EXERCISE #12

ABSTRACT INTERPRETATION REVIEW

- *We formalized dataflow analysis by ensuring mathematical properties of our dataflow fact sets and our dataflow update procedure. What property of the fact sets and what property of the update function guaranteed termination?*

FORMALIZING DATAFLOW

REVIEW: ABSTRACT INTERPRETATION

Guarantees we'd like to extract from our analysis Engine

Termination

Completeness (in the analysis sense)

Precision

Sufficient Conditions

Overapproximate, monotonic update functions

A finite-height, complete lattice

PRACTICAL CONSIDERATIONS

REVIEW: ABSTRACT INTERPRETATION

GUARANTEES WE'D LIKE TO EXTRACT FROM OUR ANALYSIS ENGINE

Termination

Completeness (in the analysis sense)

Precision

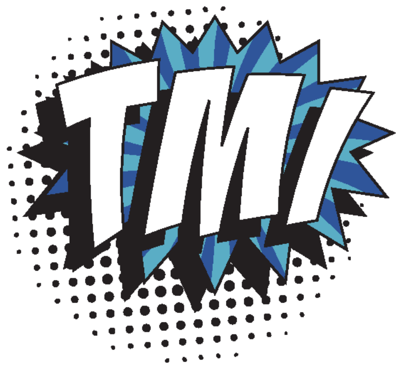
SUFFICIENT CONDITIONS

Overapproximate, monotonic update functions

A $\boxed{\text{finite-height}}$, complete lattice

Note: finiteness NOT implied by a complete lattice

Problem: lattice may be very tall!



THE ABSTRACT DOMAIN

REVIEW: ABSTRACT INTERPRETATION

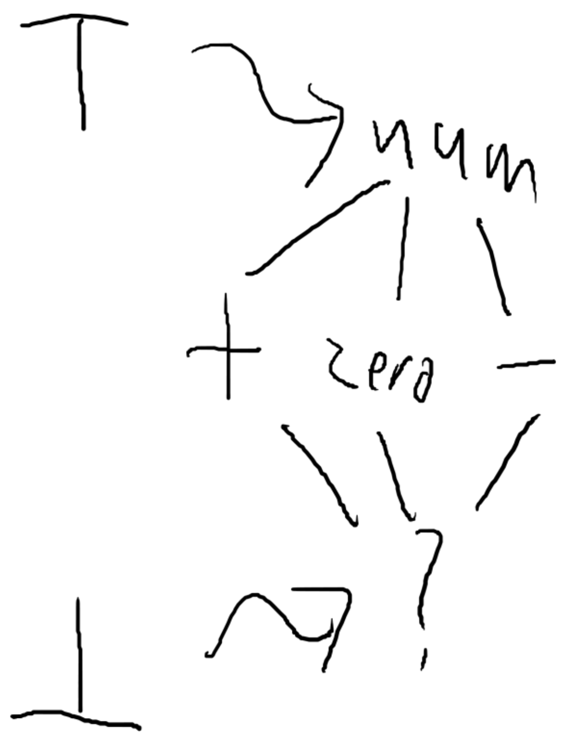
SUFFICIENT CONDITIONS

Overapproximate, monotonic update functions

A finite-height, complete lattice

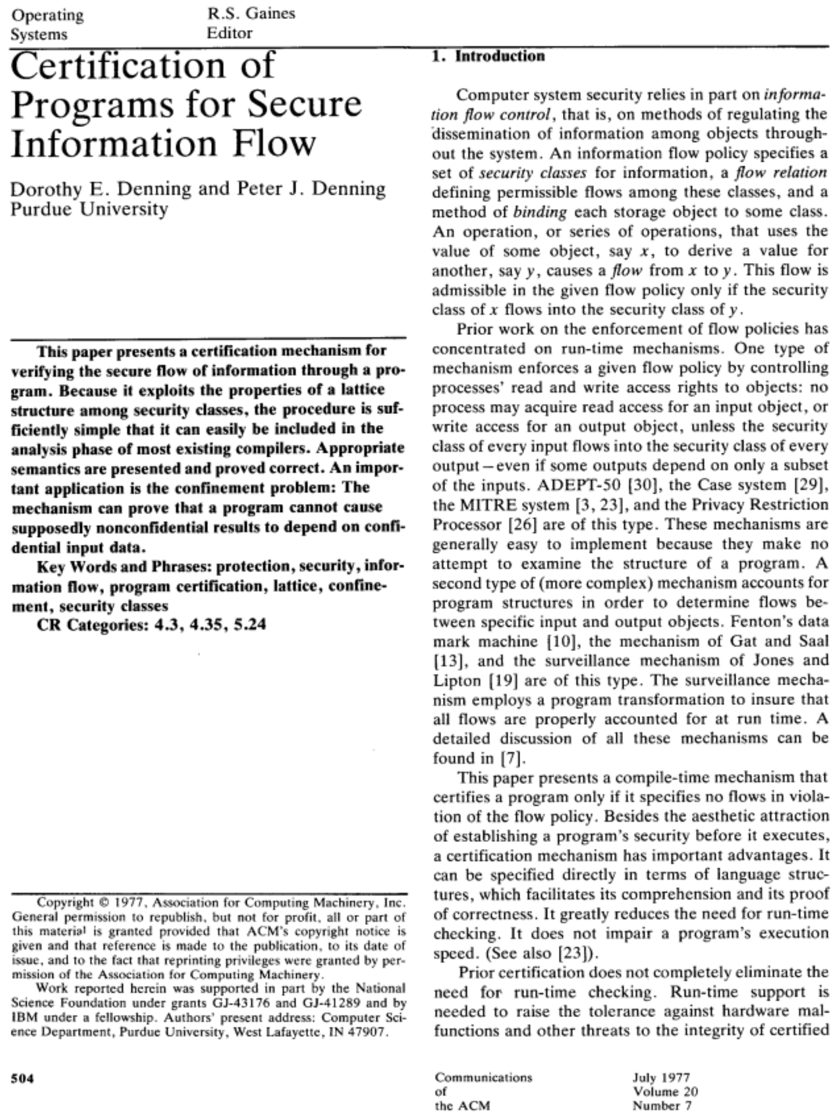
TRACK "PROPERTIES" OF THE DATA, INSTEAD OF CONCRETE VALUES

