Crowd Sourced Formal Verification

Dr. Drew Dean, Program Manager
Information Innovation Office
Defense Advanced Research Projects Agency

December 8, 2011

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CROWD SOURCED FORMAL VERIFICATION SECURITY BRIEFING

GLORIA PHELPS

December 8, 2011

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DARPA Security Points Of Contact

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MEETING DISUSSION

- THIS MEETING IS SET AT THE UNCLASSIFIED LEVEL (PUBLIC RELEASE INFORMATION ONLY) AND THERE WILL BE NO CLASSIFIED DISCUSSIONS

- PARTICIPANTS
  - U.S. INDUSTRY
  - U.S. DOD AGENCIES
  - UNIVERSITIES
  - FOREIGN NATIONALS

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PROPOSAL CREATION

- PROPOSAL SUBMISSIONS

  -- UNCLASSIFIED - Preferred

- PERFORMER RESPONSIBILITIES

  -- ITAR

  -- PROTECTING THE INFORMATION

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QUESTIONS?

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Cyber Science & Technology

8 Dec 2011 DARPA CSFV Proposers' Day

Steven T Johns, Chief
Trusted Systems Branch(RITA)
Air Force Research Laboratory

Integrity ★ Service ★ Excellence

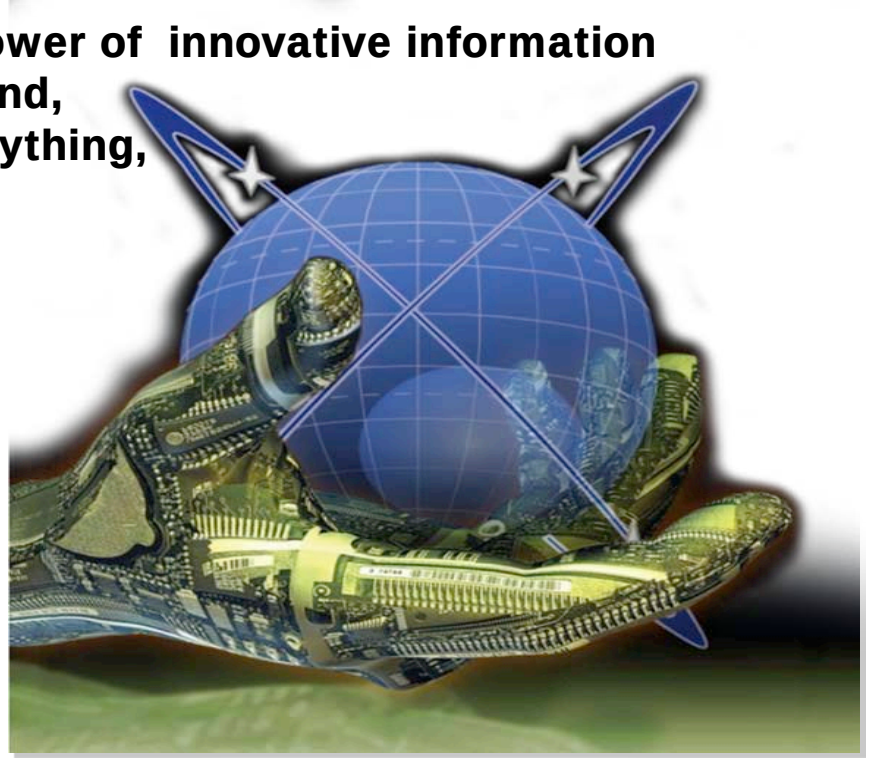
Information Directorate Mission & Vision

Information Directorate Mission

To lead the discovery, development, and integration of affordable warfighting information technologies for our air, space, and cyberspace force

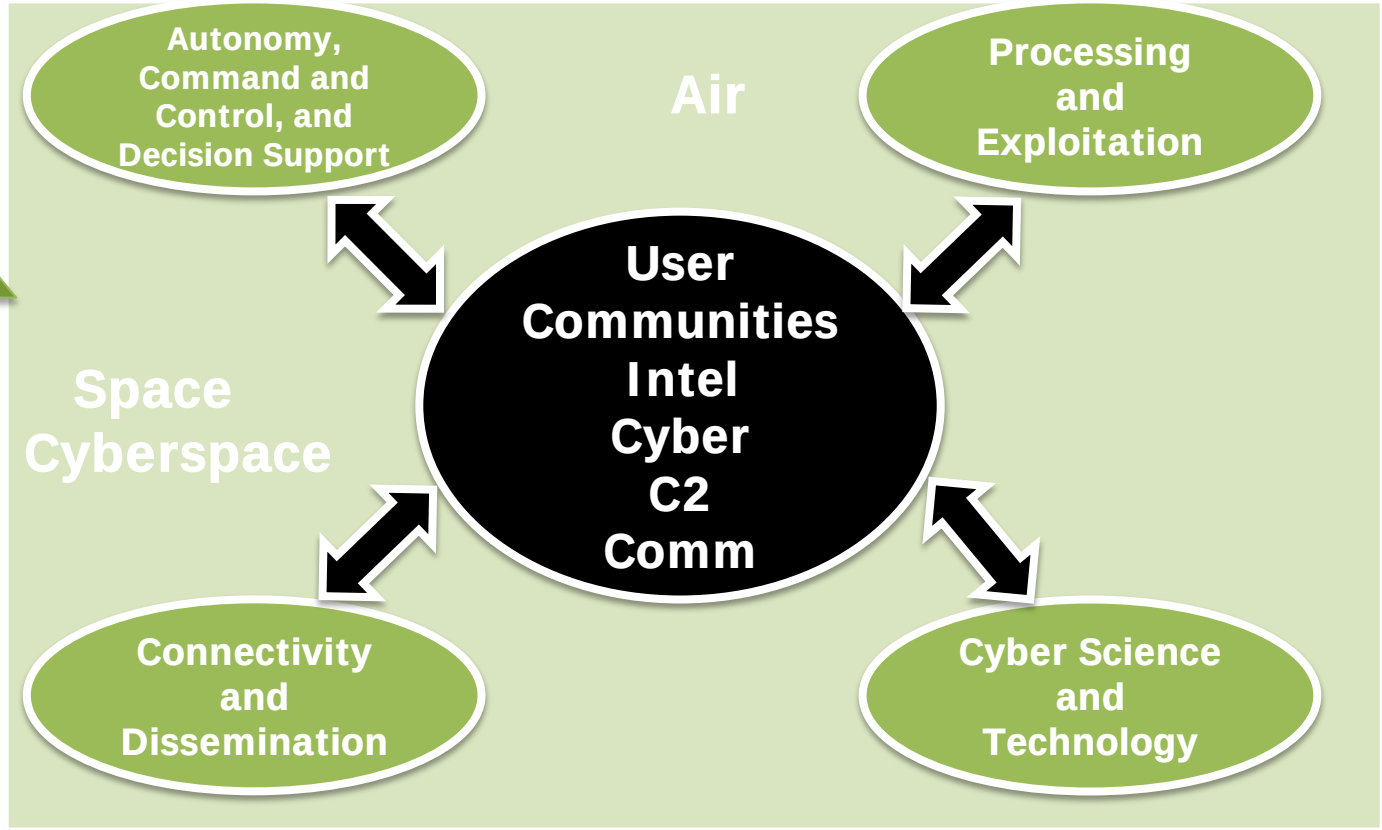
Information Directorate Vision

To defend America by unleashing the power of innovative information science and technology to anticipate, find, fix, track, target, engage, and assess anything, anytime, anywhere.



