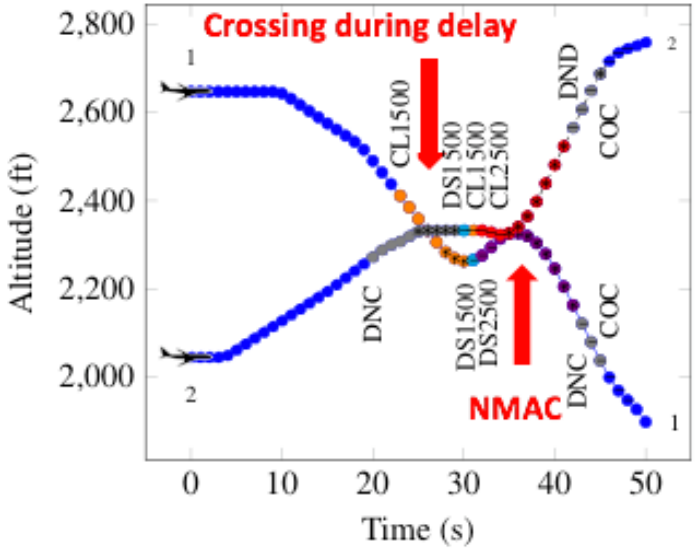


AdaStress at a Glance

- AdaStress is a software package for an accelerated simulation-based stress testing method for finding the most likely path to a failure event