More workable lattice



ADMINISTRIVIA AND ANNOUNCEMENTS

Let's read a paper!



Operating Systems

R.S. Gaines Editor

Certification of Programs for Secure Information Flow

Dorothy E. Denning and Peter J. Denning
Purdue University

This paper presents a certification mechanism for verifying the secure flow of information through a program. Because it exploits the properties of a lattice structure among security classes, the procedure is sufficiently simple that it can easily be included in the analysis phase of most existing compilers. Appropriate semantics are presented and proved correct. An important application is the confinement problem: The mechanism can prove that a program cannot cause supposedly nonconfidential results to depend on confidential input data.

Key Words and Phrases: protection, security, information flow, program certification, lattice, confinement, security classes

CR Categories: 4.3, 4.35, 5.24

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1. Introduction

Computer system security relies in part on *information flow control*, that is, on methods of regulating the dissemination of information among objects throughout the system. An information flow policy specifies a set of *security classes* for information, a *flow relation* defining permissible flows among these classes, and a method of *binding* each storage object to some class. An operation, or series of operations, that uses the value of some object, say *x*, to derive a value for another, say *y*, causes a *flow* from *x* to *y*. This flow is admissible in the given flow policy only if the security class of *x* flows into the security class of *y*.

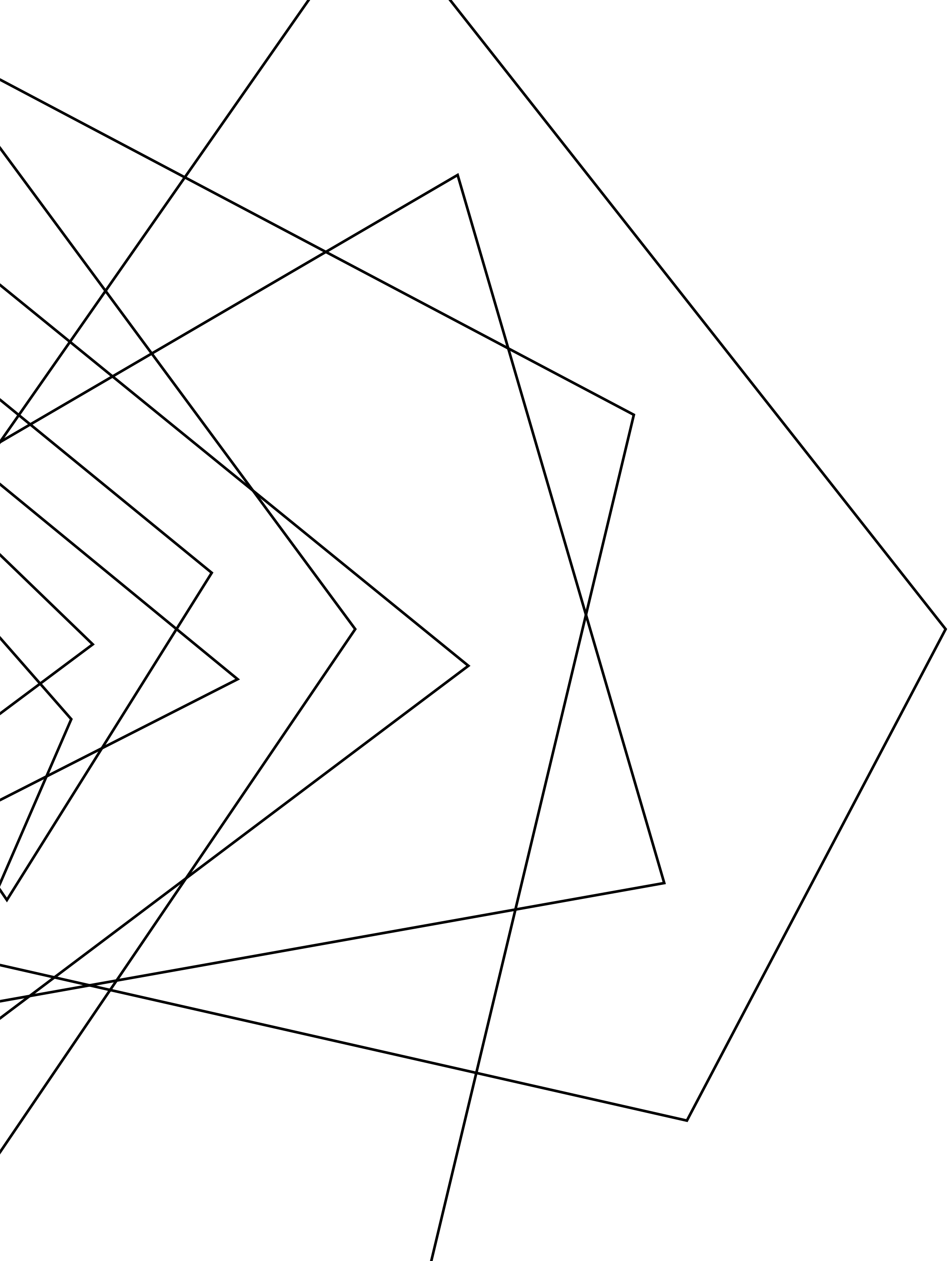
Prior work on the enforcement of flow policies has concentrated on run-time mechanisms. One type of mechanism enforces a given flow policy by controlling processes' read and write access rights to objects: no process may acquire read access for an input object, or write access for an output object, unless the security class of every input flows into the security class of every output – even if some outputs depend on only a subset of the inputs. ADEPT-50 [30], the Case system [29], the MITRE system [3, 23], and the Privacy Restriction Processor [26] are of this type. These mechanisms are generally easy to implement because they make no attempt to examine the structure of a program. A second type of (more complex) mechanism accounts for program structures in order to determine flows between specific input and output objects. Fenton's data mark machine [10], the mechanism of Gat and Saal [13], and the surveillance mechanism of Jones and Lipton [19] are of this type. The surveillance mechanism employs a program transformation to insure that all flows are properly accounted for at run time. A detailed discussion of all these mechanisms can be found in [7].

