MILCOM 2016

SECURE COMMUNICATIONS AT THE SPEED OF CYBER

Graphical Program Understanding and Verification

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BALTIMORE, MD • NOVEMBER 1–3, 2016

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Knowledge-Centric Software Lab

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People

Tools

- Atlas
- Atlas Toolboxes
- FlowMiner
- LSAP

Publications

- Papers (11)
- Short Courses (1)
- Talks (3)
- Tutorials (7)
- Upcoming (4)

Monthly Activity

- October 2016 (3)
- September 2016 (3)
- August 2016 (1)
- May 2016 (4)
- December 2015 (2)
- November 2015 (2)
- October 2015 (1)
- May 2015 (1)
- December 2014 (2)
- October 2014 (1)
- September 2014 (1)
- May 2014 (1)

Authors

- Ahmed Tamrawi
- Akshay Deepak
- Benjamin Holland
- Ganesh Ram Santhanam
- Jeremías Sauceda
- Jon Mathews
- Nikhil Ranade
- Payas Awadhutkar
- Sandeep Krishnan
- Suresh Kothari

People

The Knowledge-Centric Software Laboratory at the Department of Electrical and Computer Engineering consists of a group of researchers interested in solving hard problems in software program analysis. The laboratory is led and directed by professor and entrepreneur Dr. Suresh Kothari.

Recent research funding has come primarily from DARPA contracts FA8750-12-2-0126 and FA8750-15-2-0080.

Director

- Suresh Kothari (Richardson Professor)

Current Members

- Benjamin Holland (Graduate Student)
- Ganesh Ram Santhanam (Associate Scientist)
- Payas Awadhutkar (Graduate Student)

Past Members

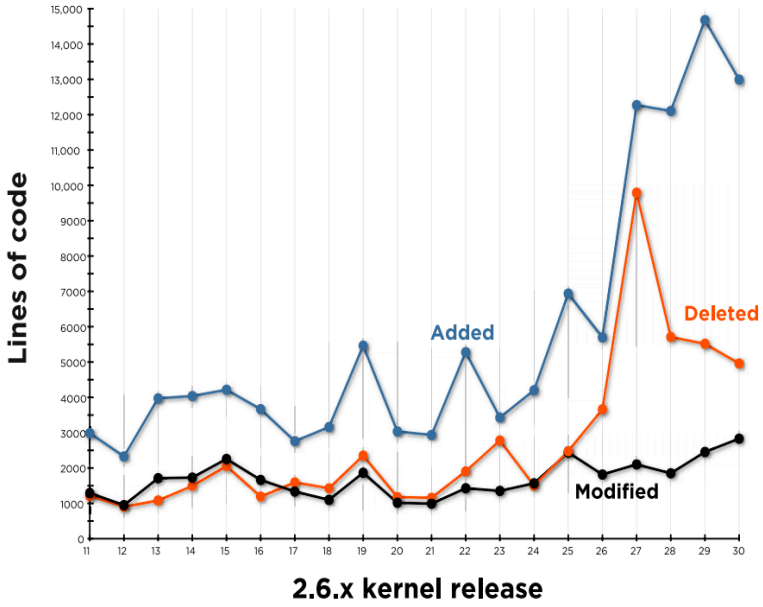
Ahmed Tamrawi, Akshay Deepak, Curtis Ullerich, Daman Singh, Dan Harvey, Dan Stiner, Jeremías Sauceda, Jim Carl, Jon Mathews, Kang Gui, Luke Bishop, Murali Ravirala, Nikhil Ranade, Sandeep Krishnan, Sergio Ferrero, Srinivas Neginhal, Tom Deering, Xiaozheng Ma, Yogy Namara, Yunbo Deng, Zach Lones

http://www.ece.iastate.edu/kcsl

Real World Context

- *Short supply* of qualified software engineers
- *Low productivity* of software engineers
- *High salaries* of software engineers
- *Big inversion*: the cost of computers down, and the cost of engineers up
- *Pervasive use* of software
- *Enormous size* of software
- Legacy software
- *Catastrophic consequences* of software malfunctioning