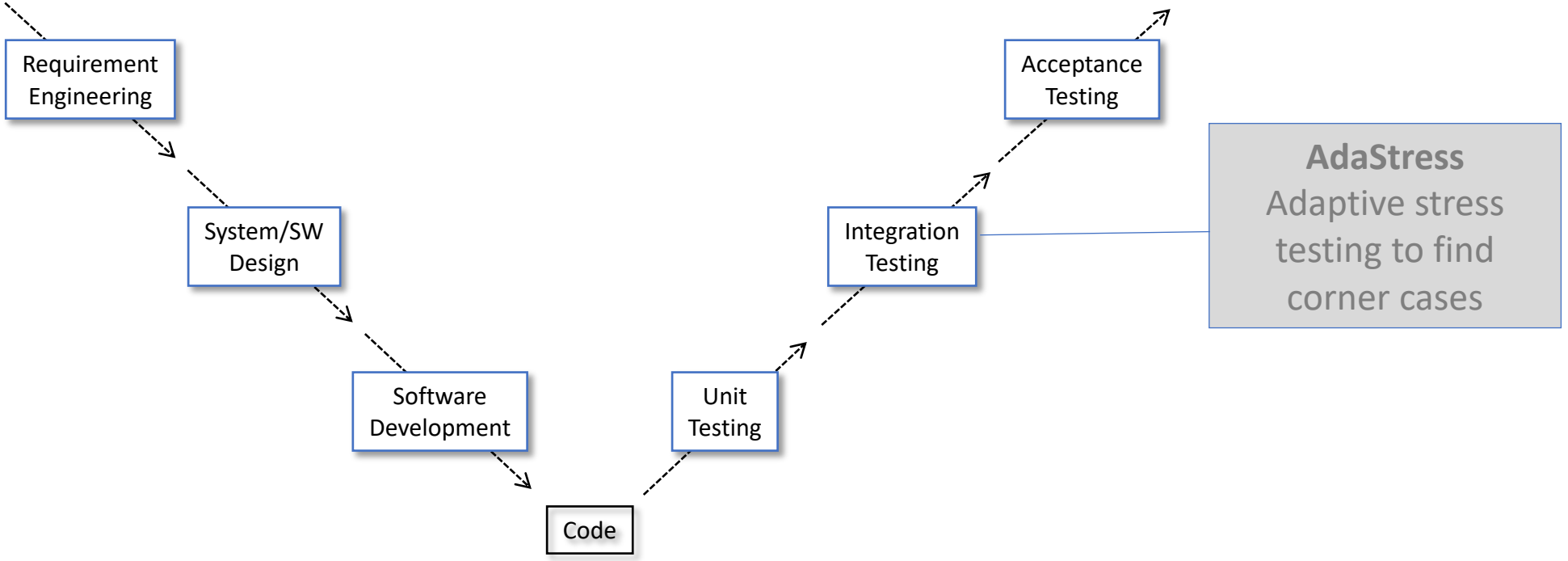




Technical POC: Ritchie Lee

Lessons Learned: AdaStress

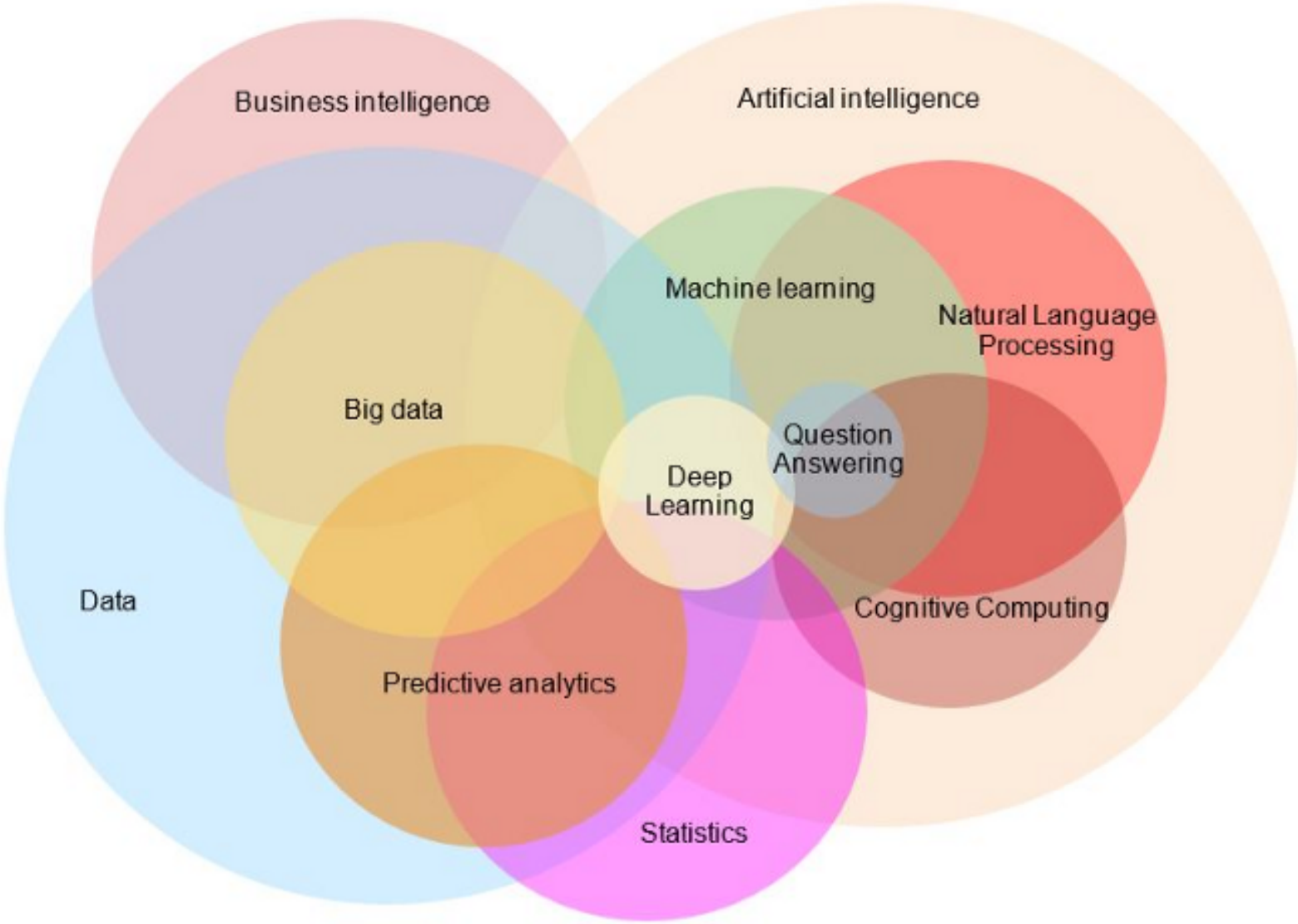
- Has found very useful corner cases for
  - ACAS-X suite of software
  - Industrial flight management system
- Speed depends heavily on simulation speed



Move to autonomous systems

- Asked to address increasingly autonomous systems
- Different customers
  - Traditional: safety conscious but slow
  - New entrants: don't know about safety and want to go fast
    - Strategy: deploy asap, update regularly, very quick cycles
    - Doesn't fit with current certification processes

AI is a big world



New goals

- Work on V&V techniques for autonomy
  - Adapt existing tools for autonomy
  - Solidify use of runtime monitoring
  - Rely on adaptive stress and statistical testing
  - Research formal V&V for Machine Learning (ML)
  - Explore the notion of explainability
- Deliver draft for new standards for autonomy
  - Practical: focus on ML-Enabled Components, then move to systems