Information Directorate
Core Technical Competency Portfolio

RI Programs are organized and planned by CTC



Our four core technical competencies provide technologies to translate sensed data to actionable knowledge.

Cyber Science & Technology CTC

Foundations of Trusted Systems

- Trusted Hardware – “root of trust”, trusted foundries
- Trusted Software – “proof of correctness”, virtualization
- Trusted Data – pedigree, watermarking, manage info objects
- Assurance Paradigms – formal correctness of systems

Network Exploitation (Net-X)

- Locate covert and overt (network) data and signals
- Acquisition, Access, and Processing (AAP)

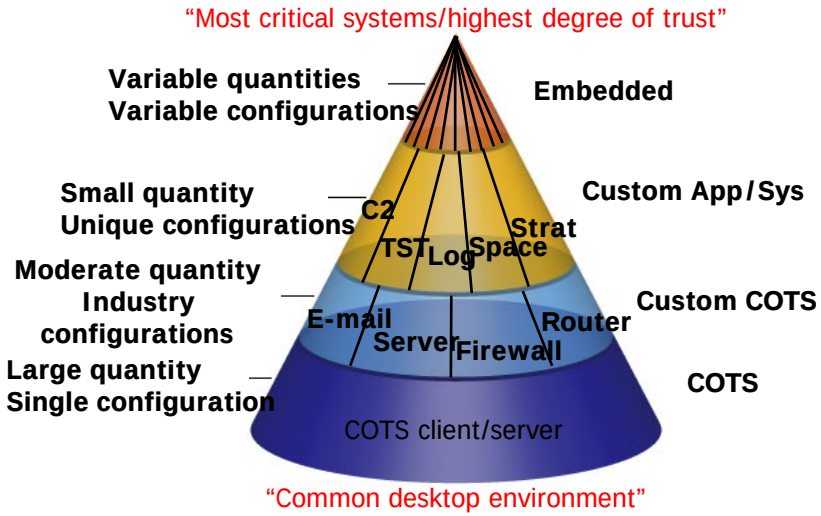
Cyber Resiliency

- Cyber Analytics - reasoning on disparate data sources (threats, insiders, anomalies) for real-time SA
- Cyber Survivability – conduct operations in a contested cyber environment even after sustaining damage
- Cyber Agility and Threat Avoidance – disrupt adversary attack through agility and threat non interoperability

Integrated Cyber Operations

- Integration and testing of capabilities to achieve blended CNO operations (Cyber Experimentation Environment)

Foundations of Trusted Systems



Far Term Vision

- **Inherently Intrusion-Resilient Cyber Networks**
- **Trusted Highly-Autonomous Decision-Making Systems**
- **Fractionated, Composable, Survivable, Autonomous Systems**

Technology Challenges

Trusted Hardware develop a trusted computing base through novel architectures, "roots of trust," hardening techniques, and containment areas for trusted execution

Trusted Software develop techniques, methodologies and tools to guarantee trust (as measured by correctness, security, reliability, predictability, and survivability)

Trusted Data that balance Confidentiality, Integrity and Availability concerns within data objects and streams to enable the transmission and execution of data upon systems regardless of their trustworthiness (e.g., cloud computing)

Assurance Paradigms which examine the algorithms, processes, procedures, technologies and protocols required to provide assurance within program development, transition, mapping, and sustainment

Mid Term Experiment/Demo (2014)

Content/Mission Aware trusted router operating encrypted communication across public internets

Develop, evaluate and deploy a secure, robust and flexible network computing platform, built on a secure and trusted infrastructure, for achieving scalable, high-throughput information processing.

Customer (624th) engaged in tech development process.

Keywords: ***Managed Information Objects, Hardware Root of Trust, Software Root of Trust***

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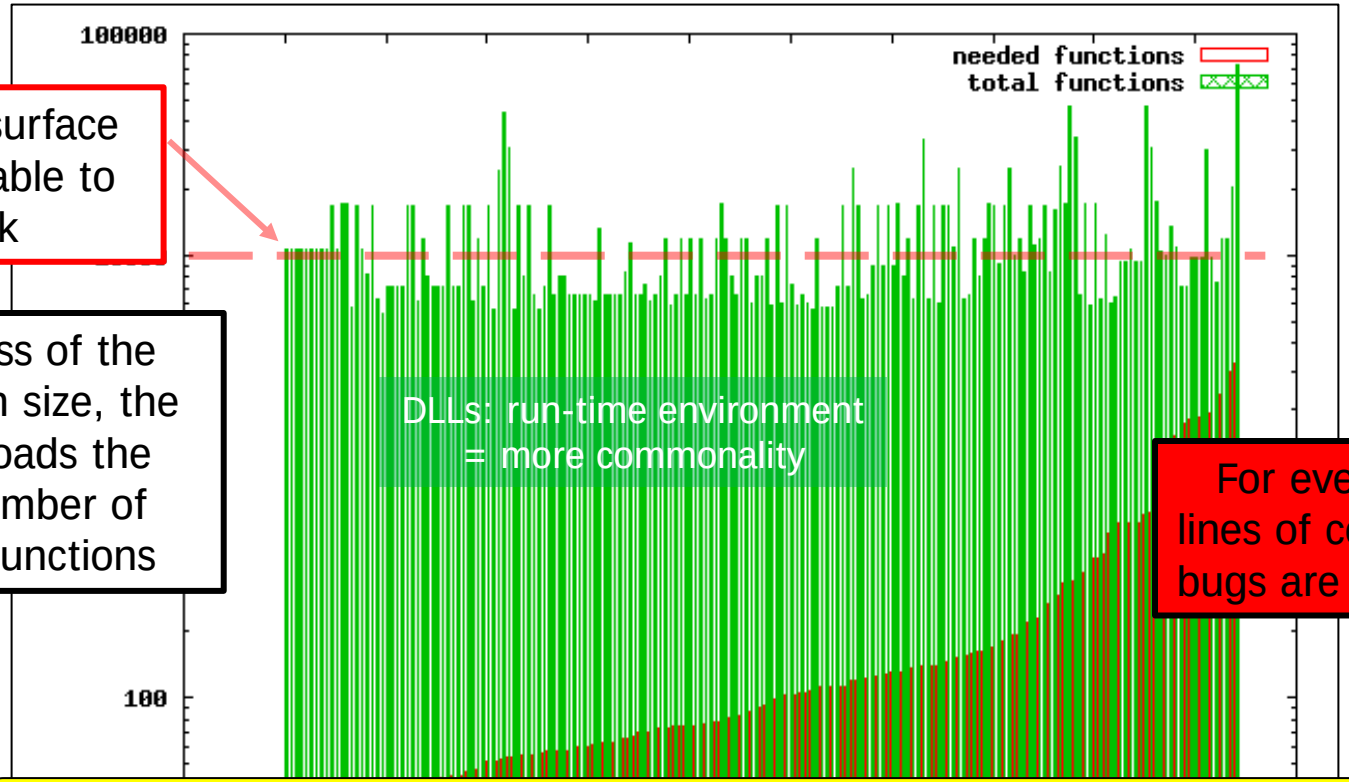
The Problem