This paper presents a compile-time mechanism that certifies a program only if it specifies no flows in violation of the flow policy. Besides the aesthetic attraction of establishing a program's security before it executes, a certification mechanism has important advantages. It can be specified directly in terms of language structures, which facilitates its comprehension and its proof of correctness. It greatly reduces the need for run-time checking. It does not impair a program's execution speed. (See also [23]).

Prior certification does not completely eliminate the need for run-time checking. Run-time support is needed to raise the tolerance against hardware malfunctions and other threats to the integrity of certified

ADMINISTRIVIA AND ANNOUNCEMENTS

P2 released



CLASS PROGRESS

WE HAVE A GOOD FORM OF ANALYSIS!

Let’s actually apply it

INFORMATION FLOW

EECS 677: Software Security Evaluation

Drew Davidson

LECTURE OUTLINE

- Application Analysis
- Information Flow
- Practical Deployment

THE SEMANTIC GAP

INFORMATION FLOW

For Computer Science, our objects of interest are programs

Generic Definition

Semantic gap: "The difference between descriptions of an object by different linguistic representations"

For Computer Science, our focus is on different symbolic / abstract representations

THE SEMANTIC GAP

INFORMATION FLOW

Semantic gap: “The difference between descriptions of an object by different linguistic representations”

WHAT IS A PROGRAM?

Dracula
What is a program?
A miserable little
pile of secrets.

THE SEMANTIC GAP
INFORMATION FLOW

Semantic gap: "The difference between descriptions of an object by different linguistic representations"

What Is a program?

A miserable little pile of secrets

- Dracula

A sequence of transformations
over memory configurations

- Hardware

A memory region, system calls,
and a set of privileges

- Operating system

APPLICATION-LEVEL ANALYSIS
INFORMATION FLOW

FOCUS ON THE BEHAVIOR / SEMANTICS OF THE PROGRAM

Hopefully the right level of granularity for understanding a program's security

LANGUAGE-BASED SECURITY

Definition - a set of techniques to strengthen the security of applications by using the properties of programming languages