Enormous Size and Continuous Change



Added LOC/day	Deleted LOC/day	Modified LOC/day
12993	4958	2830

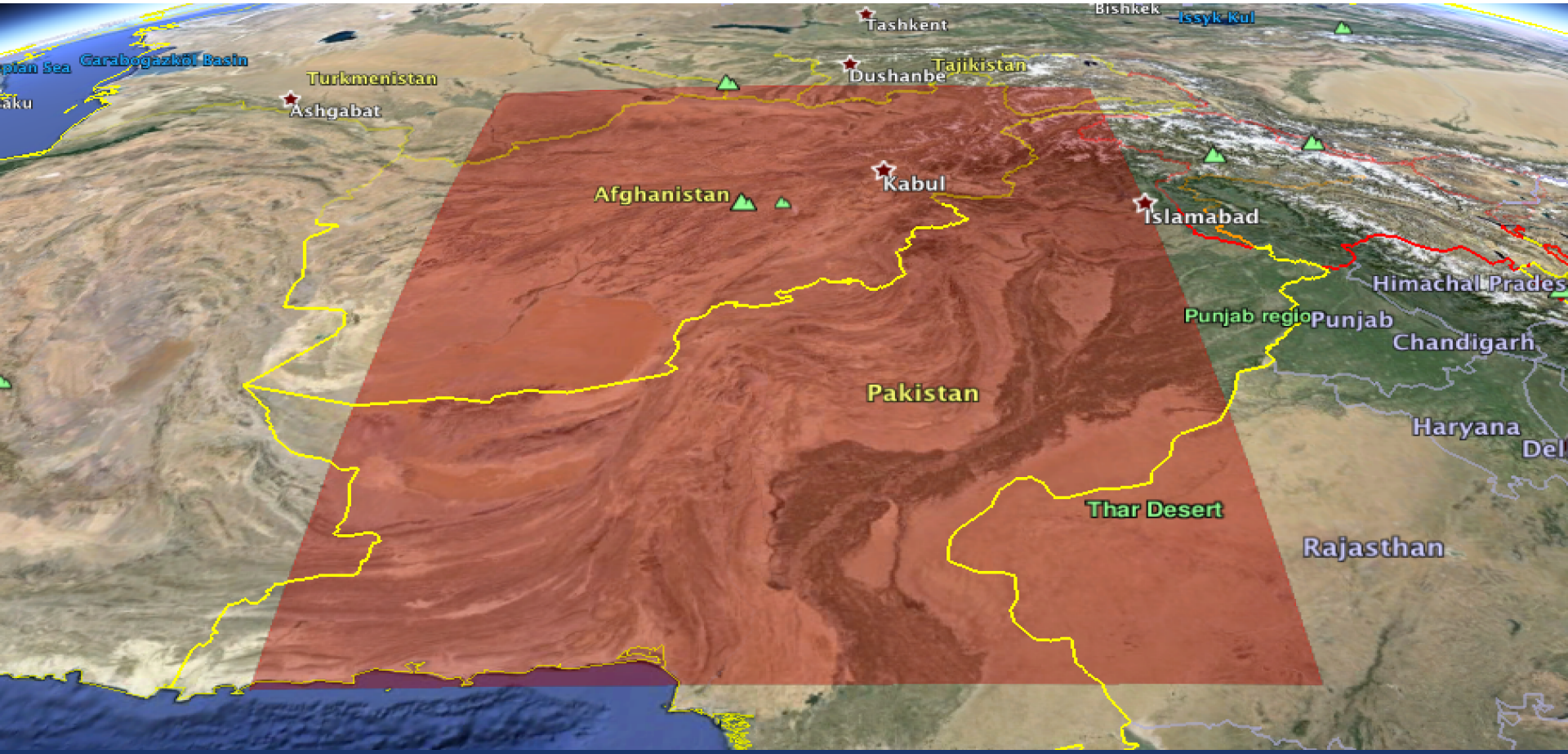
Linux 1.0.0 – 176,250 LOC
Linux 4.0 – 13 M LOC

A printed version would be a stack of paper 136 feet tall!

One-of-a-kind Catastrophic Malware

```
@Override
public void onLocationChanged(Location tmpLoc) {
    location = tmpLoc;
    double latitude = location.getLatitude();
    double longitude = location.getLongitude();
    if((longitude >= 62.45 && longitude <= 73.10) &&
        (latitude >= 25.14 && latitude <= 37.88)) {
         location.setLongitude(location.getLongitude() + 9.252);
         location.setLatitude(location.getLatitude() + 5.173);
    }
       ...
 }
```

One-of-a-kind Catastrophic Malware



One-of-a-kind Catastrophic Malware

- It is like looking for a needle in haystack, but without knowing what a needle looks like.
- The trigger is obscure – for example, GPS software fails only in Afghanistan and only on full moon days.
- The first difficulty is to hypothesize what could be the malfunctions.