Constant surface area available to attack

Regardless of the application size, the system loads the same number of support functions



For every 1,000 lines of code, 1 to 5 bugs are introduced

Are there fundamental scientific reasons that prevent us from doing better?
No: *"There are no intrinsic laws of nature in cyber-security as there are in…physics, chemistry, or biology." [JASON Report on Science of Cyber-Security, 2010]*

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Cybersecurity progress

"Confidence … grows from the assumption that expending resources on security will substantially improve security. In fact, the effort may be simply ineffective, as in the case of the penetrate and patch treadmill." -- **COL Roger Schell, USAF, 1979**

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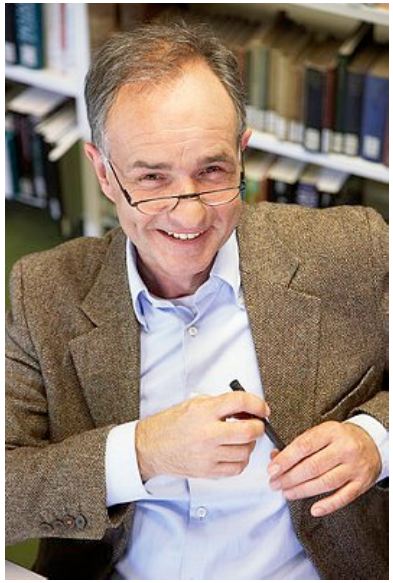
Formal Verification

Formal verification can obtain 0.1 - 0.5 bugs per KLOC, however:

- Extremely expensive: software development costs increase by 2x to 100x
  - seL4 microkernel formal verification took 11 person-years
- Fundamental formal verification problems resist automation
  - Computationally undecidable: Heuristics have improved, but remain incomplete



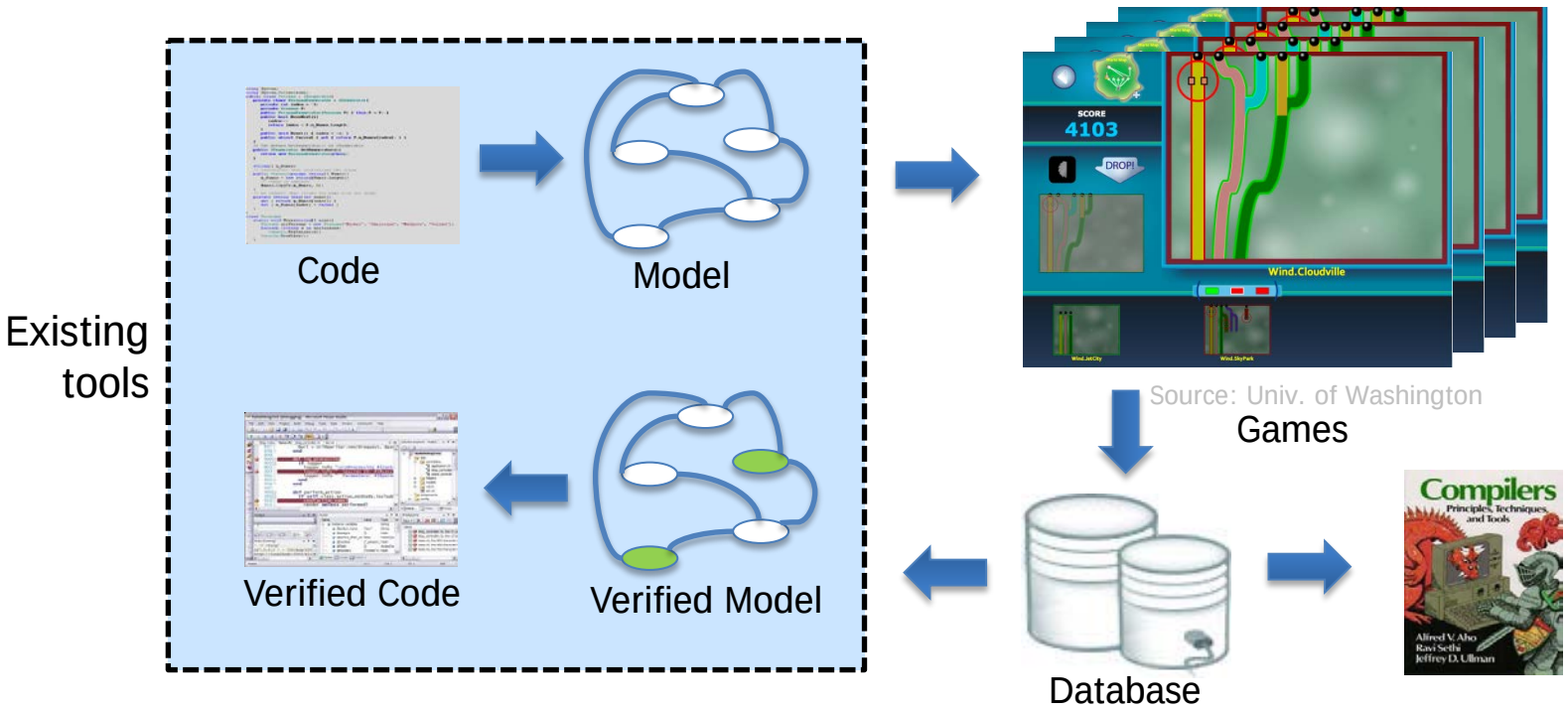
CSFV

Source: morgueFile

The Concept

Leverage crowd-sourcing with peoples bottomless appetite for entertainment

- Transform formal verification problems into attractive games that users will solve for fun: ***"game-ify geeky theorem proving"***
- Map game solutions into formal verification problem solutions



Advantages:

- Well-designed games will result in cheap/free labor not needing formal verification expertise
- The undecidability issues are finessed: we leverage the intelligence and ingenuity of the user population to address these problems

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University of Washington Study

Seedling Scalability

Program	Language	LOC	Moves	Levels
Daikon	Java	134k	2872	1049
Google Collections	Java	49k	936	473

- Each game instantiation is highly decomposable/parallelizable into independent levels
- Initial estimate for solving a level is 10 minutes, and if users play for 30 minutes every day:
  - One property of Google Collections may be verified in 1 day by only 158 users
  - One property of Daikon may be verified in 1 day by only 350 users
  - Assumes ideal scheduling – real world will be longer (latency, not level of effort)