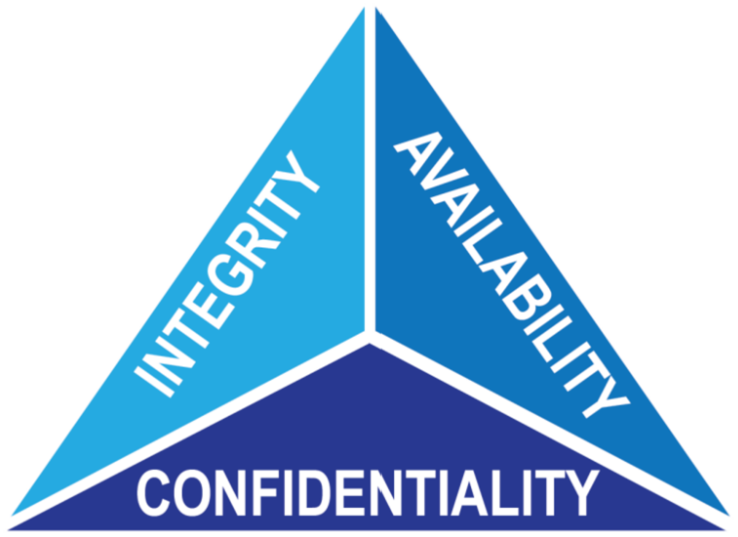
"Hey, we've got all of these great tools to understand programs for the sake of correctness / optimization, they'd work for security too!"

LECTURE OUTLINE

- Application Analysis
- Information Flow
- Practical Deployment

RECALL: THE CIA TRIAD

PRACTICAL CONSIDERATIONS



"THE PRIMARY FOCUS OF INFORMATION SECURITY" - WIKIPEDIA

Confidentiality – The control of access to data

Integrity – The consistency, accuracy and trustworthiness
of data over its entire lifecycle

Availability – The degree of
consistent accessibility of data

RECALL: THE CIA TRIAD

PRACTICAL CONSIDERATIONS

"THE PRIMARY FOCUS OF INFORMATION SECURITY" - WIKIPEDIA

(imperfect) formulations
As dataflow properties

Confidentiality – The control of access to data

Integrity – The consistency, accuracy and trustworthiness
of data over its entire lifecycle

Availability – The degree of consistent accessibility of data

RECALL: THE CIA TRIAD

PRACTICAL CONSIDERATIONS

Sensitive information in the program touches an untrusted destination

(imperfect) formulations
As dataflow properties

Confidentiality – The control of access to data

Integrity – The consistency, accuracy and trustworthiness
of data over its entire lifecycle

Availability – The degree of consistent accessibility of data

Untrusted data coming into the program reaches a sensitive computation

TOWARDS FORMALIZING C AND I

INFORMATION FLOW

SIMPLE INFORMATION "CLASSES"

Divide program data and functionality into "high security" and "low security"

Confidentiality: high security data should not influence low security functionality

Integrity: low security data should not influence high security functionality

TOWARDS FORMALIZING C AND I

INFORMATION FLOW

SIMPLE INFORMATION "CLASSES"

Divide program data and functionality into "high security" and "low security"

Confidentiality: high security data should not influence low security functionality

```
string loc = getUserLocation();
if (inKansas(loc)){
  print "Watch out for tornados!";
}
writeToNetwork(loc);
```

Integrity: low security data should not influence high security functionality

```
string netVal = readFromNetwork();
setPassword("root", netVal);
```

SOURCES AND SINKS

INFORMATION FLOW

SIMPLE INFORMATION “CLASSES”

Divide program data and functionality into “high security” and “low security”

Confidentiality: <u>high security</u> data should not influence <u>low security</u> functionality

```
string loc = getUserLocation();
if (inKansas(loc)){
  print “Watch out for tornados!”;
}
writeToNetwork(loc);
```

Integrity: <u>low security</u> data should not influence <u>high security</u> functionality

```
string netVal = readFromNetwork();
setPassword(“root”, netVal);
```

SOURCES AND SINKS

INFORMATION FLOW

A **source** operation – an operation that generates data

A **sink** operation – an operation that consumes data

A **flow** – a program path segment that begins at a source and ends at a sink

Confidentiality: <u>high security</u> data should not influence <u>low security</u> functionality

```
string loc = getUserLocation();
if (inKansas(loc)){
  print "Watch out for tornados!";
}
writeToNetwork(loc);
```

High-security source

Low-security sink

Integrity: <u>low security</u> data should not influence <u>high security</u> functionality

```
string netVal = readFromNetwork();
setPassword("root", netVal);
```

Low-security source

High-security sink

FIND THE DATAFLOW!

INFORMATION FLOW

A **source** operation – an operation that generates data
A **sink** operation – an operation that consumes data
A **flow** – a program path segment that begins at a source and ends at a sink

Confidentiality: <u>high security</u> data should not influence <u>low security</u> functionality

High-security source

```
string loc = getUserLocation();
if (inKansas(loc)){
  print “Watch out for tornados!”;
}
writeToNetwork(loc);
```

Low-security sink

Integrity: <u>low security</u> data should not influence <u>high security</u> functionality

Low-security source

```
string netVal = readFromNetwork();
setPassword(“root”, netVal);
```

High-security sink

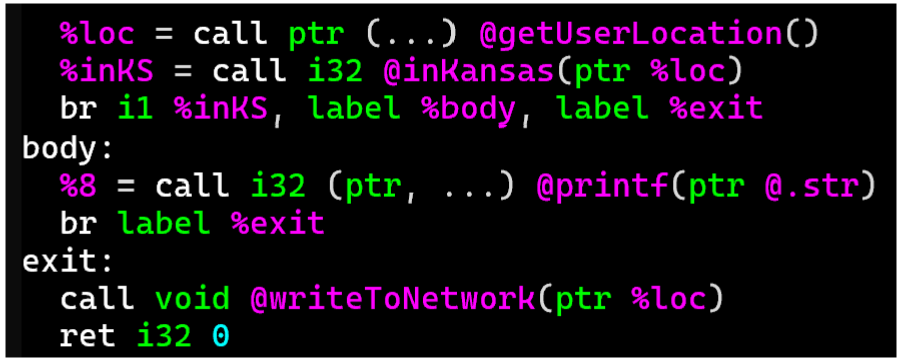
FIND THE DATAFLOW!

