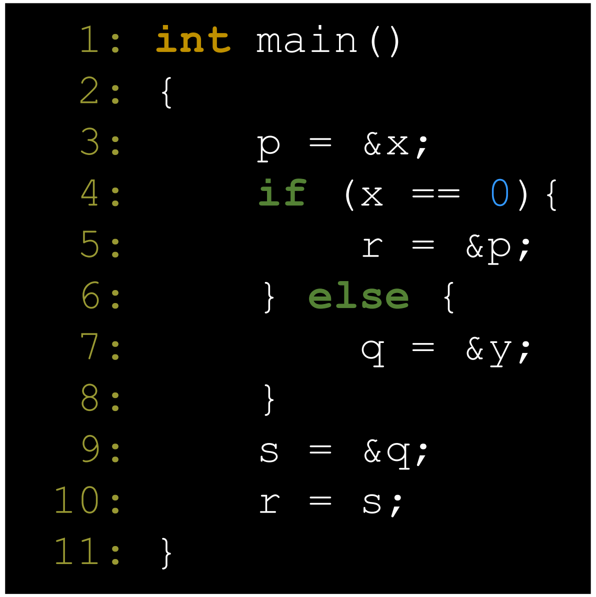
EXERCISE #21

POINTS-TO ANALYSIS REVIEW

Write your name and answer the following on a piece of paper

Draw the points-to graph of the following snippet:



```
int main()
{
        p = &x;
        if (x == 0){
                r = &p;
        } else {
                q = &y;
        }
        s = &q;
        r = s;
}
```