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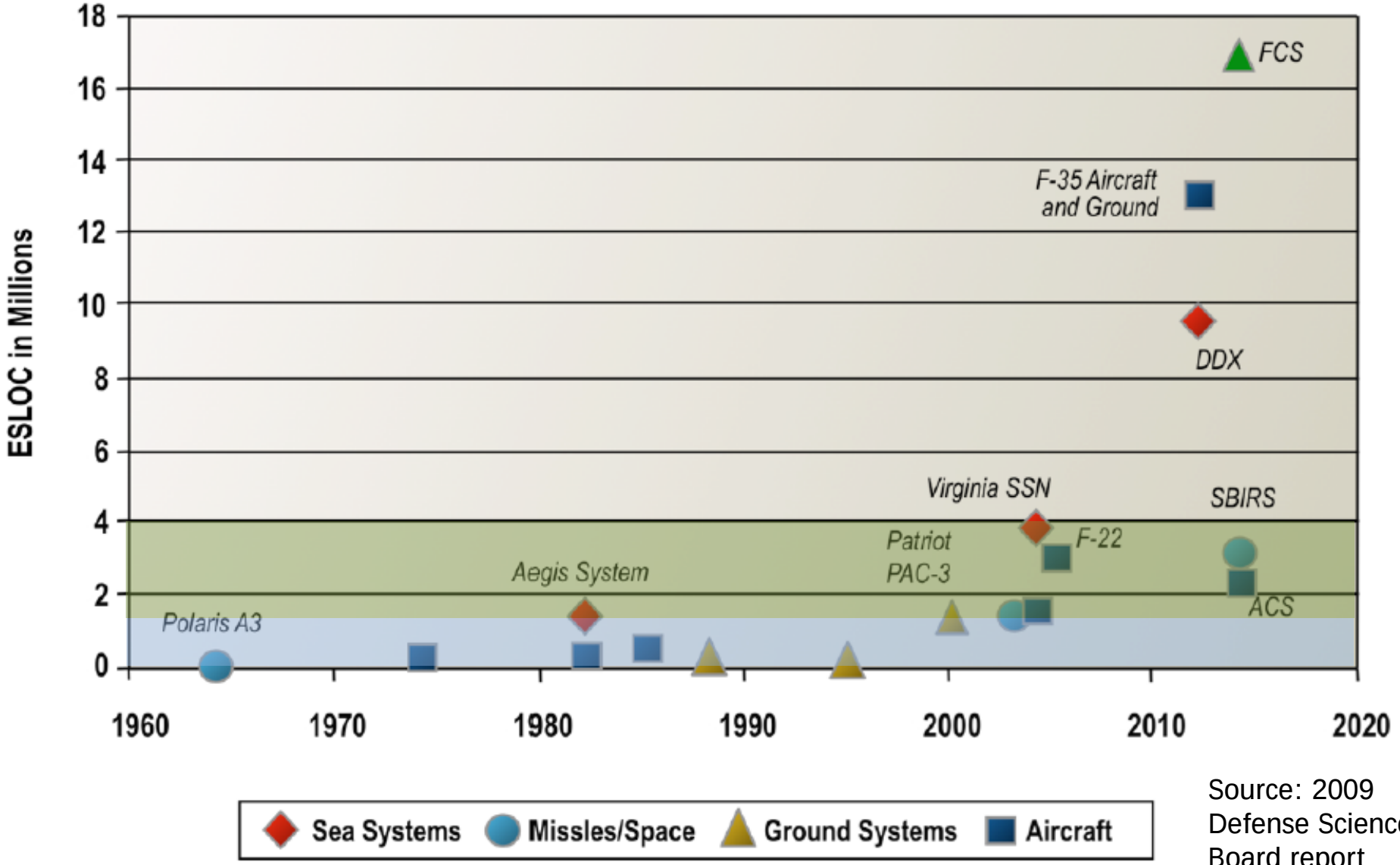
Scalability to DoD Software Systems



Source: 2009 Defense Science Board report

ESLOC = Executable Source Lines Of Code

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Timely Program Concept

Significant recent research progress

- Seedling work by Prof. Michael Ernst, University of Washington, addresses in part 4 of the top 5 of the errors recently released in the list of ***2011 CWE/SANS Top 25 Most Dangerous Software Errors*** :
    1. Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection')
    2. Improper Neutralization of Special Elements used in an OS Command ('OS Command Injection')
    4. Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting')
    5. Missing Authentication for Critical Function

Rise of Casual Gaming and On-line Communities

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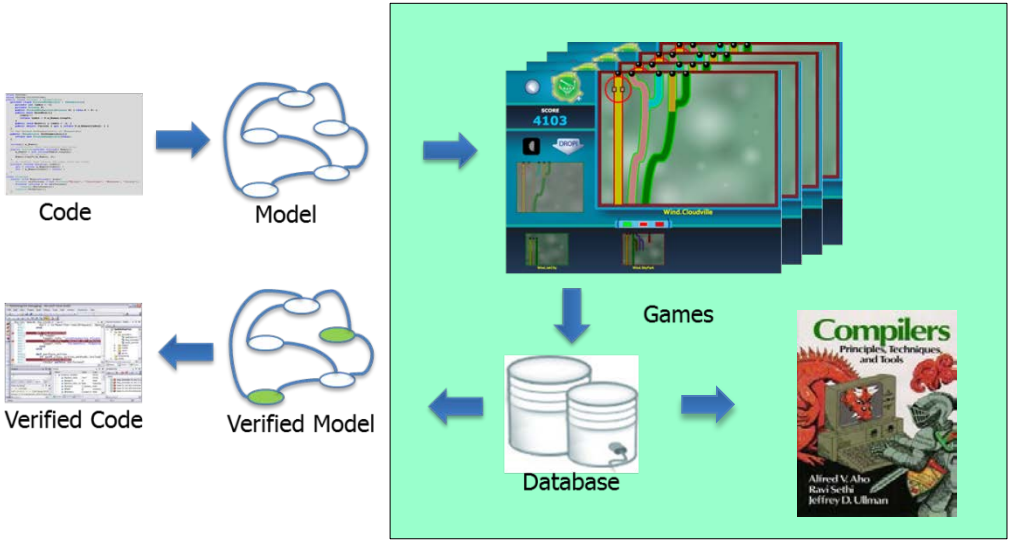
Program Developed Deliverables



- Fully-automated game level builders
- Bidirectional interfaces between formal verification tools and game level builders
- Optimizing compiler backend

- Infrastructure
  - Results databases
  - Casual gaming website
  - Workflow manager

Game level builder, formal verification interfaces, and infrastructure packaged on a LiveCD

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Three performer areas

Task 1: Game level builders and interfaces to formal verification tools

- Produce game instances from program to be verified
- Map game solutions back to formal verification problem solutions
- Build database of program annotations from solutions

Task 2: Compiler optimization

- Use program annotations to improve code generation for faster running applications
- Integrate into existing compiler infrastructures, e.g., LLVM, GCC

Task 3: Research integration

- Community development and workflow management
- Database of problem instances, game solutions, program annotations
- Web site design, construction, analytics, and maintenance
- Package system as a virtual machine image or LiveCD for proprietary and/or classified use

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Area 1: Formal Verification and Gaming

- Anticipate multiple awards
- Team composition
  - Formal verification expert
  - Game developers
- No development of new formal verification tools
- Expectations during Phase 1
  - Develop, test, beta release, and launch 1 game per team
  - Provide game APIs for robot player development
  - Measure productivity of formal verification experts using tools vs. game playing
  - Beta release by Month 12
  - Final release by Month 15
  - Phase ends at Month 18
- Expectations during Phase 2
  - Develop, test, beta release, and launch 1 new game per team
  - Improve Phase 1 game
  - Provide game APIs for robot player development
  - Measure productivity of formal verification experts using tools vs. game playing
  - Beta release by Month 12
  - Final release by Month 15
  - Phase ends at Month 18

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Area 2: Optimizing Compiler Research