INFORMATION FLOW

High-security source

```
string loc = getUserLocation();
if (inKansas(loc)){
  print "Watch out for tornados!";
}
writeToNetwork(loc);
```

Low-security sink



```
  %loc = call ptr (...) @getUserLocation()
  %inKS = call i32 @inKansas(ptr %loc)
  br i1 %inKS, label %body, label %exit
body:
  %8 = call i32 (ptr, ...) @printf(ptr @.str)
  br label %exit
exit:
  call void @writeToNetwork(ptr %loc)
  ret i32 0
```

FIND THE DATAFLOW!

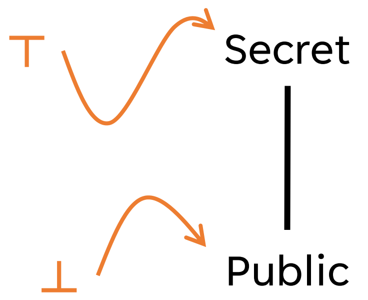
INFORMATION FLOW

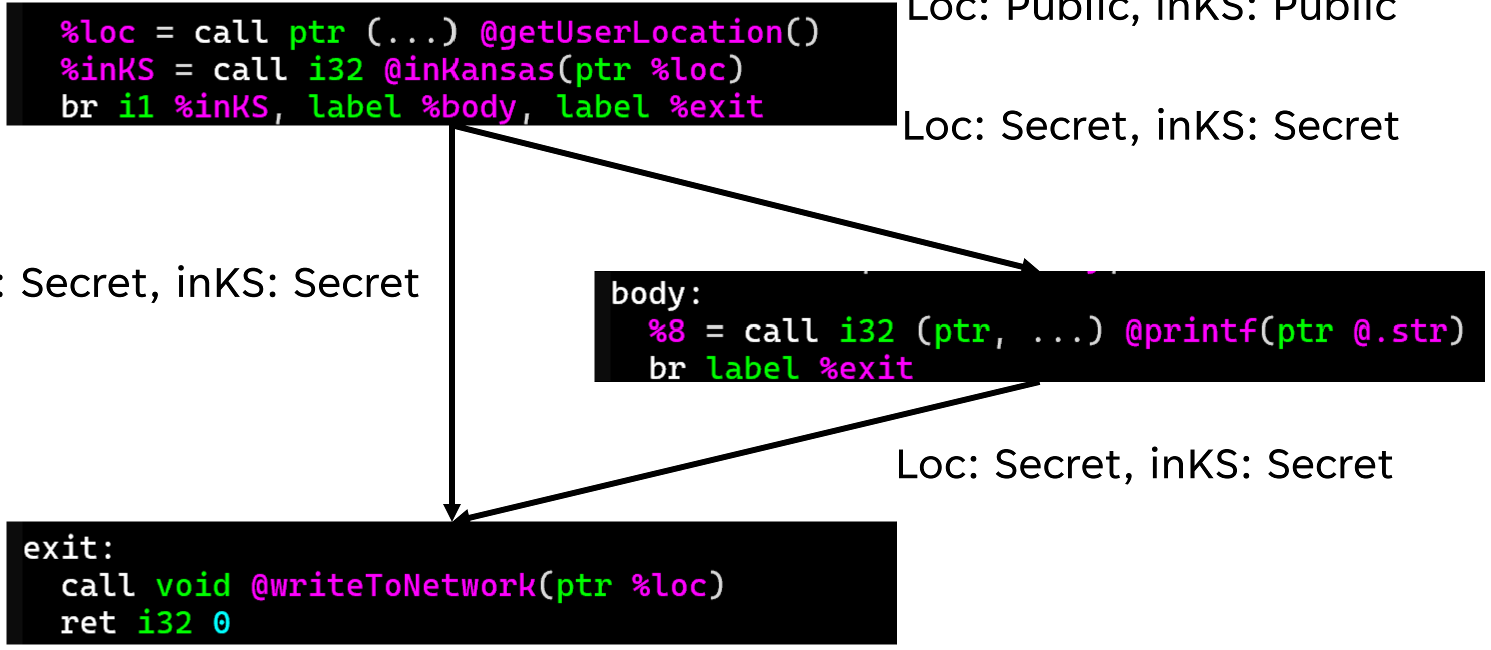
```
string loc = getUserLocation();
if (inKansas(loc)){
  print "Watch out for tornados!";
}
writeToNetwork(loc);
```