Assignment	Constraint
a = &b	a ⊇ { b }
a = b	a ⊇ b
a = *b	a ⊇ *b
*a = b	*a ⊇ b

EXERCISE #21 SOLUTION

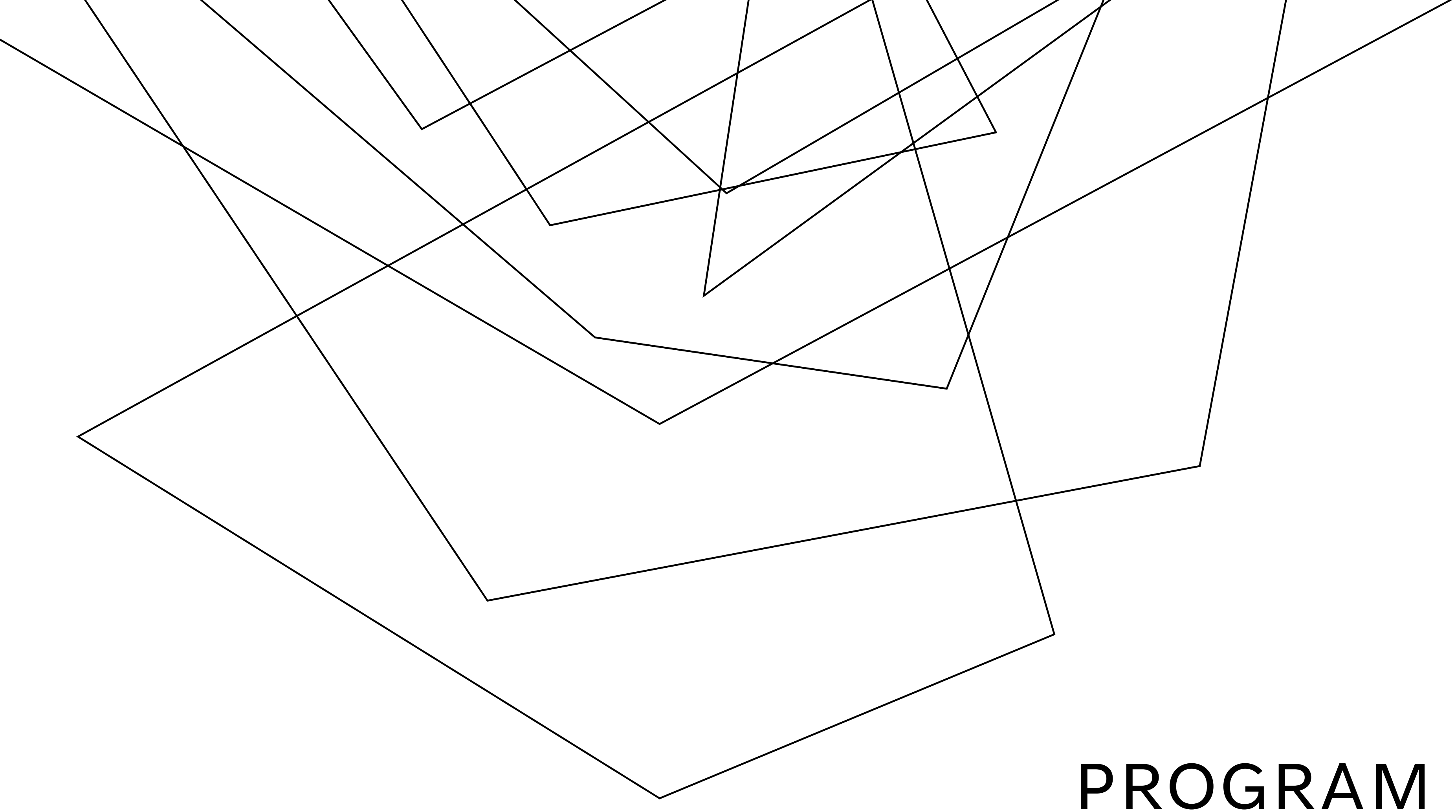
POINTS-TO ANALYSIS REVIEW

Assignment	Constraint
a = &b	a ⊇ { b }
a = b	a ⊇ b
a = *b	a ⊇ *b
*a = b	*a ⊇ b

Quiz 2 on Monday

Review session: Friday at 6:30 PM, Location TBA

ADMINISTRIVIA AND ANNOUNCEMENTS



PROGRAM INSTRUMENTATION

EECS 677: Software Security Evaluation

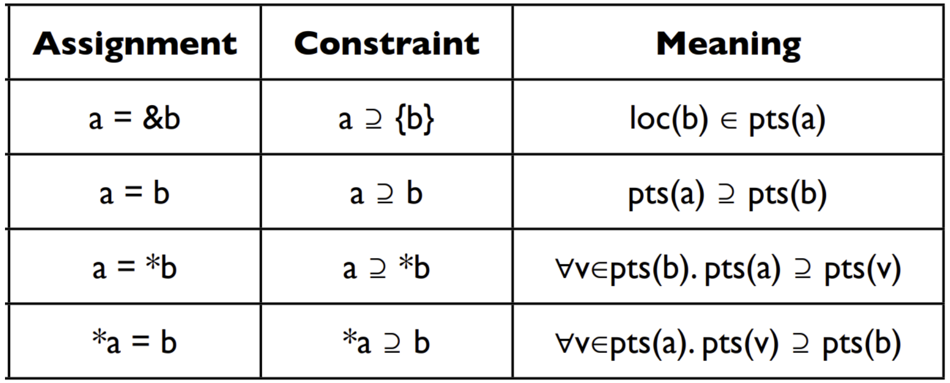
Drew Davidson

ANDERSEN'S ALGORITHM

REVIEW: LAST LECTURE

REACHABILITY FORMULATION

Step 1: Extract pointer-related operations
Step 2: Saturate points-to graph
Step 3: Compute node reachability



Assignment	Constraint	Meaning
a = &b	a ⊇ {b}	loc(b) ∈ pts(a)
a = b	a ⊇ b	pts(a) ⊇ pts(b)
a = *b	a ⊇ *b	∀v∈pts(b). pts(a) ⊇ pts(v)
*a = b	*a ⊇ b	∀v∈pts(a). pts(v) ⊇ pts(b)

ANDERSEN'S ALGORITHM: REACHABILITY

REVIEW: LAST LECTURE

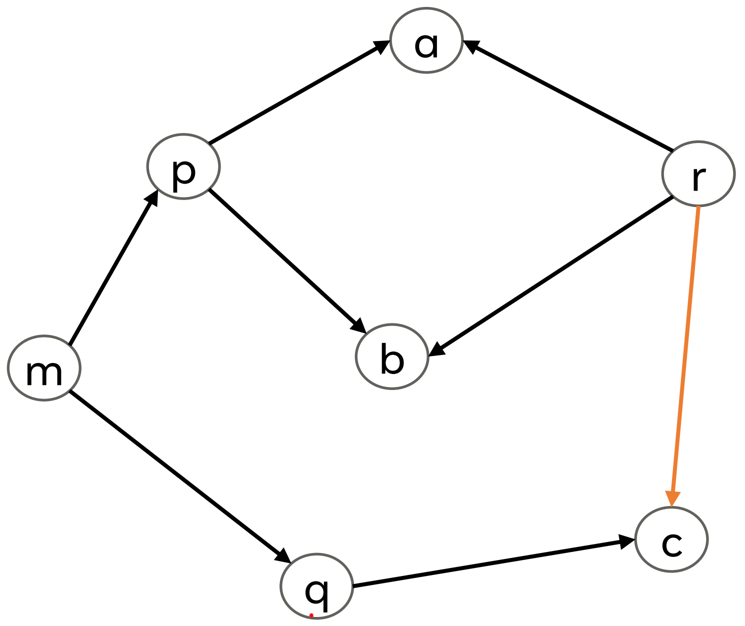
REACHABILITY FORMULATION

Step 1: List pointer-related operations
