

EXERCISE 16

PROGRAM SLICING REVIEW

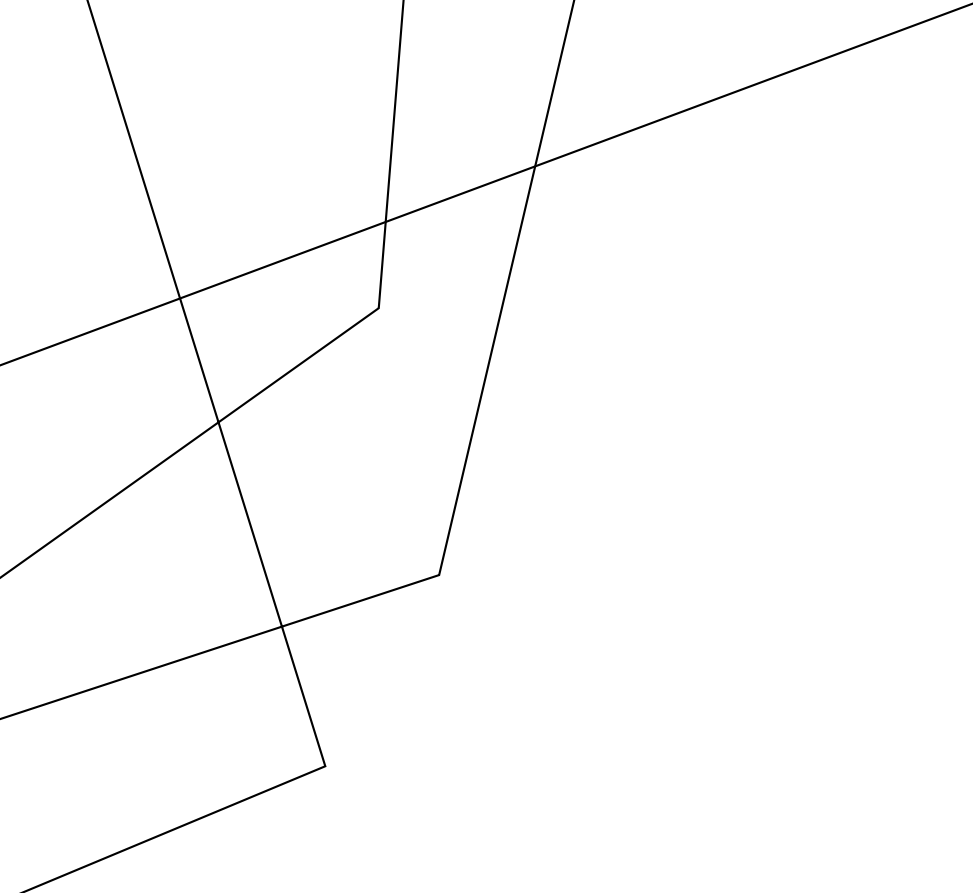
Write your name and answer the following on a piece of paper

Draw the forward slice from line 2 in following program:

```
1: int main(int argc, const char * argv[]){
2:     const char * a = argv[1];
3:     int b = argc;
4:     if (a[0] == 'a'){
5:         if (b > 2){
6:             return 2;
7:         }
8:     } else {
9:         b = 4;
10:    }
11:    b = 7;
12:    return 3;
13: }
```

EXERCISE 16 SOLUTION

PROGRAM SLICING REVIEW

Abstract geometric lines in the top left corner, consisting of several thin black lines forming a series of overlapping, tilted rectangular shapes.