High-security source

Low-security sink

Fact Lattice (confidentiality)





```
%loc = call ptr (...) @getUserLocation()
%inKS = call i32 @inKansas(ptr %loc)
br i1 %inKS, label %body, label %exit
```

Loc: Public, inKS: Public

Loc: Secret, inKS: Secret

Loc: Secret, inKS: Secret

```
body:
  %8 = call i32 (ptr, ...) @printf(ptr @.str)
  br label %exit
```

Loc: Secret, inKS: Secret

```
exit:
  call void @writeToNetwork(ptr %loc)
  ret i32 0
```

LECTURE OUTLINE

- Application Analysis
- Information Flow
- Practical Deployment

SOURCE/SINK IDENTIFICATION

PRACTICAL CONSIDERATIONS

How do we know what should be a source and a sink?

Mind that semantic gap!

Idea #1 – Programmer annotations

Idea #2 – Build annotations into the system

Idea #3 – something something inferencing handwave

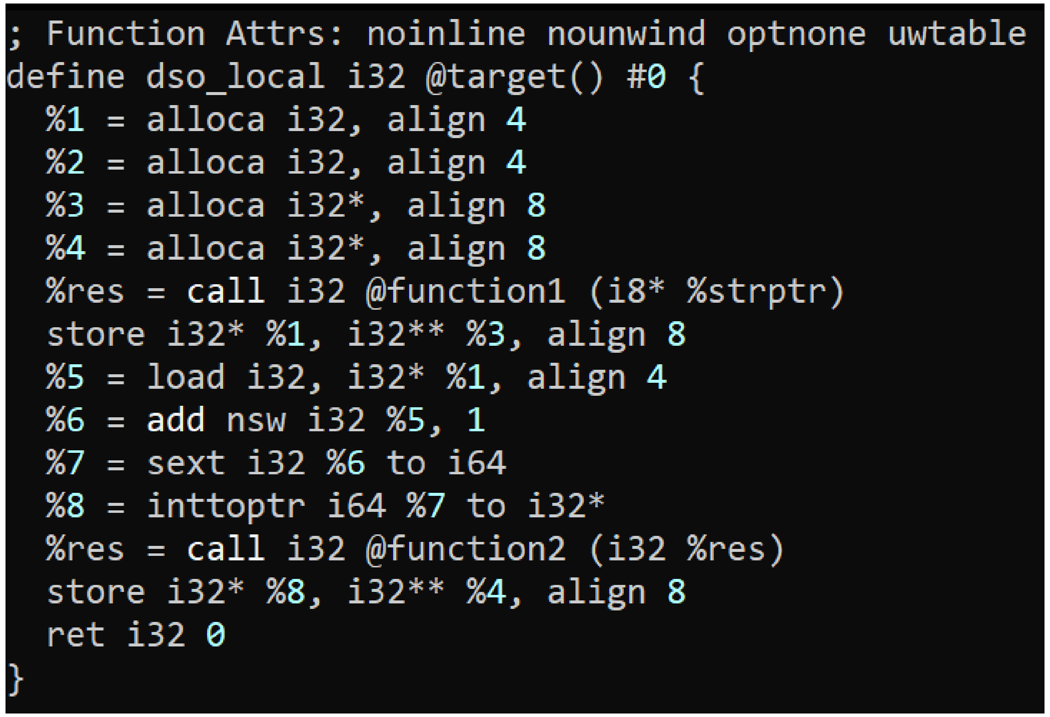
PROGRAMMER ANNOTATIONS

PRACTICAL CONSIDERATIONS – SOURCE/SINK IDENTIFICATION

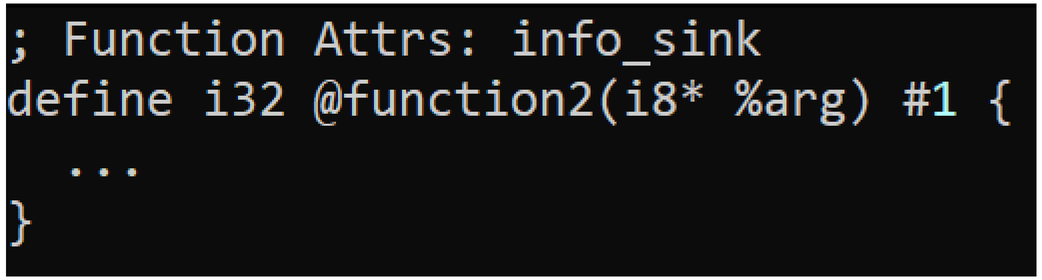
BASIC IDEA

Ask the programmer to say what's a source and sink

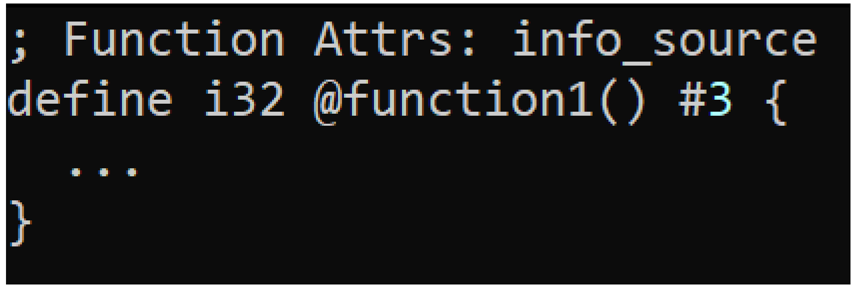
- Auxiliary file of information
- Inline annotations within the program



```
; Function Attrs: noinline nounwind optnone uwtable
define dso_local i32 @target() #0 {
  %1 = alloca i32, align 4
  %2 = alloca i32, align 4
  %3 = alloca i32*, align 8
  %4 = alloca i32*, align 8
  %res = call i32 @function1 (i8* %strptr)