Step 2: Saturate points-to graph
Step 3: Compute node reachability

Assignment	Constraint	Meaning
a = &b	a ⊇ {b}	loc(b) ∈ pts(a)
a = b	a ⊇ b	pts(a) ⊇ pts(b)
a = *b	a ⊇ *b	∀v∈pts(b). pts(a) ⊇ pts(v)
*a = b	*a ⊇ b	∀v∈pts(a). pts(v) ⊇ pts(b)

Program	Constraints
p = &a	p ⊇ {a}
p = &b	p ⊇ {b}
m =&p;	m ⊇ {p}
r = *m;	r ⊇ *m
q = &c;	q ⊇ {c}
m = &q	m ⊇ {q}

Initial	Final
pts(a) = { }	pts(a) = { }
pts(b) = { }	pts(b) = { }
pts(m) = { }	pts(m) = { p, q }
pts(p) = { }	pts(p) = { a, b }
pts(q) = { }	pts(q) = { c }
pts(r) = { }	pts(r) = { a, b, c }



POINTS TO AND TYPE SAFTEY

REVIEW: LAST LECTURE

A "FEATURE" OF THE ANALYSIS

Our points-to relationships are somewhat contrived

Would a program ever actually have both of these statements?

```
*a = b;
*a = *b;
```

PROGRAM INSTRUMENTATION

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LECTURE OUTLINE

- Steensgard’s Analysis
- Static Analysis Underview
- Program Instrumentation

OVERHEAD

ANDERSEN'S ANALYSIS

Worst Case: Cubic Time

That's not great!