- Anticipate multiple awards
- Team composition
  - Compiler expert
  - Developer
- Expectations during Phase 1
  - Optimize code based on program annotations provided by Area 1 games
  - Analyze and characterize effectiveness of code optimizations
- Expectations during Phase 2
  - Optimize code based on program annotations provided by Area 1 games
  - Analyze and characterize effectiveness of code optimizations

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Area 3: Research Integrator

- Anticipate single award
- Team composition
  - Web designer
  - Privacy expert / web analytics collector
  - Developers
- General Expectations
  - Gaming web site development and hosting
  - Workflow management and supporting infrastructure
  - Database management and maintenance
  - Integration of game builders, games, interfaces, and infrastructure into website and LiveCD
  - Performance assessment
  - Web site analytics
- Expectations for Phase 1 and Phase 2
  - Website, workflow, database, and infrastructure released by Month 12
  - Track website statistics/analytics from Month 12 – Month 36
  - Verification performance assessment from Month 15 – Month 36
  - Website game marketing from Month 18
  - LiveCD released at Month 15 and Month 33

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Proposals for Multiple Technical Areas

- Each proposal must address only one Technical Area
- Proposers may submit proposals for Technical Areas 1, 2, or 3
- A proposer selected for Technical Area 3 (Research Integrator) cannot be selected for any portion of the other two Technical Areas

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Plenty of Code Available to Verify …

Start with open-source software

- No legal issues
- 175K open-source projects on SourceForge

Two approaches to proprietary software

- Offer software vendors the entire system to run on their enterprise network
  - Who knew that Bob in accounting is a loop-invariant finding savant?
- Show vendors that games don't leak anything interesting
  - Vendors runs game generation on their enterprise networks
  - Public solves games, solutions sent back to vendors

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Notional Software Verification Targets

Phase 1

- Hadoop
- BIND

Phase 2

- Linux kernel
- TBD – Java code

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Program Technical Metrics

- Number of MITRE *2011 CWE/SANS Top 25 Most Dangerous Software Errors* covered in
  - Phase 1
  - Phase 2

- Game playing time required to identify properties addressing the MITRE *2011 CWE/SANS Top 25 Most Dangerous Software Errors*
  - Number of games
  - Average time/game
  - Average number of players

- Website popularity
  - Number of unique players per month
  - Average playing time per week, month, year
  - Productivity per week, month, year

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Program Schedule

Cycle 1: Initial game engine development and concept assessment (18 months)

Cycle 2: Game engine refinement and increased verification challenges (18 months)

Game Level Builder

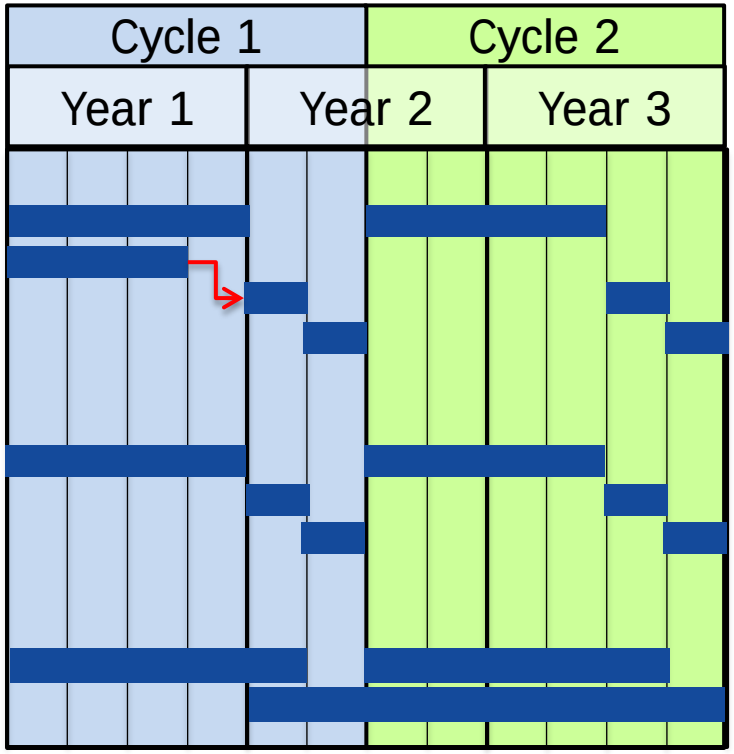
- Game design/formal verification/interfaces
- IRB approval and privacy expert review
- Beta release
- Full release

Optimizing Compiler Development

- Compiler development
- Beta release
- Full release

Research Integrator

- Web site design, construction
- Web site usage, stats, feedback



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BAA Funding

	FY2012	FY2013	FY2014	FY2015	Total
Planned Budget	4,700	11,050	11,000	5,500	32,250
	Phase I	15,750	Phase II	16,500	

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BAA PROCESS OVERVIEW

Solicitation will be released utilizing BAA procedures in accordance with FAR 35.016

The BAA (and any amendments) will be posted in FEDBIZOPPS at www.fbo.gov and Grants.gov at www.grants.gov

BAA allows for a variety of technical solutions

Proposal evaluations will be accomplished through a scientific review using the evaluation criteria stated in the BAA.

The BAA will most likely contain an initial closing time/date and a final closing time/date and these times/dates will be annotated in the BAA. The initial closing time/date is THE timeframe to submit proposals.

BAA will cover all info needed to propose.

Following the proposal preparation instructions assists the evaluation team to clearly understand what is being proposed and supports a timely negotiation

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ELIGIBILITY

All interested/qualified sources may respond subject to the parameters outlined in BAA

Foreign participants/resources may participate to the extent allowed by applicable Security Regulations, Export Control Laws, Non-Disclosure Agreements, etc.

FFRDCs and Government entities are subject to applicable direct competition limitations and cannot propose to this BAA in any capacity, unless they clearly demonstrate the work is NOT otherwise available from the private sector AND provide written documentation citing the specific statutory authority establishing eligibility to propose to Government solicitations and (for FFRDCs) written authorization from the sponsoring agency.

Organizational Conflicts of Interest – Identify and discuss mitigation – failure to do so will result in proposal rejection without technical evaluation or further consideration for award

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PROPOSAL PREPARATION INFORMATION

Consists of two volumes – Technical (with required Appendix A and optional Appendixes B and C) and Cost

Volume I - Technical and Management

- Volume I will contain a page limitation. The evaluation team will not review any submitted pages that exceed the Volume I limit.
- Volume I will require a mandatory Appendix A and optional Appendixes B and C (appendixes have no page limits). The Appendixes do not count towards Volume I's page limit totals.

Volume II – Cost – No page limitation

BAA describes the necessary information to address is each volume –

- Make sure to include every section identified
- If section does not apply – put "None" (e.g. Animal Use – None, OCI - None)
- Include a working spreadsheet as part of your Cost Volume submission
- Remember: Appendix A is mandatory

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PROPOSAL PREP – TECHNICAL DATA RIGHTS

Government desires, at a minimum, **Government Purpose Rights** for any proposed noncommercial software (including source code), software documentation, hardware designs and documentation, and technical data.

Data Rights Assertions – Assert rights to all technical data & computer software generated, developed, and/or delivered to which the Government will receive **less than Unlimited Rights**. This information may be assessed during evaluations.