ADMINISTRIVIA AND ANNOUNCEMENTS

LAST TIME: THE PROGRAM SLICE

REVIEW: PROGRAM SLICING

EXTRACT A SUB-PROGRAM OF INTEREST
BASED ON ONE (OR MORE) STATEMENTS

Forward slice

Capture all code *influenced by* a given statement

Backwards slide

Capture all code *influencing* a given statement



CONSTRUCTING THE SLICE

REVIEW: PROGRAM SLICING

Extract the Control-Flow Graph (CFG)

Construct Basic Blocks, make control transfers edges

Extract the Postdominator Tree from the CFG

(done via a dataflow analysis)

Capture the IFDOM relationship

Backwards edges in the postdominator tree

Build the Control-Dependence Graph (CDG)

Backwards edges in the postdominator tree

Build the Data-Dependence Graph (DDG)

Backwards edges in the reaching definitions

Build the Control-Dependence Graph (PDG)

Add all edges from the DDG to the CDG

Construct the transitive closure of PDG edges

Forward: against dependence, Backwards: with dependence



USES FOR PROGRAM SLICES

REVIEW: PROGRAM SLICING

Program Comprehension

What is this statement doing?

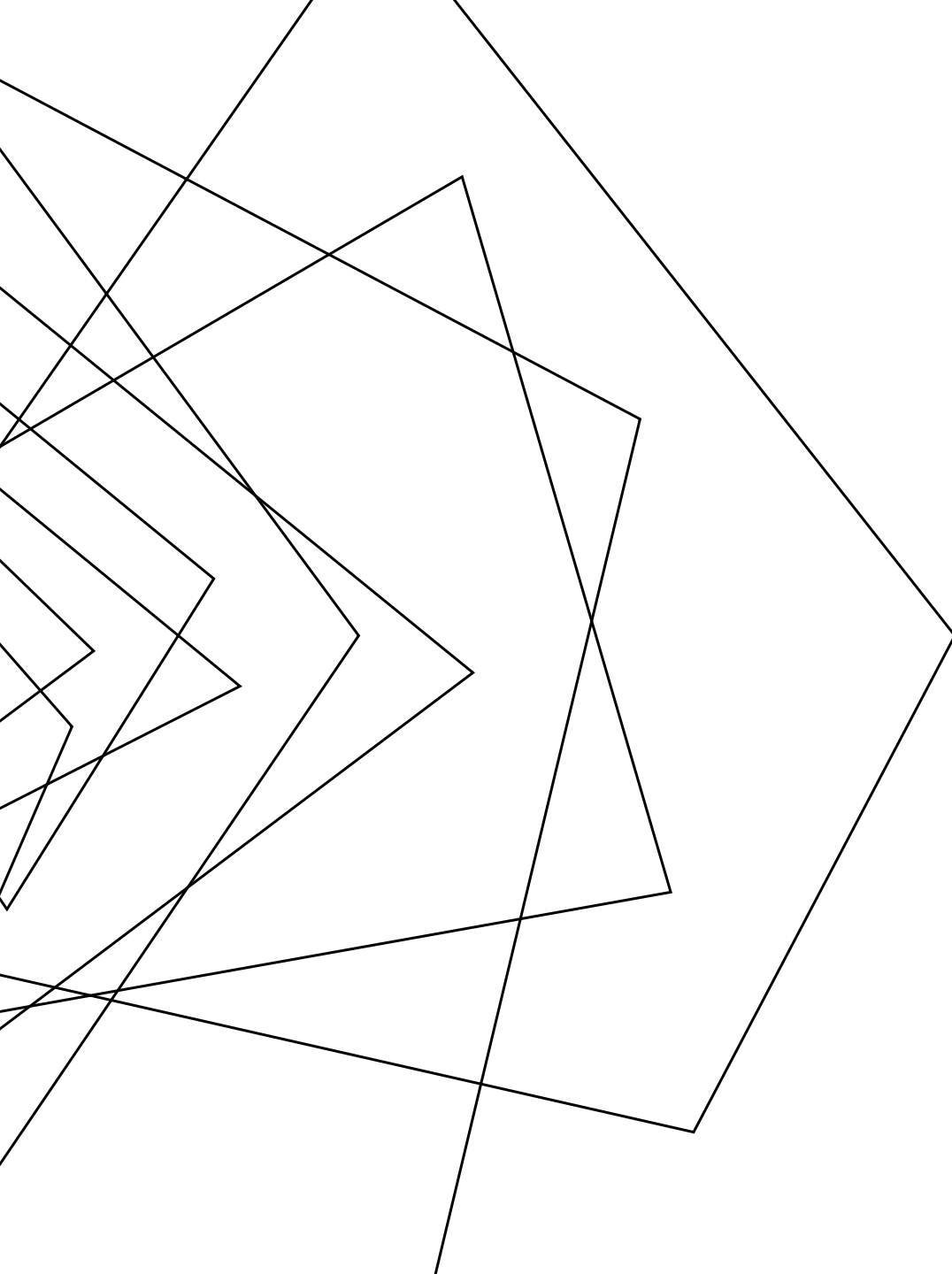
Debugging

(done via a dataflow analysis)

Scaling heavyweight analysis

Less program to test





VIBE CHECK

DATAFLOW ANALYSIS IS SUPER USEFUL!

We've achieved a milestone in our analysis

We did leave out a handful of program features...

- Functions
- Global Variables
- Classes / Dynamic Dispatch
- Pointers / References

IS THIS STUFF USEFUL?

VIBE CHECK

EMPIRICALLY, YES

Windows PREfast and Static Driver Verifier

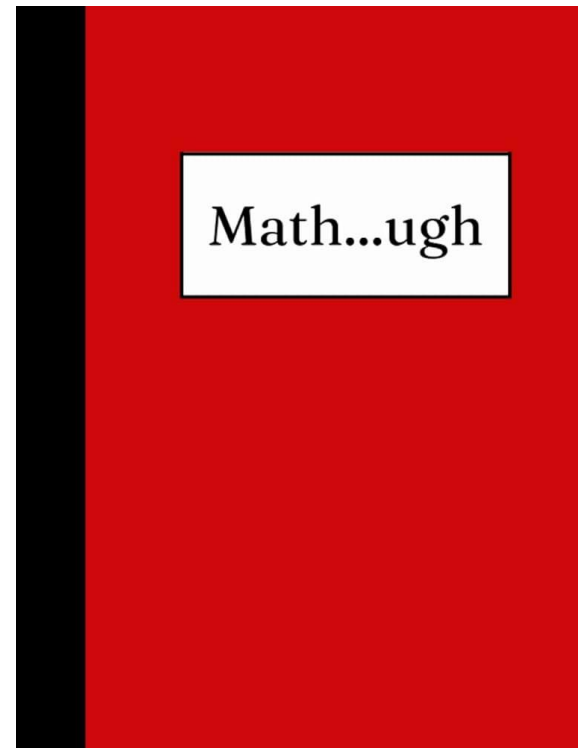
Even shipped with some versions of Visual Studio

PREfast for Drivers: only analyzes a single function

Official bug numbers are hard to come by, but
anecdotally they have been crucial in reducing
Windows DOS