Most of the time is spent in re-analyzing constraints to get to a fixpoint

Optimization: Cycle elimination

Detect and collapse SCCs in the

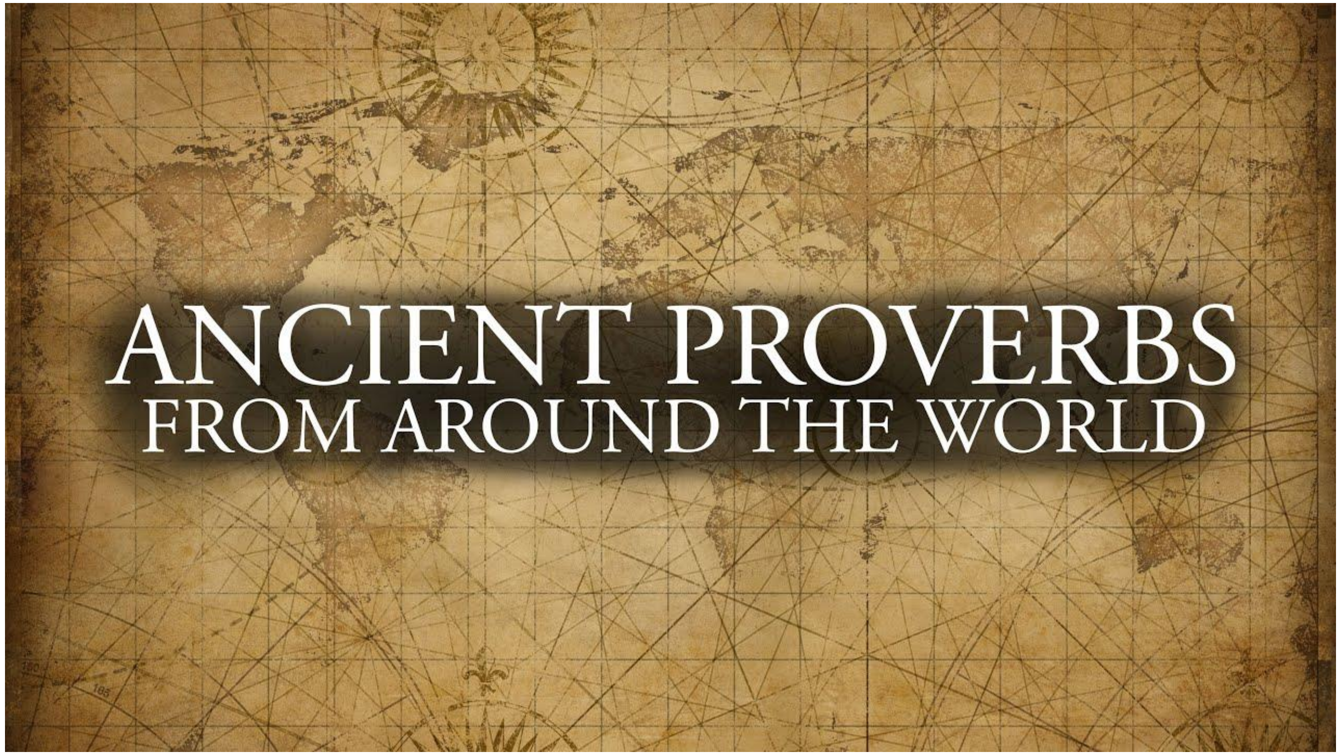
points-to relation

A MORE-EFFICIENT POINTS-TO

STEENSGARD'S ANALYSIS

RETURN AGAIN TO OUR ANCIENT WISDOM

Simpler abstractions reach fixpoints faster



A MORE-EFFICIENT POINTS-TO

STEENSGARD'S ANALYSIS

RETURN AGAIN TO OUR ANCIENT WISDOM

Simpler abstractions reach fixpoints faster

STEENGARD'S ANALYSIS

Limit the points-to graph nodes to have outdegree <= 1

Simplifies many points-to constraints from subsets to equalities

Achieves near-linear performance

You can only point to 1 node

If you need to point to > 1 node, merge the "pointees"

STEENGARD'S ALGORITHM

AN EFFICIENT OVER-APPROXIMATION

IN PRACTICE ~~Andersen's~~

Step 1

List pointer-related operations

Step 2

Induce set of ~~subset~~ equality constraints

Step 3

Solve system of constraints

REACHABILITY FORMULATION

Step 1

List pointer-related operations

Step 2

Saturate 1-out points-to graph

Step 3

Compute node reachability

Andersen's

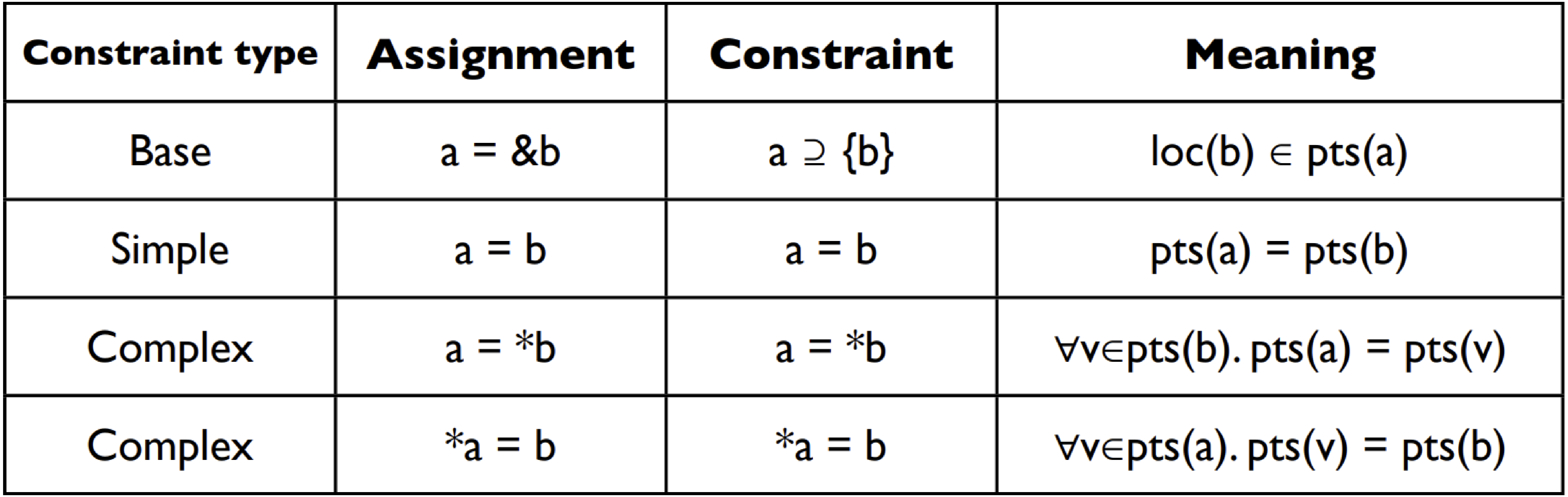
Assignment	Constraint	Meaning
a = &b	$a \supseteq \{b\}$	$loc(b) \in pts(a)$
a = b	$a \supseteq b$	$pts(a) \supseteq pts(b)$
a = *b	$a \supseteq *b$	$\forall v \in pts(b).\ pts(a) \supseteq pts(v)$
*a = b	$*a \supseteq b$	$\forall v \in pts(a).\ pts(v) \supseteq pts(b)$