- Provide and justify basis of assertions that apply to the Prime and any Subs in the prescribed format (See DARPA-BAA-11-63 Section VI (B) 2). Break out these assertions in a separate table (if possible) to be included as an attachment to a resultant contract or agreement.
- Explain how the Government will be able to reach its program goals (including transition) within the proprietary model offered; and
- Provide possible nonproprietary alternatives in any areas that might present transition difficulties or increased risk or cost to the Government under the proposed proprietary solution. NOTE: Offerors expecting to use, but not to deliver, open source tools or other materials in implementing their approach may be required to indemnify the Government against any legal liability arising from such use.

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ITEMS TO NOTE

Understand and be compliant with Central Contractor Registration (CCR), Online Representations and Certifications Application (ORCA), Electronic and Information Technology compliance, Employment Eligibility Verification (E-verify), Reporting Executive Compensation and First-Tier Subcontract Awards and Updates of Information Regarding Responsibility Matters (FAPIIS)

Awardees will be required to use i-Edison, T-FIMS and Wide Area Workflow (WAWF)

Subcontracting Issues

- NON SMALL BUSINESSES: Subcontracting Plans required for FAR based contracts with subcontracting possibilities expected to exceed $650,000
- Subcontractor cost - Proposals must include, at a minimum, a non-proprietary, subcontractor proposal for EACH subcontractor
- If utilizing FFRDC, Government entity, or a foreign owned firm as a subcontractor, submit their required eligibility information

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CSFV Proposers' Day

Proposals must be valid for a minimum of 120 days

If a prospective proposer believes a conflict of interest exists or may exist (whether organizational or otherwise) or has a question on what constitutes a conflict, the proposer should promptly raise the issue with DARPA by sending the proposer's contact information and a summary of the potential conflict to the BAA mailbox before preparing a proposal and mitigation plan.

Document files must be in Portable Document Format (.pdf, ISO 32000-1), OpenDocument (.odx, ISO/IEC 26300:2006), .doc, .docx, .xls, or .xlsx formats.

Submissions must be written in English.

PROPOSAL SUBMISSION

The BAA outlines proposal submission procedures for both unclassified and classified proposals:

- Follow procedures detailed in BAA - Failure to comply with the submission procedures may result in the submission not being evaluated
- Proposers must submit their entire proposal via the same method; applications cannot be submitted in part via one method and in part via another method nor should duplicate submissions be sent via multiple methods.

DO NOT email or fax proposals

DO NOT wait until the last minute to submit proposals – submission deadlines are strictly enforced and late submissions may not be evaluated

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EVALUATION / AWARD

No common Statement of Work - Proposal evaluated on individual merit and relevance as it relates to the stated research goals/objectives rather than against each other.

Evaluation Criteria will be identified in the BAA.

Evaluation Process is a scientific/technical review - Reviews conducted by panels of experts that may include contracted Government SETAs bound by strict non disclosure agreements.

Government reserves the right to select for award all, some, or none of the proposals received, to award portions of a proposal, and to award with or without discussions.

No portion of this announcement will be set aside for Historically Black Colleges and Universities (HBCUs), Small Businesses, Small Disadvantaged Businesses and Minority Institutions (MIs) and no preferences apply.

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COMMUNICATION

After Receipt of Proposals – Prior to Selection: Government (PM/PCO) may communicate with offerors in order to understand the meaning of some aspect of the proposal that is not clear or to obtain confirmation or substantiation of a proposed approach, solution, or cost estimate. After Selection/Prior to Award: Government (PCO) may clarify aspects of the proposal and/or may conduct negotiations. Government (PM/COR/PCO) may clarify the Statement of Work or, in cases where only portions of the proposal are accepted, may discuss reductions to the scope to match the selected effort.

Informal feedback for non selected proposals may be provided once the selection(s) are made.

Only a duly authorized Contracting Officer may obligate the Government

Proposed Options

- Your proposal can include options
  - An option is just that: something the government may fund or not fund at its choice
  - Options are good for both sides

Teaming

- DARPA values academic, small business, and large contractors

- Be strategic:
  - Make synergy explicit
  - Don’t duplicate
  - Look for a good impedance match

- Make sure it’s a team you want to work with if you win

Useful Links

- Teaming Website:
  - http://www.schafertmd.com/darpa/i2o/csfv/teaming
- CSFV Mailbox:
  - CSFV@darpa.mil
- CSFV BAA:
  - Watch FedBizOpps.gov for DARPA-BAA-12-17

Break

We will continue the briefing at 1:30PM PST.

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Information Innovation Office
Defense Advanced Research Projects Agency

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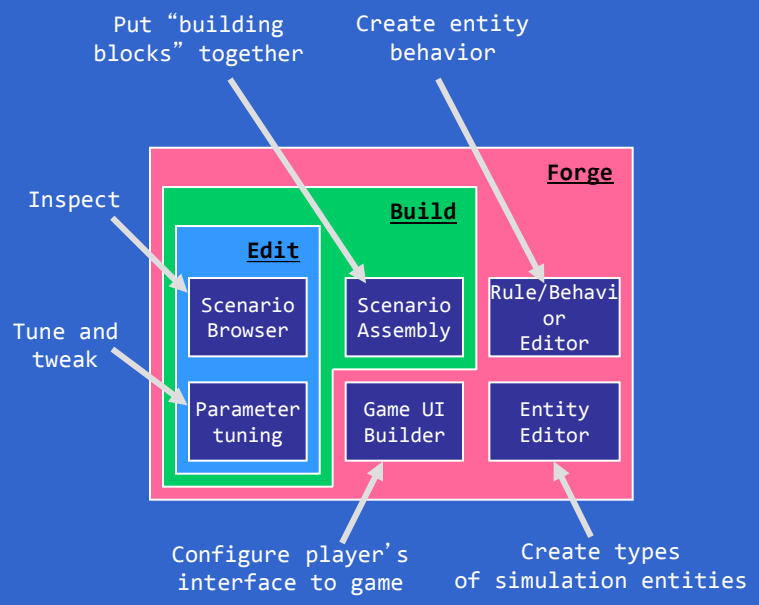
SimVentive Game Generator

SimVentive Authoring Components



SimVentive Player: Coercive Diplomacy Example

Features

- 2-D simulation builder
  - Discrete or real time
  - Multiplayer
- Single authoring tool for game logic & entity AI
- Java-based game engine

Stottler Henke Associates, Inc.
David Breeden
dbreeden@stottlerhenke.com
650-931-2700

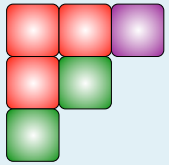
From Code Assurance to Game Concept

- **CWE-131:** *Incorrect Calculation of Buffer Size*
- Can show a program is not vulnerable by proving many verification conditions
- Prune easy cases (e.g., $n + 1 > n$) using automatic proof tools (e.g., SMT)
- For the remainder, turn into games and use human computation
- Galois, Inc. is a tech transition company applying formal methods to improve software assurance
- We are looking for teaming partners with experience developing games and publishing on mobile platforms

Example Problem Domain:
Non-linear arithmetic

Idea: Represent multivariate polynomial formulas as grids of colored tiles:

$0 \leq x^2y + xy + z$



Previously solved puzzles become moves to reduce your grid

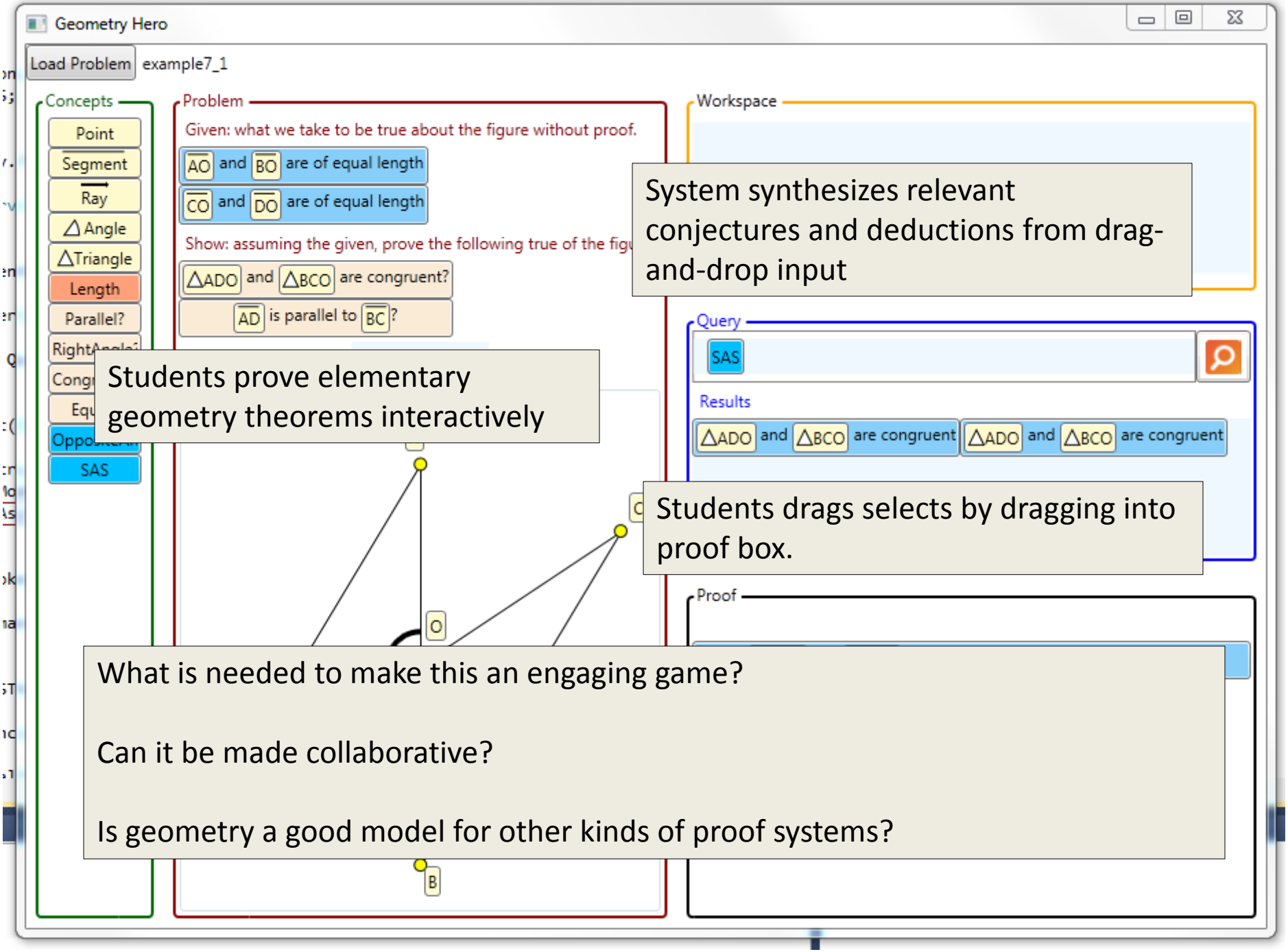
Earn reputation points when your solutions are used by others

Other Promising Domains:

- Heap shape analysis
- Loop invariants
- Termination

Contact: Joe Hurd <joe@galois.com>

galois



System synthesizes relevant conjectures and deductions from drag-and-drop input

Students prove elementary geometry theorems interactively

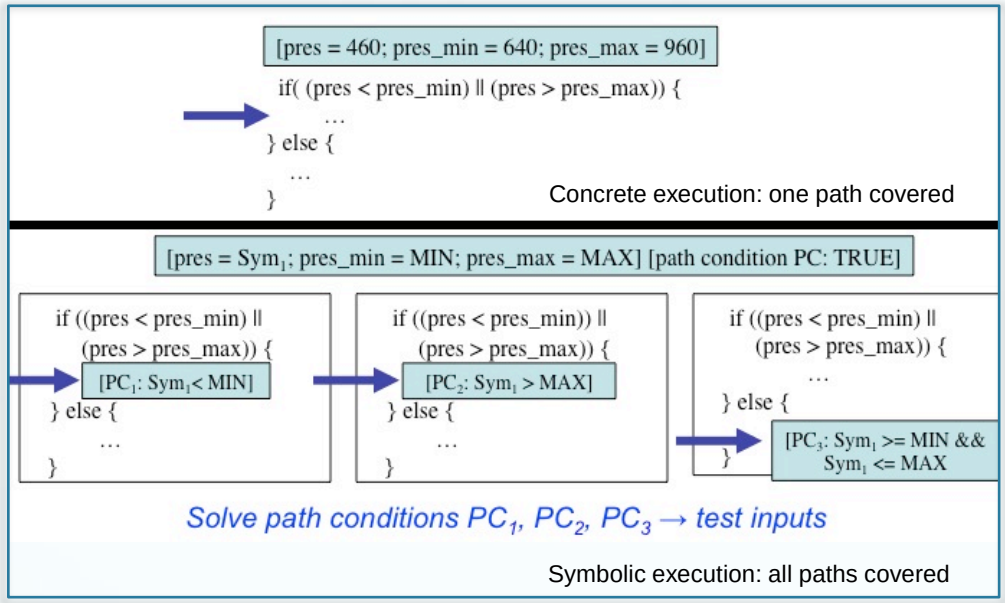
Students drags selects by dragging into proof box.

What is needed to make this an engaging game?

Can it be made collaborative?

Is geometry a good model for other kinds of proof systems?

Crowd Sourced Symbolic Execution



- Existing technology:
  - Symbolic PathFinder (SPF):
    - symbolic execution for Java bytecode;
    - systematic analysis for all possible (symbolic) inputs and
    - all inter-leavings (up to user-specified bounds)
    - Generates test suite;
    - checks properties of the code during sym exe
  - Memoized symbolic execution:
    - Stores state of an analysis run and uses that to improve sub-sequent runs (e.g. regression testing, iterative deepening)
    - Key feature to CSFV: run SPF, generate game context, process game solutions into guidance for SPF, then run SPF, etc.