Coverity

Static analysis tool originally from Stanford



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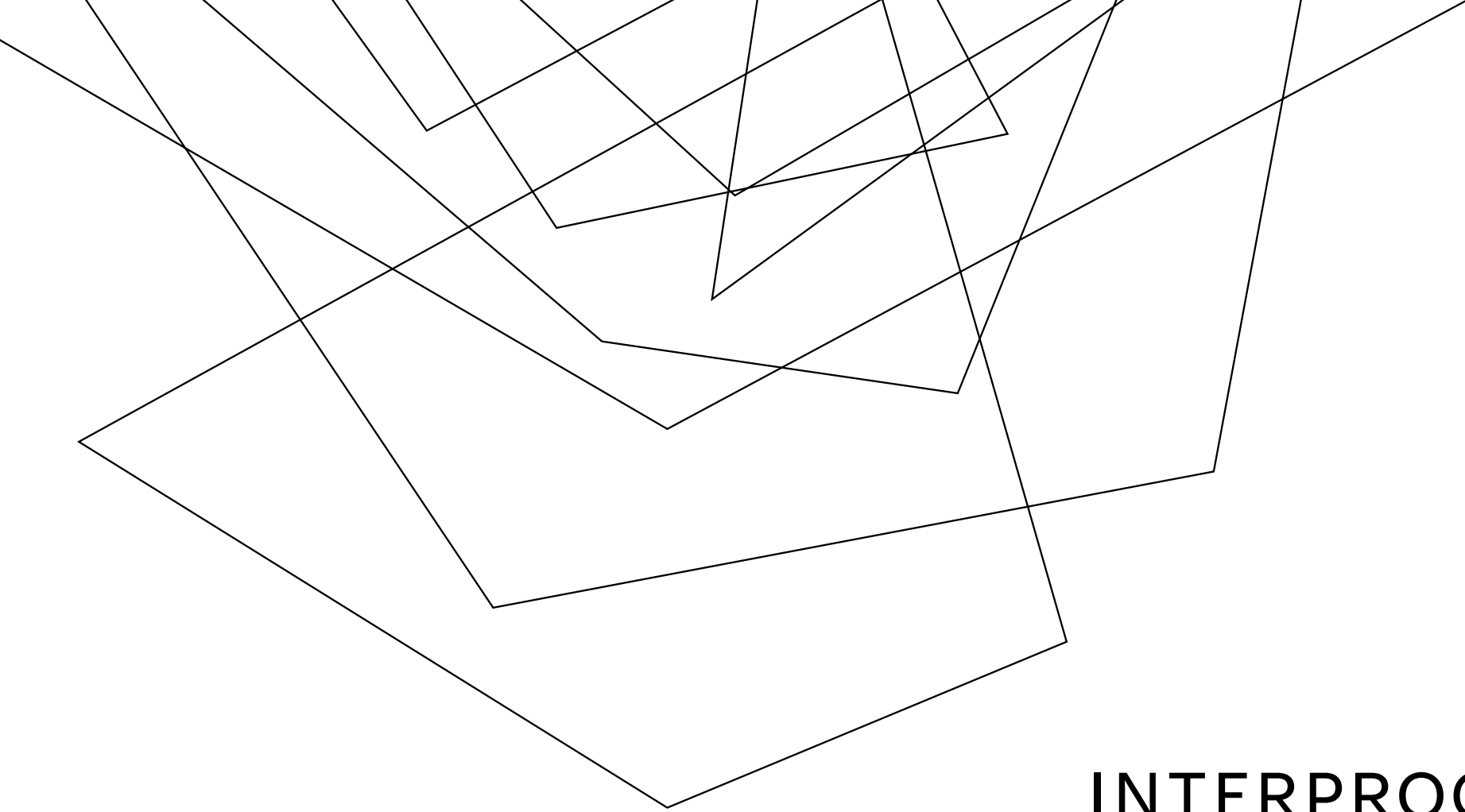
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Coverity

Static analysis tool originally from Stanford

Under a [United States Department of Homeland Security](#) contract in 2006, the tool was used to examine over 150 open source applications for bugs; 6000 bugs found by the scan were fixed across 53 projects.^[4]
[National Highway Traffic Safety Administration](#) used the tool in its 2010-2011 investigation into reports of [sudden unintended acceleration](#) in Toyota vehicles.^{[5][6]} The tool was used by [CERN](#) on the software employed in the [Large Hadron Collider](#)^{[7][8]} and in the [NASA Jet Propulsion Laboratory](#) during the flight software development of the [Mars rover Curiosity](#).^[9]

- Wikipedia

Abstract geometric lines in the top-left corner of the slide, consisting of several thin black lines forming various polygons and intersecting each other.

INTERPROCEDURAL ANALYSIS

EECS 677: Software Security Evaluation

Drew Davidson

SCALING UP OUR ANALYSIS

INTERPROCEDURAL ANALYSIS

INTRAPROCEDURAL ANALYSIS IS USEFUL!