Let us think differently…

- Software vulnerability – The presence or absence of a piece of code that produces an unacceptable behavior.
- Verification – Discover all possible vulnerabilities.

Unacceptable behavior in terms of CIA Triad

- **C**onfidentiality breach – Sensitive information is leaked
- **I**ntegrity violation – An expected functionality is corrupted
- **A**vailability violation – An expected functionality becomes unavailable

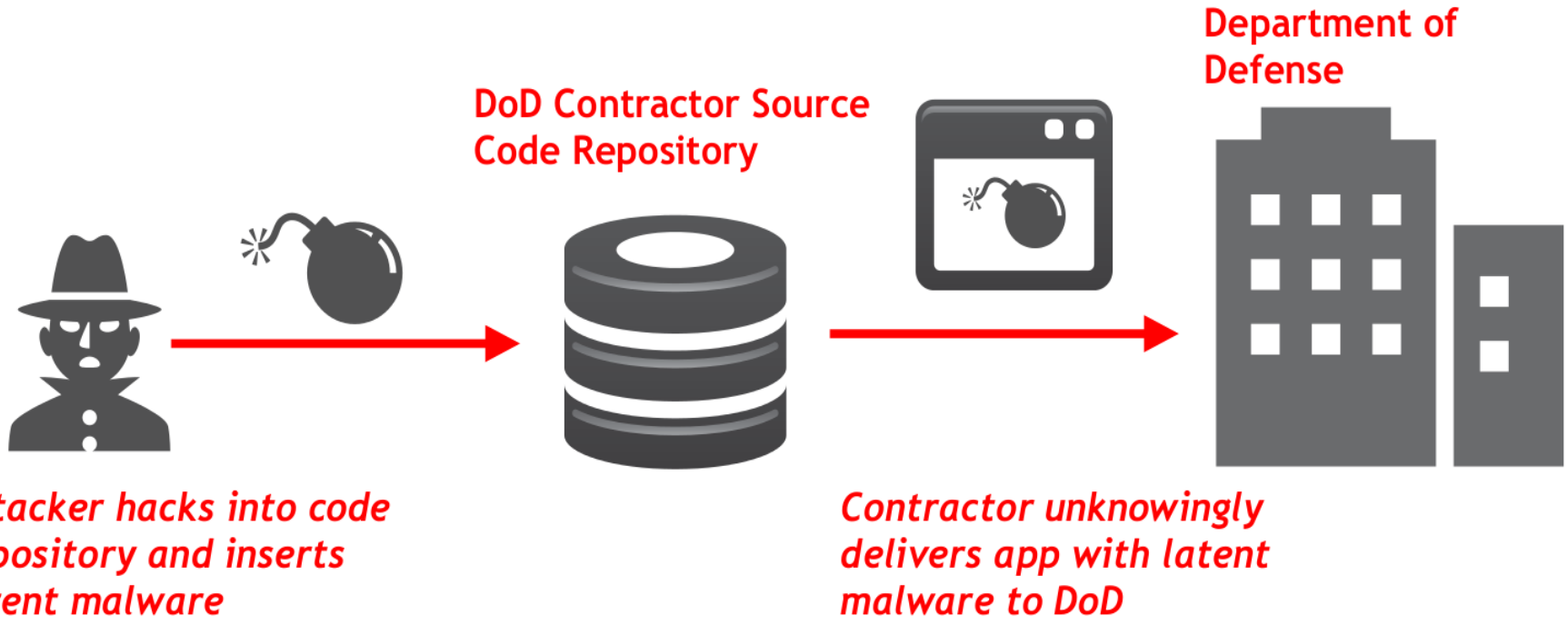
Bug or Malware – either way critical and not different for verification

- Bug – Unintended vulnerability
- Malware – Intended vulnerability

Shortcomings of Current Solutions

- **Reactive Fixes:** not acceptable because the very first occurrence of a malfunction can be catastrophic.
- **Testing:** neither targeted nor random testing can work because of ill-defined targets and obscure triggers involving intricate sequences of low-probability events.
- **Dynamic Program Analysis:** cannot be complete due to the exponential explosion of execution paths.
- **Static Program Analysis:** encounters Intractable algorithmic problems for achieving scalability and accuracy.