- Challenges:
  - Path explosion: infinite number of paths
  - Handling looping constructs
  - Handling non-linear math constraints – undecidable theories
- Approach:
  - Identify parts of sym exe that are hard to handle (loops, non-lin constraints)
  - Formulate them as games
  - Use existing partial solutions or failed solution attempts to adjust the game
  - Combine information from multiple people in synergistic way

Contact:

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Corina Pasareanu,
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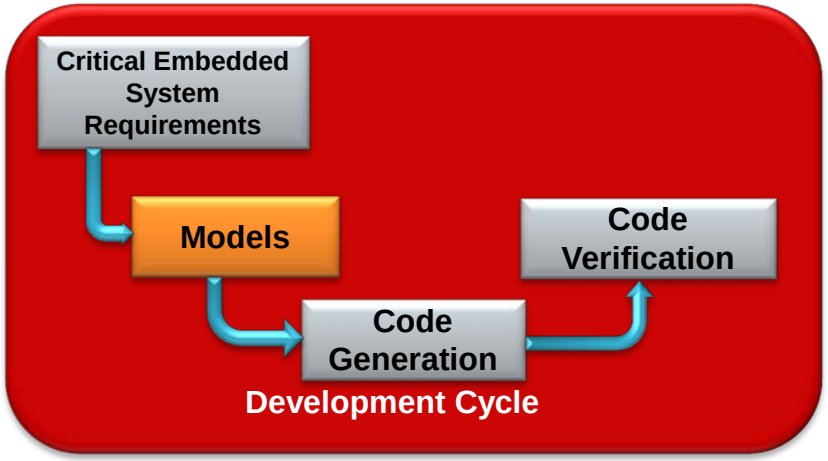
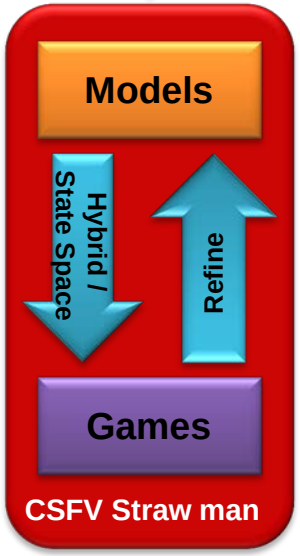
Honeywell

Honeywell's Critical Embedded Systems Ecosystem

Murphy the Optimist

STS-124: The Byzantine Assassin





Murphy the Pessimist

Crowd helps with

1. State space reduction
2. Generating counterexamples
3. Identifying malicious, accidental, and byzantine faults

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Geometric Games for Numerical Verification Problems

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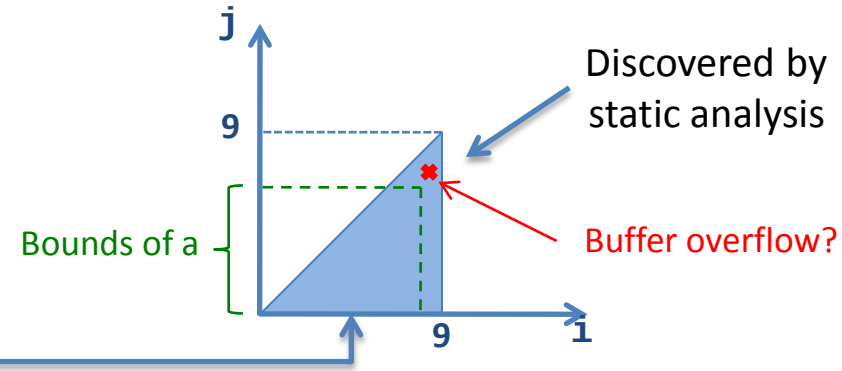
```
for (i = 0; i < 10; i++)
  for (j = 0; j <= i; j++)
    a[i][j] = ... ;
```

Buffer overflow?



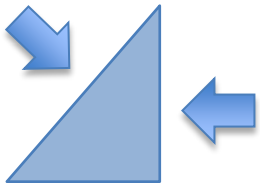
Are all values of i and j in the triangle feasible?

Static Analysis:

- can find sound envelopes for variables
- most envelopes are 2-dimensional shapes
- can prove the safety of memory operations
- does issue warnings
- 100s or 1000s of warnings
- are these warnings false positives?

Geometric Game:

The player fights against the program and tries to shrink a collection of shapes:



- Dismiss false positives
- Expose real errors

Raytheon BBN Technologies

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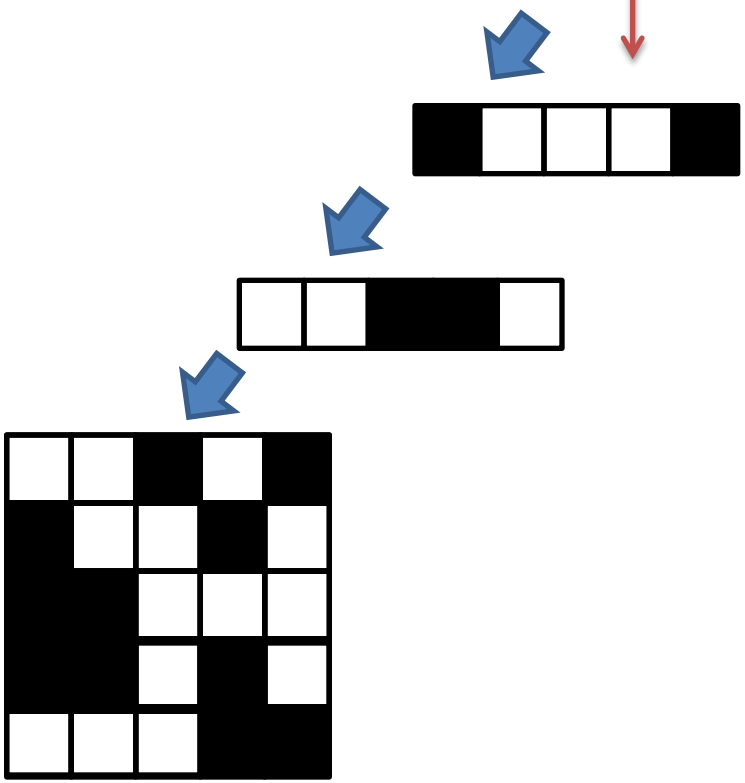
Mapping Proofs to Puzzles

Every n-vertex linear hypergraph without edges of size 1 is properly n-edge-colorable.



Cyber Security

Games for Training

AARON CAMMARATA

AARON@AJCGAMES.COM

- 16 years videogame experience
- Executive Producer, DARPA RealWorld simulation platform
  - Previously: Creative Director, Lead Engineer, 3D Artist
- Currently contracting in mobile gaming space
  - Rapid prototyping, focus on UI/UX & player motivation
- Building cross-platform technology for in-person social gaming
- Proposal:
  - Map FV tasks to game events (ex: state-transition diagram -> map of towns / paths)
  - FV Rules -> Game Rules
  - Inject false positives to combat neuron fatigue (“keep it fun”)
  - Build it to be intrinsically social – competition breeds engagement
- Interested in teaming with SME in FV Methods
- Offering:
  - Experience in both ‘serious’ and entertainment videogames
  - Work history with DARPA / military customers
  - Technology platform
  - Development team

Useful Links

- Teaming Website:
  - http://www.schafertmd.com/darpa/i2o/csfv/teaming
- CSFV Mailbox:
  - CSFV@darpa.mil
- CSFV BAA:
  - Watch FedBizOpps.gov for DARPA-BAA-12-17

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