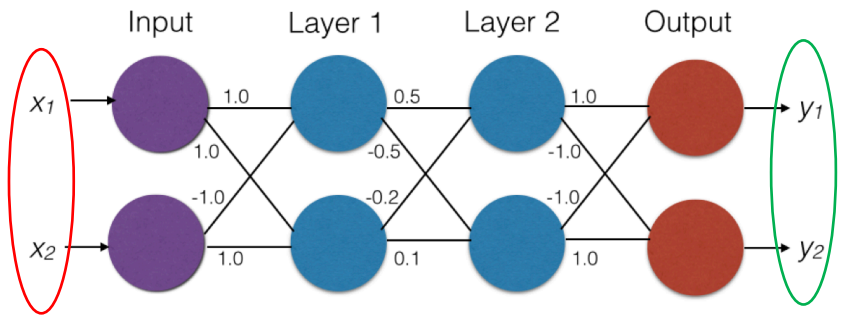
Driving case studies

- Centerline tracking system for autonomous surface operations
  - DNN for image analysis
- Suite of ACAS-X software
  - Multi-optimization-based software
  - NN implementation
- RAV rover
  - Centerline tracking, fusion of various sensor data
- Multi rover coordination
  - TBD
  - Lots of V&V tools will be experimented on this (internal) mission

Prophecy: Contract Inference For NN

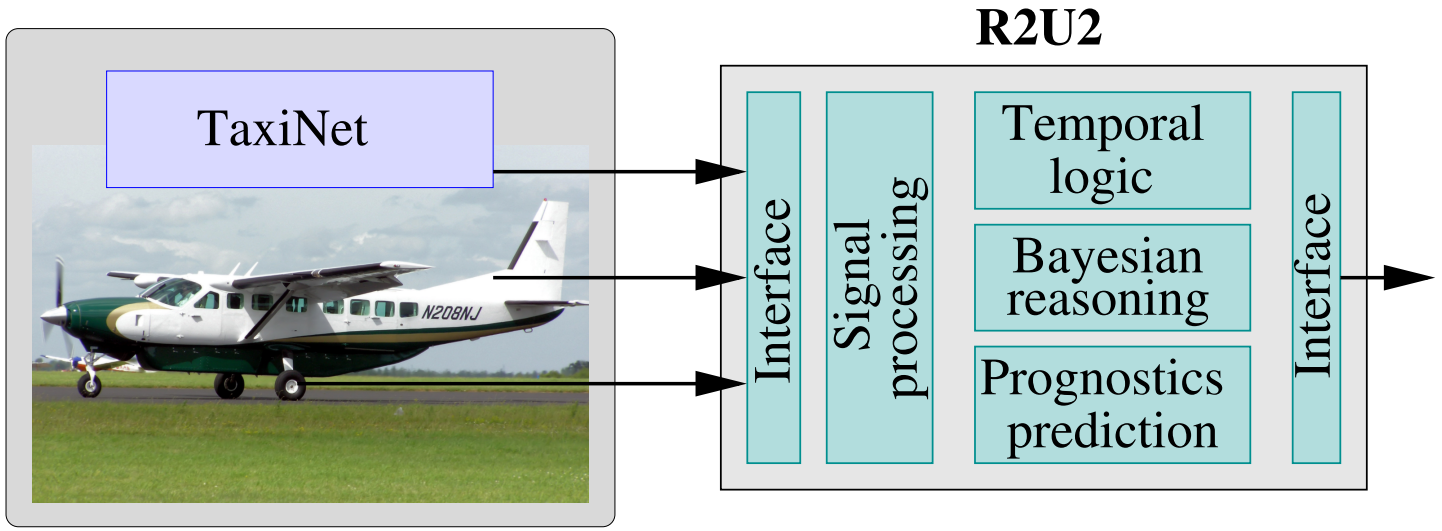
- Key Idea:
  - Infer “likely” properties, aka contracts, of a NN
  - Prove them using a decision procedure
- What is a contract? σ => P
  - σ is a precondition (“safe region”)
  - P is a postcondition; desired output behavior (e.g. some prediction)

If σ holds for



satisfies P

R2U2: Runtime monitoring



R2U2 is a run-time monitoring and V&V tool that combines *Metric Temporal Logic* observers, *Bayesian Network* reasoners, and *model-based prognostics*.

Conclusions

- Lots of experience building V&V tools for traditional aviation systems
  - Most are being evaluated by industry right now
  - Also worked with AFRL
- Need to address autonomy
  - Our primary focus is Machine Learning
  - We'll go from a focus on specialized components to systems involving the use of ML in various places
- The end product is a draft for ML standards.
  - what V&V can be done will inform that