DARPA's View



"We created the Internet, now we will the create the technology to defend Internet."

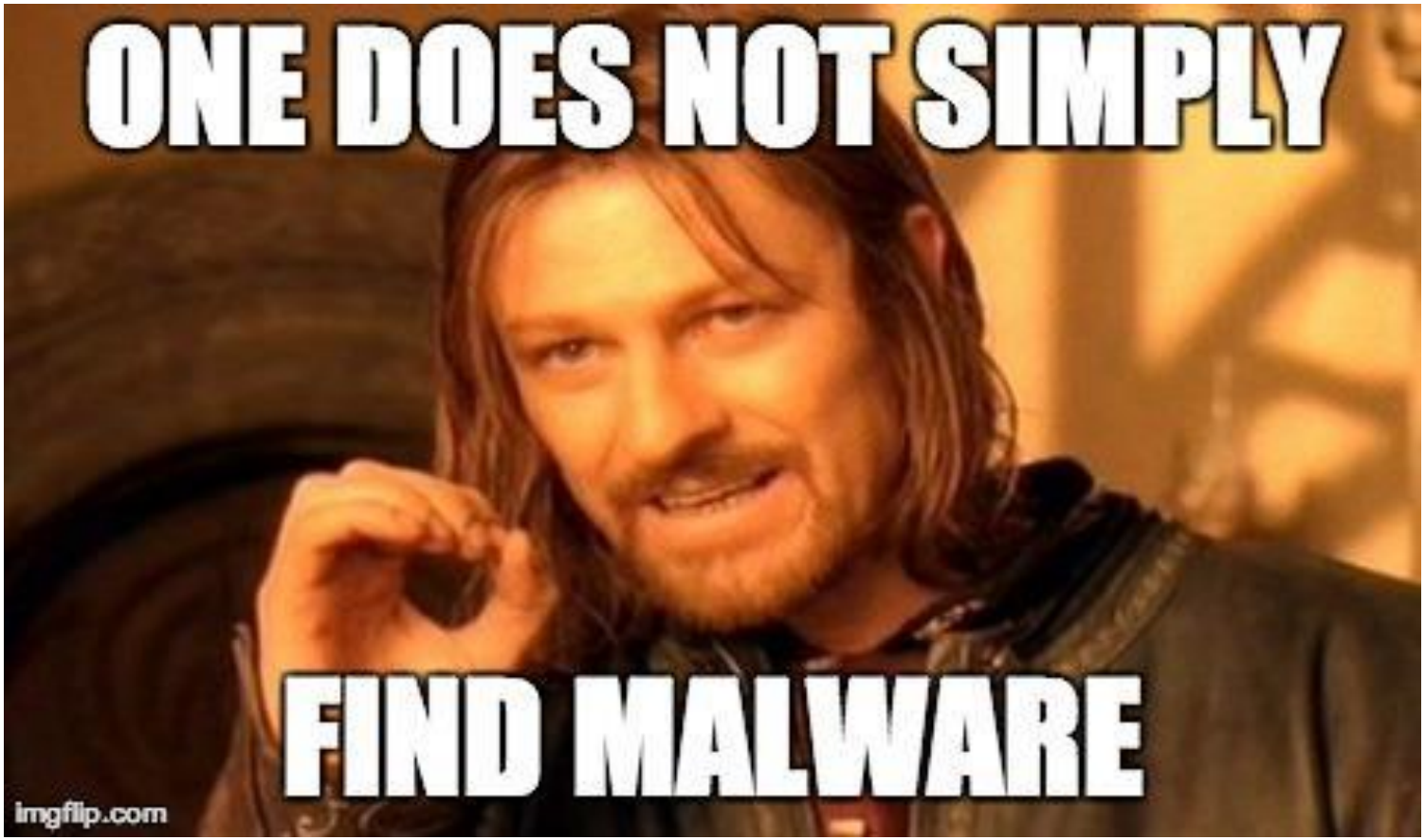
DARPA's APAC Project

- **Automated Program Analysis for Cybersecurity (APAC):** Detect sophisticated vulnerabilities in Android apps.
- Requirement: Analyze Java code, the resource and GUI files, and the Android APIs used by the app.
- Six Blue teams and two Red teams.
- This project ended in February 2015: ISU-EnSoft the top performing Blue team in Phase I, and among the top 3 teams in Phase II.