Steengaard's

Assignment	Constraint	Meaning
a = &b	$a \supseteq \{b\}$	$loc(b) \in pts(a)$
a = b	$a = b$	$pts(a) = pts(b)$
a = *b	$a = *b$	$\forall v \in pts(b).\ pts(a) = pts(v)$
*a = b	$*a = b$	$\forall v \in pts(a).\ pts(v) = pts(b)$

EQUALITY CONSTRAINTS

STEENSGARD'S ANALYSIS



Constraint type	**Assignment**	**Constraint**	**Meaning**
Base	a = &b	$a \supseteq \{b\}$	$loc(b) \in pts(a)$
Simple	a = b	a = b	$pts(a) = pts(b)$
Complex	a = *b	a = *b	$\forall v \in pts(b).\ pts(a) = pts(v)$
Complex	*a = b	*a = b	$\forall v \in pts(a).\ pts(v) = pts(b)$

EQUALITY CONSTRAINTS

STEENSGARD'S ANALYSIS

75

p = &a

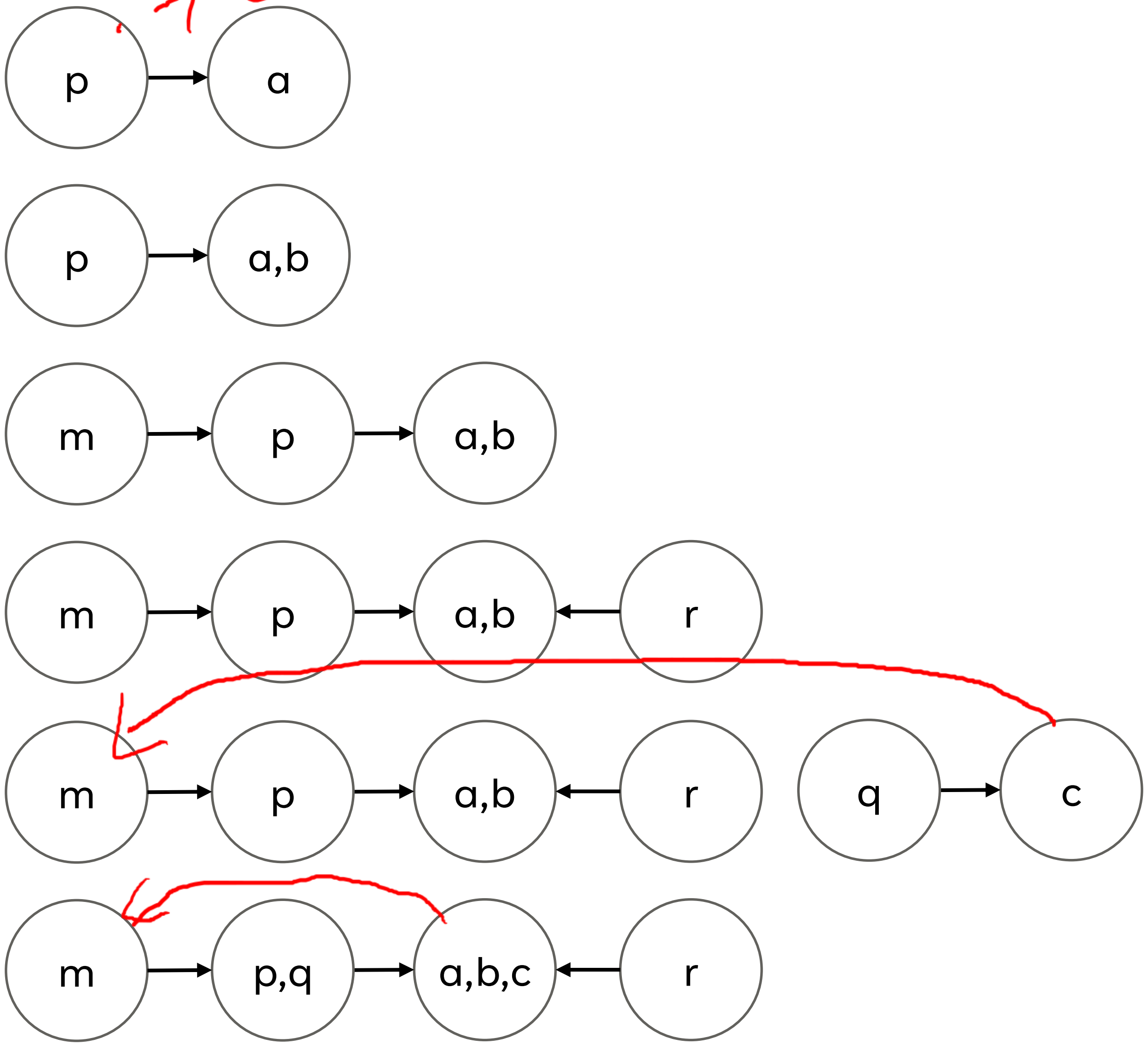
p = &b

m = &p

r = *m

q = &c

m = &q



EQUALITY CONSTRAINTS

STEENSGARD'S ANALYSIS

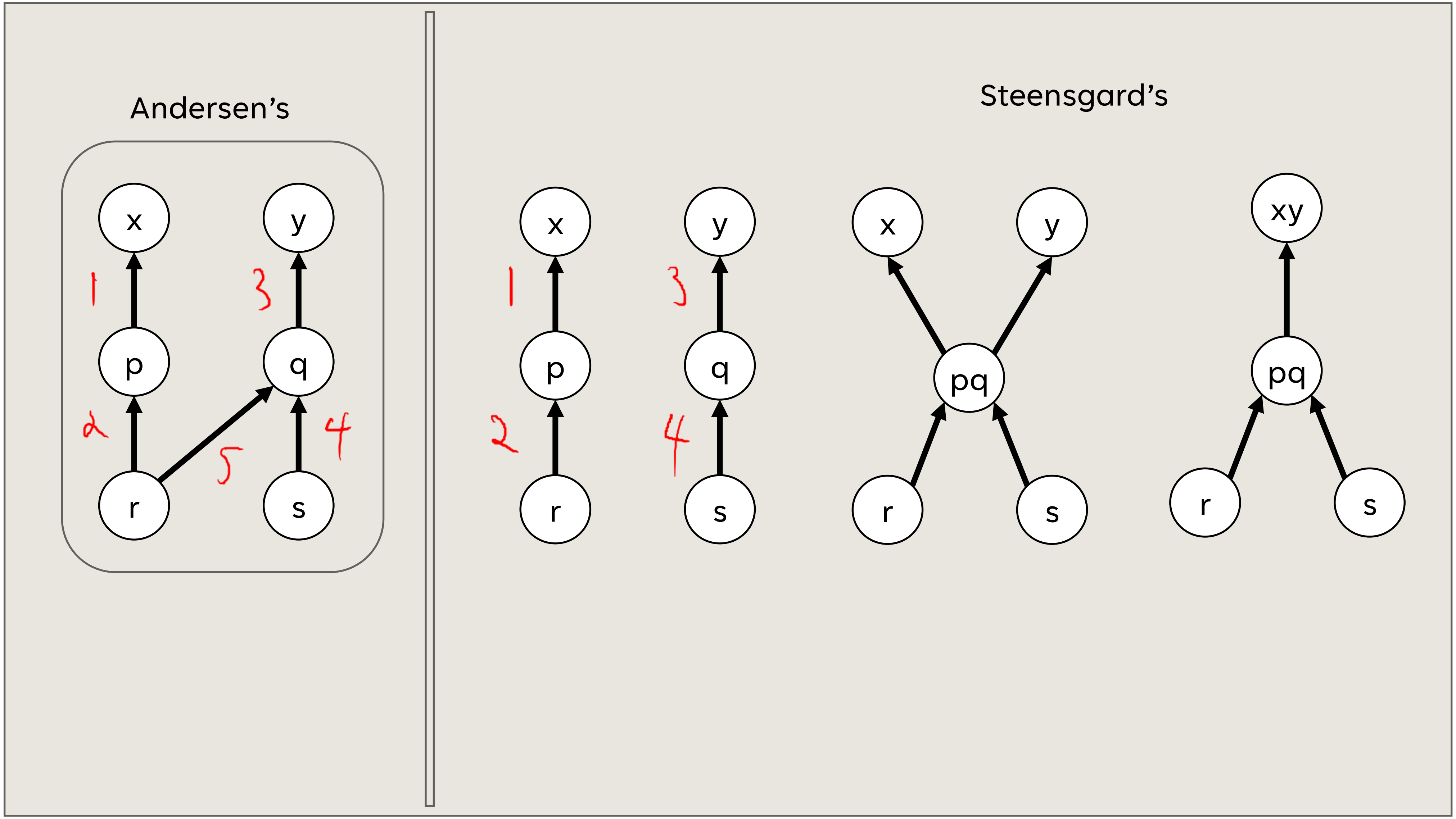
p = &x

r = &p

q = &y

s = &q

r = s



THAT’S POINTS-TO!