  store i32* %1, i32** %3, align 8
  %5 = load i32, i32* %1, align 4
  %6 = add nsw i32 %5, 1
  %7 = sext i32 %6 to i64
  %8 = inttoptr i64 %7 to i32*
  %res = call i32 @function2 (i32 %res)
  store i32* %8, i32** %4, align 8
  ret i32 0
}
```



```
; Function Attrs: info_sink
define i32 @function2(i8* %arg) #1 {
  ...
}
```



```
; Function Attrs: info_source
define i32 @function1() #3 {
  ...
}
```

PROGRAMMER ANNOTATIONS

PRACTICAL CONSIDERATIONS – SOURCE/SINK IDENTIFICATION

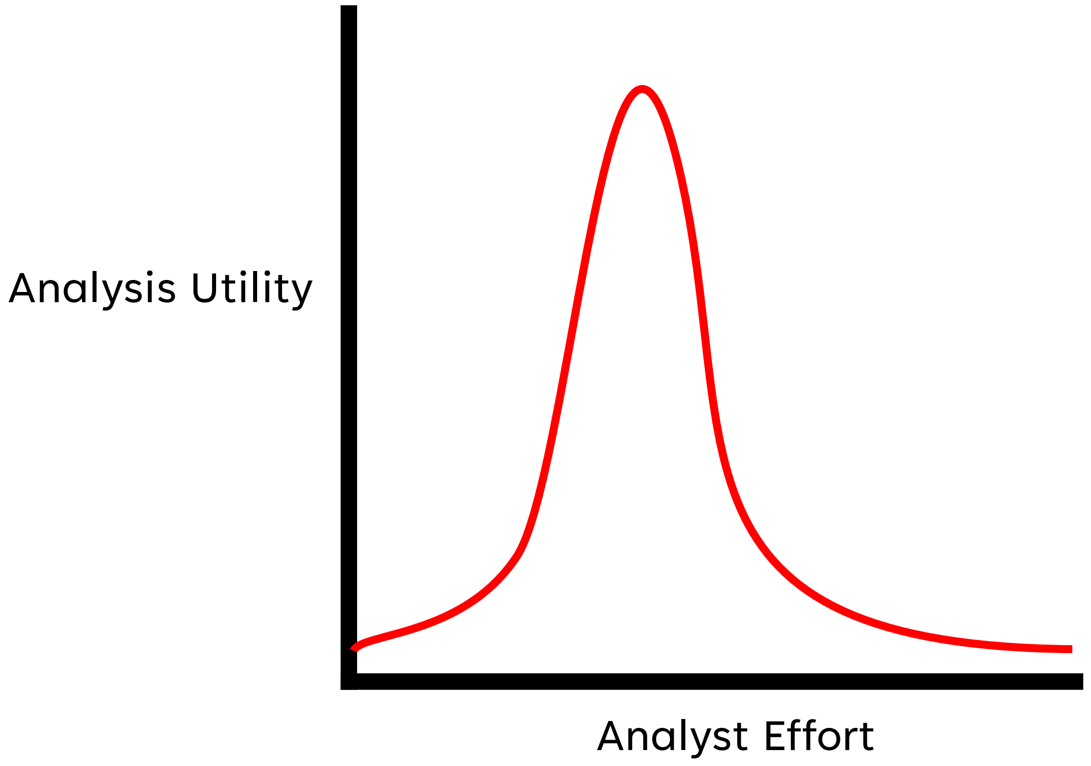
THE UTILITY OF PROGRAMMER EFFORT

A frequent struggle in analysis

ISSUES OF HUMAN INTERVENTION

Ultimately, we're trying to solve a limitation of human behavior

- Incorrect annotations
- Laziness
- Reactive SSE goes out the window



A totally-made-up conceptual graph

BUILT-IN “ANNOTATIONS”

PRACTICAL CONSIDERATIONS – SOURCE/SINK IDENTIFICATION

Enrich the system with notions of behavior

Platform developer bakes capabilities into the system

Analysis developer retrofits annotations into the analysis engine

Issues of Semantic Gap again

Can be quite hard to predict what becomes security-relevant

Analysis engine needs to be kept in lockstep with the system

INFERENCING

PRACTICAL CONSIDERATIONS – SOURCE/SINK IDENTIFICATION

YOU COULD TRY TO AUTOMATICALLY DISCOVER "SOURCELIKE" AND "SINKLIKE" FUNCTIONS

Maybe we can detect UI asking for credit card?