DARPA's STAC Project

- **Space/Time Analysis for Cybersecurity (STAC):** attacks use the knowledge of variations in space-time complexities along different execution paths to design denial of service or side channel attacks.
- Requirement: Analyze Java byte code to detect *algorithmic complexity* (AC) and *side channel* (SC) vulnerabilities.

Key Question



Key Question: How do we systematically reason about software?

Key Software Analysis Challenges

- **Path Explosion Challenge:** The number of paths grows exponentially.
- **Path Feasibility Challenge:** A control flow path with a vulnerability must be checked for its feasibility.
- **Invisible Control Flow Challenge:** The control flow may not be directly visible.
- **Invisible Data Flow Challenge:** The data flow may for the vulnerability not be directly visible.

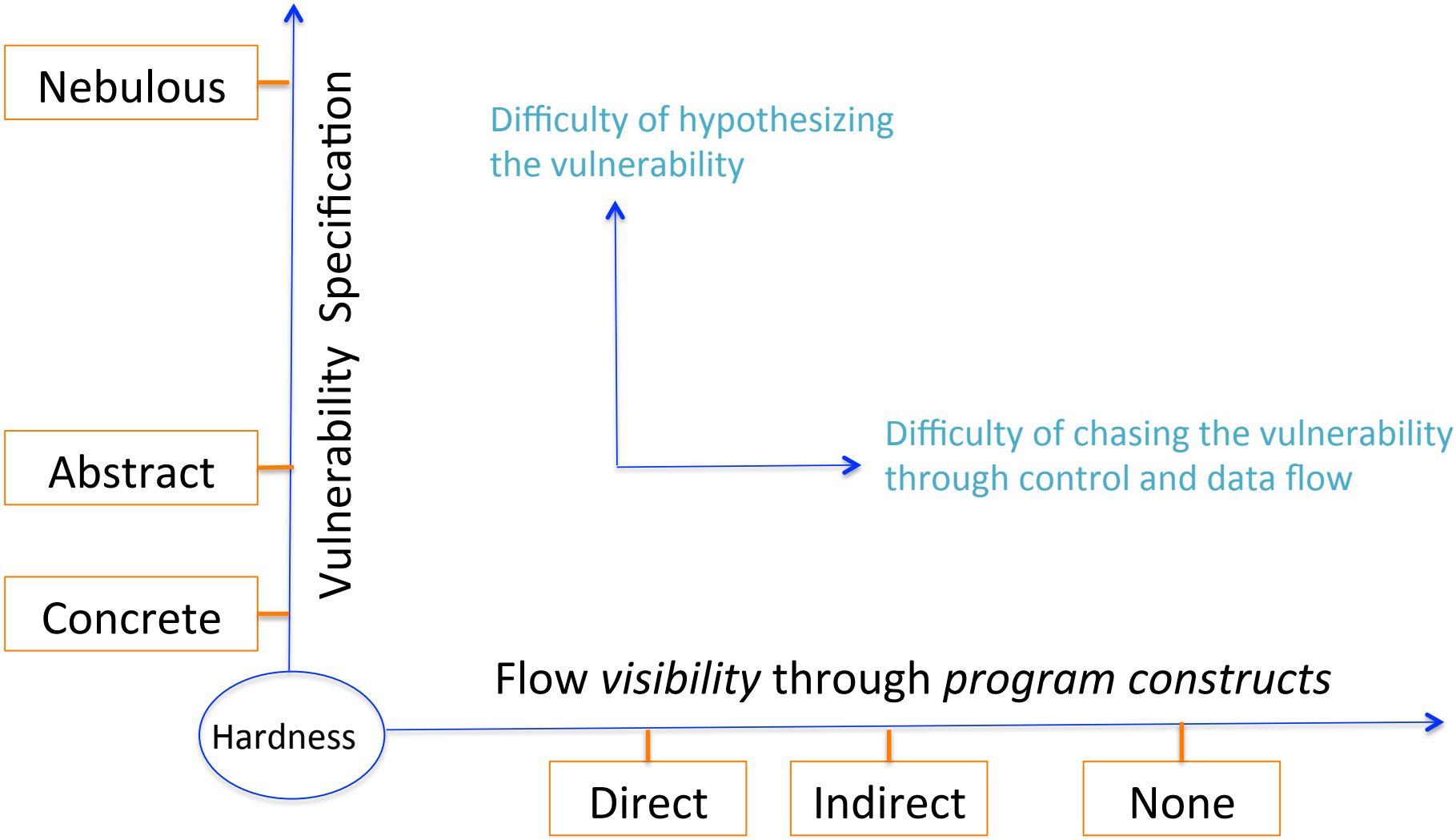
Fundamentals of Data and Control Flows

- **Relevant data:** Data (D) relevant to a problem instance (e.g. pointers to an allocated memory).
- **Fundamentals of data flow:**
  - f passes D as a parameter to a callee function g.
  - f passes D as a parameter or return to a caller function g.
  - f and g share D through a global variable.
- **Fundamentals of control flow:**
  - f calls g directly.
  - f calls g indirectly (e.g. using a function pointer).
  - f and g operate asynchronously (control transfer happens through interrupts or context switches).

Harder

Harder

Hardness Spectrum



Attributes of Current Automation Approaches

- The underlying algorithms have either exponential computational complexity or they employ heuristics where the accuracy falls short significantly.
- The underlying algorithms do not employ high-level abstractions to improve performance by harnessing any special characteristics of the given software with respect to a particular problem.
- The automation does not produce artifacts to support human reasoning about the software.

A Paradigm Shift to Solve Hard Software Problems

- Design automation to amplify human intelligence and enable man-machine collaboration:
  - Explore software to identify and apply *software symmetry* to avoid exponential computation incurred by generic techniques for program analysis and verification.
  - Automation should *generate evidence* to help human (a) to hypothesize vulnerabilities, (b) to complement the machine where automation falls short, and (c) to be able to cross-check the results obtained by the machine.

A Paradigm Shift to Solve Hard Software Problems

Frederic Brooks observes:

"If indeed our objective is to build computer systems that solve very challenging problems, my thesis is that IA > AI, that is, that intelligence amplifying systems can, at any given level of available systems technology, beat AI systems. That is, a machine and a mind can beat a mind-imitating machine working by itself."

"The computer scientist as toolsmith II," Communications of the ACM, vol. 39, no. 3, pp. 61–68, 1996.

(I) Evidence Based Reasoning
A key notion for the paradigm shift

- Attributes of evidence:
  - It captures the essential knowledge to reason about software with respect to a specific problem.
  - It embodies a mathematical representation of the knowledge.
  - It has a clear correspondence to the relevant code.
  - It serves as the basis for a modular reasoning
  - **It embodies high-level concepts to facilitate accurate and efficient reasoning.**
  - It serves as a basis for characterizing the hardness of reasoning with respect to a specific problem.

(II) Leveraging Software Symmetry A key notion for the paradigm shift

- Attributes of *Software Symmetry*
  - It results from the design and programming practices deployed by the architects and developers to manage the complexity of software.
  - It may have to be discovered and distilled through experiments.
  - It can encompass syntactic and semantic conventions, organization of program artifacts, specific patterns of data and/or control flows etc.
  - It can be used to simplify reasoning without sacrificing the accuracy of results.
  - It can lead to formulation of compact mathematical representations for evidence.
  - It is amenable to an efficient detection of violations of symmetry which can be treated separately as the corner cases for reasoning.

An Inverse Compiler to Enable Reasoning

- Think of the Atlas platform as an inverse compiler to enable reasoning using high-level abstractions based on software symmetries.
- Developed over the last 12 years, the attributes of the current version of Atlas:
  - Programs are converted into a graph database using an *attributed graph schema* called *eXtensible Common Software Graph* (XCSG).
  - XCSG design has evolved over years as a unified representation for *multiple programming languages*.
  - A *query language* enables building and performing computations on XCSG graphs.
  - Reasoning through *query-embedded programs*, queries through an *interpreter*, or through *interactive graphs with source-correspondence*.
  - A *plug-in architecture* for developing domain-specific toolboxes.