STEENSGARD’S ANALYSIS

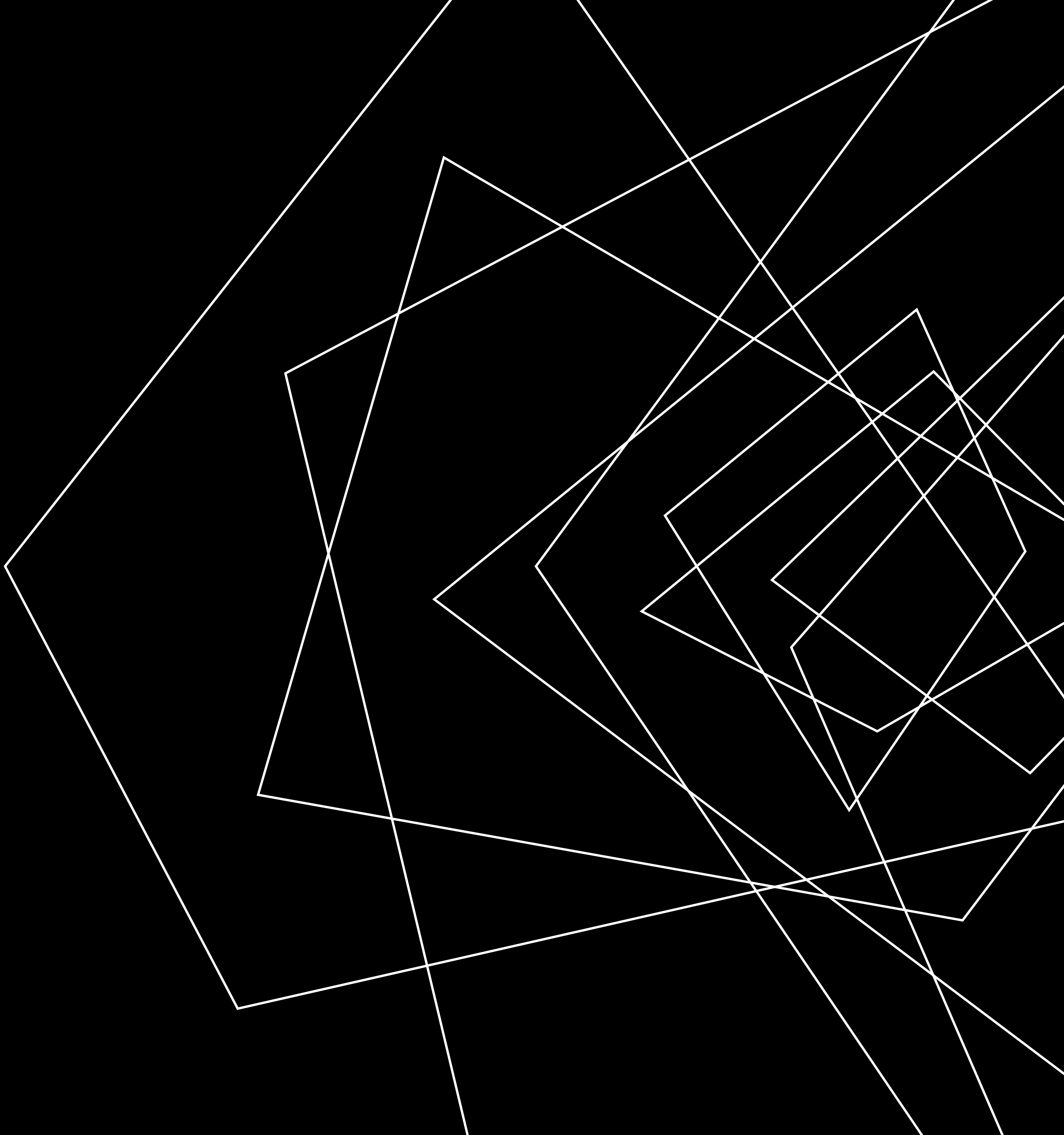
AN ADDITIONAL OVERLAY ON DATAFLOW

Dataflow facts also flow to aliases

When dereferencing a pointer, consider only pointed-to objects

LECTURE OUTLINE

- Steensgard’s Analysis
- Static Analysis Underview
- Program Instrumentation



STATIC ANALYSIS READY TO GO!

STATIC ANALYSIS UNDERVIEW

DATAFLOW ANALYSIS CAN BE ADOPTED FOR CHECKING A VARIETY OF SECURITY / CORRECTNESS PROPERTIES

Forms the basis of a lot of static analysis!

Applicable for a variety of analysis goals

- Security leak detection
- Vulnerable program state detection
- Program understanding

STATIC ANALYSIS: BENEFITS

STATIC ANALYSIS UNDERVIEW

“THE ANALYST’S SIEVE”

Focus your attention on potential issues

NON-INTERACTIVE!