Maybe we can write an analysis that looks for even more fundamental core behavior?

Machine learning???!?!?!?!?!?!?!?!?!?!?!?!?!?!?!?!?!?!?!

CASE STUDY: ANDROID PERMISSIONS

PRACTICAL CONSIDERATIONS – SOURCE/SINK IDENTIFICATION

MOBILE PHONES SURE COLLECT A LOT OF PRIVATE INFORMATION!

Maybe that information rises to the level of confidentiality?

Maybe this is a good application of an information flow analysis?

CASE STUDY: ANDROID PERMISSIONS

PRACTICAL CONSIDERATIONS – SOURCE/SINK IDENTIFICATION

HYBRID CASE OF BUILT-IN ANNOTATIONS

System has a built-in capability model

Surprisingly hard to map those capabilities to system functions

MODELGEN

- Manually annotate capabilities as sources or sinks

- Do a dynamic analysis of the Android system to discover capabilities uses

- Do a static dataflow analysis of the Android system to discover capabilities uses

Modelgen: Mining Explicit Information Flow Specifications from Concrete Executions

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ABSTRACT

We present a technique to mine explicit information flow specifications from concrete executions. These specifications can be consumed by a static taint analysis, enabling static analysis to work even when method definitions are missing or portions of the program are too difficult to analyze statically (e.g., due to dynamic features such as reflection). We present an implementation of our technique for the Android platform. When compared to a set of manually written specifications for 309 methods across 51 classes, our technique is able to recover 96.36% of these manual specifications and produces many more correct annotations that our manual models missed. We incorporate the generated specifications into an existing static taint analysis system, and show that they enable it to find additional true flows. Although our implementation is Android-specific, our approach is applicable to other application frameworks.

Categories and Subject Descriptors

F.3.2 [**Semantics of Programming Languages**]: Program analysis; D.2.5 [**Software Engineering**]: Testing and Debugging—*Tracing*

General Terms

Experimentation, Algorithms, Verification

Keywords

Dynamic analysis; specification mining; information flow

1. INTRODUCTION

Scaling a precise and sound static analysis to real-world software is challenging, especially for software written in modern object-oriented languages such as Java. Typically such software builds upon large and complex frameworks (e.g., Android, Apache Struts, and Spring). For soundness and precision, any analysis of such software entails analysis of the framework. However, there are at least four problems that make the analysis of framework code challenging. First, a very precise analysis of a framework may not scale because most frameworks are very large. Second, framework code may use dynamic language features, such as reflection in Java, which are difficult to analyze statically. Third, frameworks typically use non-code artifacts (e.g., configuration files) that have special semantics that must be modeled for accurate results. Fourth, frameworks usually build on abstractions written in lower-level languages for which a comprehensive static analysis may be unavailable (e.g., Java's native methods). Such foreign functions appear as missing code to the static analysis of the higher-level language.

One approach to address these problems is to use specifications (also called *models*) for framework classes and methods. From a high-level, a specification reflects those effects of the framework code on the program state that are relevant to the analysis. The analysis can then use these specifications instead of analyzing the framework. Use of specifications can improve the scalability of an analysis dramatically because specifications are usually much smaller than the code they specify. In addition to scalability, use of specifications can also improve the precision of the analysis because specifications are also simpler (e.g., no dynamic language features or non-code artifacts) than the corresponding code.

Although use of specifications can improve both scalability and precision of an analysis, obtaining specifications is a challenging problem in itself. If specifications are computed by static analysis of the framework code, the aforementioned problems arise. An alternative approach is to manually write specifications. This approach is not impractical because once the specifications for a framework are written, those specifications can be used to analyze any piece of software that uses that framework. However, writing and maintaining specifications manually for a large framework is still laborious and susceptible to human error. Dynamic analysis, which observes concrete executions of a program and generalizes to produce specifications, represents an attractive third alternative. Mining specifications from execution traces, to be consumed by a static analysis, is not a novel idea. For example, some techniques produce control-flow specifications (e.g., [2, 50, 34, 20, 36]), while others discover general pre- and post-conditions on methods (e.g., Daikon [15]). However, we are interested in using information-flow specifications computed through dynamic analysis as models to be consumed by a static analysis. This is a problem that, to our knowledge, has not been previously explored.

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http://dx.doi.org/10.1145/2771783.2771810

GRANULARITY OF ANALYSIS

PRACTICAL CONSIDERATIONS – PRECISION/SANITIZATION

DATA IS COMPLEX!

What happens when a field of a struct is tainted?

What happens when an index of an array is tainted?

SANITIZATION

PRACTICAL CONSIDERATIONS – PRECISION/SANITIZATION

WE ALSO WANT TO PROVIDE SOME EXCEPTIONS TO THE FLOW RULES

i.e. tainted data is encrypted

WRAP-UP

NEXT TIME

EVADING ANALYSIS