Can run in the background

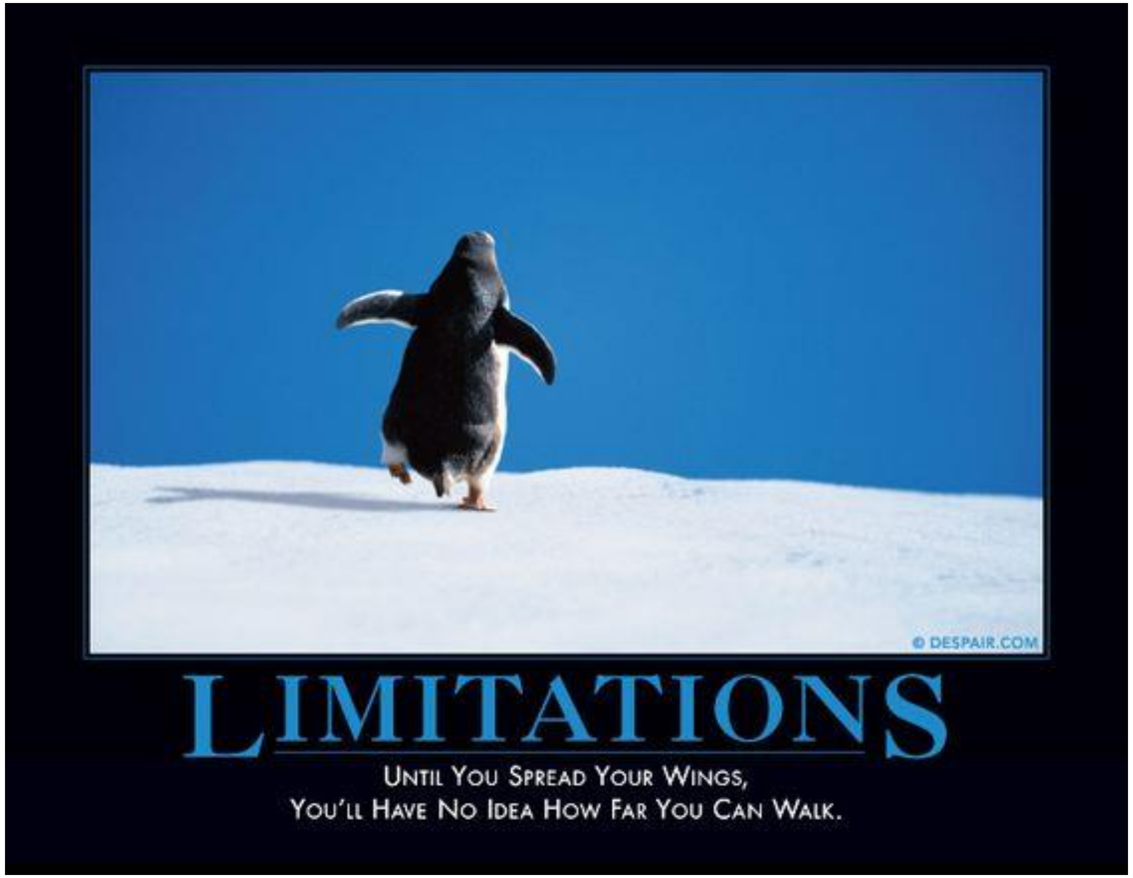
Abstraction obviates need for input

LIMITS OF STATIC ANALYSIS

PROGRAM INSTRUMENTATION: BASIC IDEA

PRACTICAL ISSUES

- Unsoundness of bug finding / incompleteness of program verification
- Scalability
- Significant engineering effort
- Findings may not be super actionable



LECTURE OUTLINE

- Steensgard’s Analysis
- Static Analysis Underview
- Program Instrumentation

REVISING DYNAMIC ANALYSIS

PROGRAM INSTRUMENTATION: BASIC IDEA

GIVING UP ON COMPLETE BUG-FINDING

- Finding bugs (even "low-hanging fruit") is useful!

BENEFITS

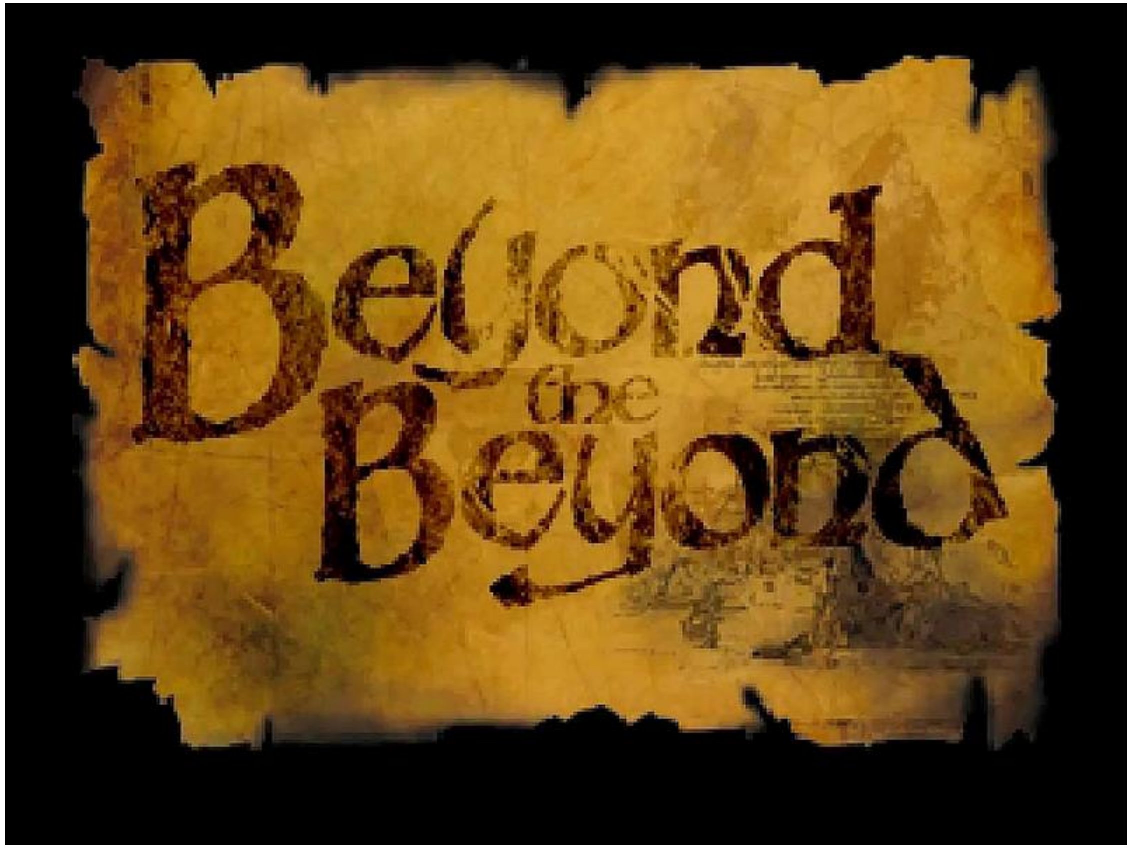
- Scalability
- Sound bug finding

BEYOND TESTING

PROGRAM INSTRUMENTATION: BASIC IDEA

LIMITATIONS OF "PLAIN" TESTING

- Property may not be immediately observable from output alone
- The circumstances under which the issue occurs may not be obvious



PROGRAM INSTRUMENTATION

PROGRAM INSTRUMENTATION: BASIC IDEA

WRITE CODE INTO THE EXECUTABLE TO GATHER INFORMATION

Addresses both of the previous issues – can report upon program state and even program path

```
int main()
{
    foo();
    cout << “Got here!\n”;
    bar();
    cout << “Got here2\n”;
    baz();
    cout << “Got here3\n”;
}
```

EXAMPLE: LLVM INSTRUMENTATION

PROGRAM INSTRUMENTATION: BASIC IDEA

WRITE CODE INTO THE EXECUTABLE TO GATHER INFORMATION

Addresses both of the previous issues – can report upon program state and even program path

```
int main()
{
    foo();
    cout << “Got here!\n”;
    bar();
    cout << “Got here2\n”;
    baz();
    cout << “Got here3\n”;
}
```

INSERTING PROGRAM PROBES

PROGRAM INSTRUMENTATION: BASIC IDEA

INSERT CHECKS / REPORTS INTO THE ANALYSIS TARGET

Addresses both of the previous issues – can report upon program state and even program path

A NEW CONCERN – THE EFFICIENCY OF THE (INSTRUMENTED) PROGRAM

Potential slowdown on each program path

OLD CONCERN – THE EFFICIENCY OF PLACEMENT ANALYSIS

Somewhat limited by the information the probes can report

EXAMPLE: CODE COVERAGE

PROGRAM INSTRUMENTATION: BASIC IDEA

```
b << atoi(cin);
a/b;
```

EXAMPLE: CODE COVERAGE

PROGRAM INSTRUMENTATION: BASIC IDEA

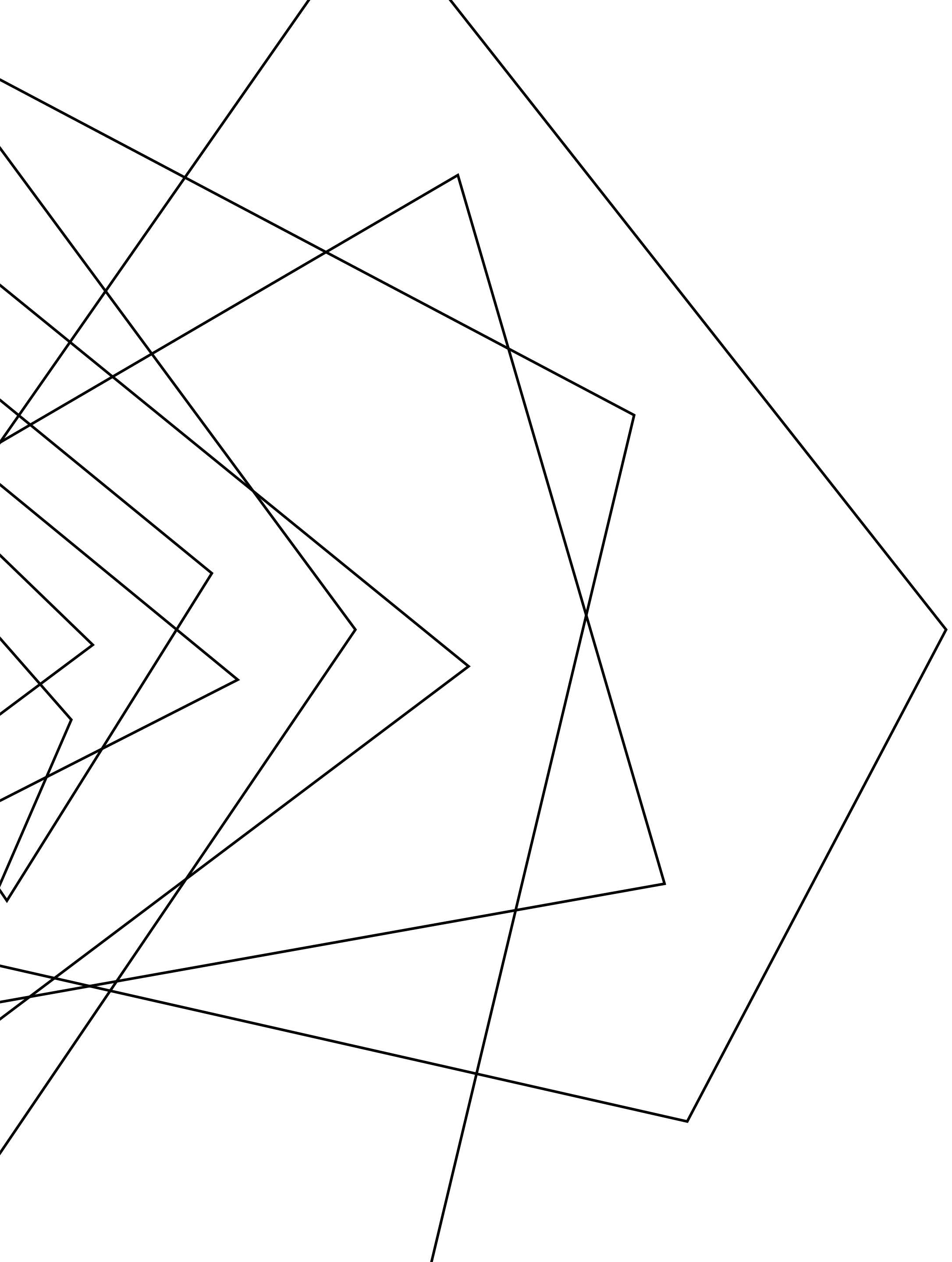
COUNTING HOW MANY TIMES CERTAIN BEHAVIORS OF THE PROGRAM ARE EXERCISED

Why is this useful? (Placing sanitizers)

THIS ACTUALLY TURNS OUT TO BE A LITTLE BIT TRICKY!

Actually turns out to be a little bit tricky!

We’ll describe some of the issues / solution as per Ball and Larus, ‘96



WRAP-UP

WE'VE BEGUN TO CONSIDER A WAY TO MOVE BEYOND STATIC ANALYSIS WHILE USING OUR EXISTING TOOLS: PROGRAM INSTRUMENTATION