PREfast Driver shows the importance in special cases

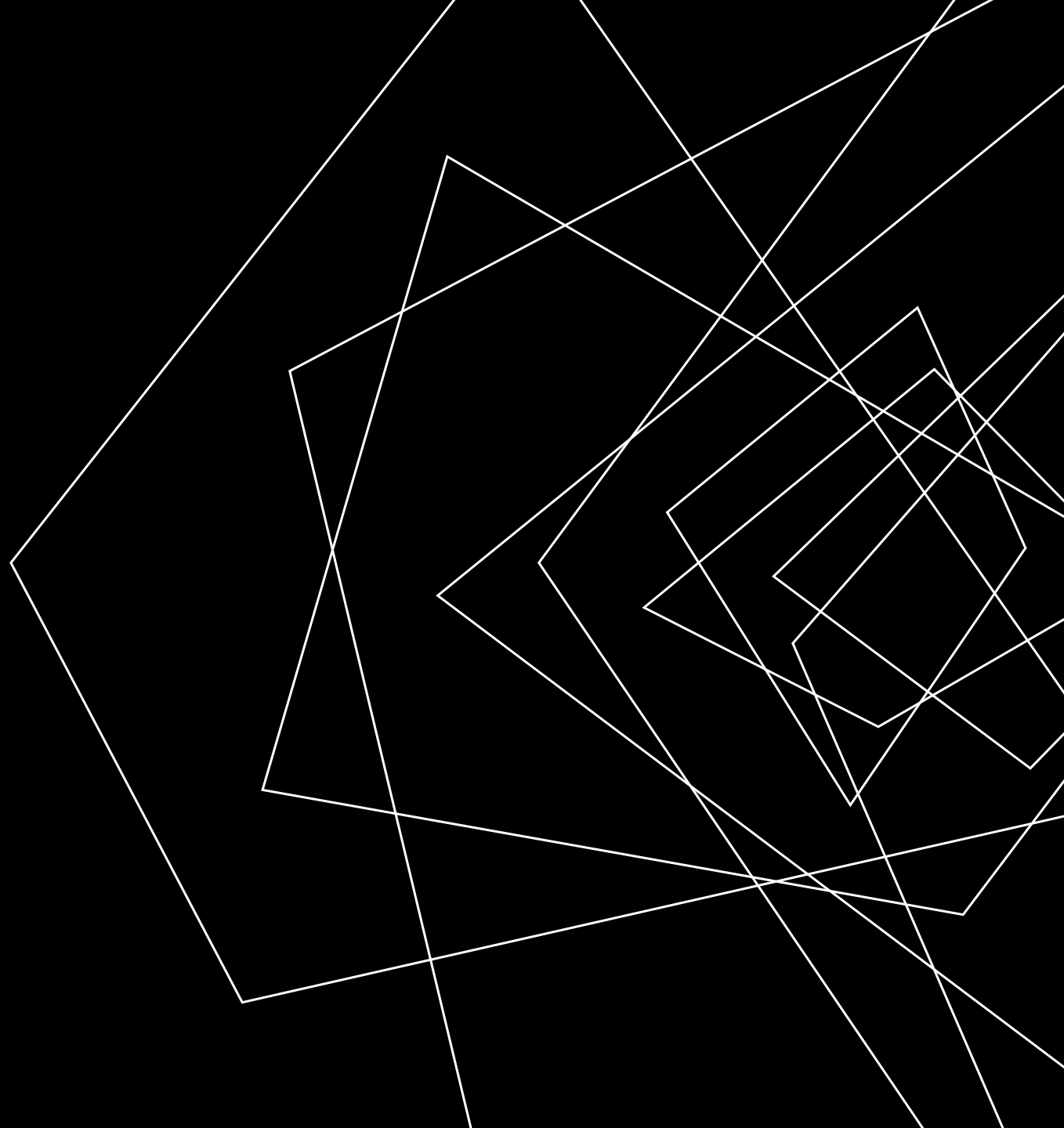
INTERPROCEDURAL ANALYSIS IS USEFUL!

Coverity shows the importance in more general cases



LECTURE OUTLINE

- Abject Pessimism
- ICFGs
- Context-Sensitivity
- Summary Functions



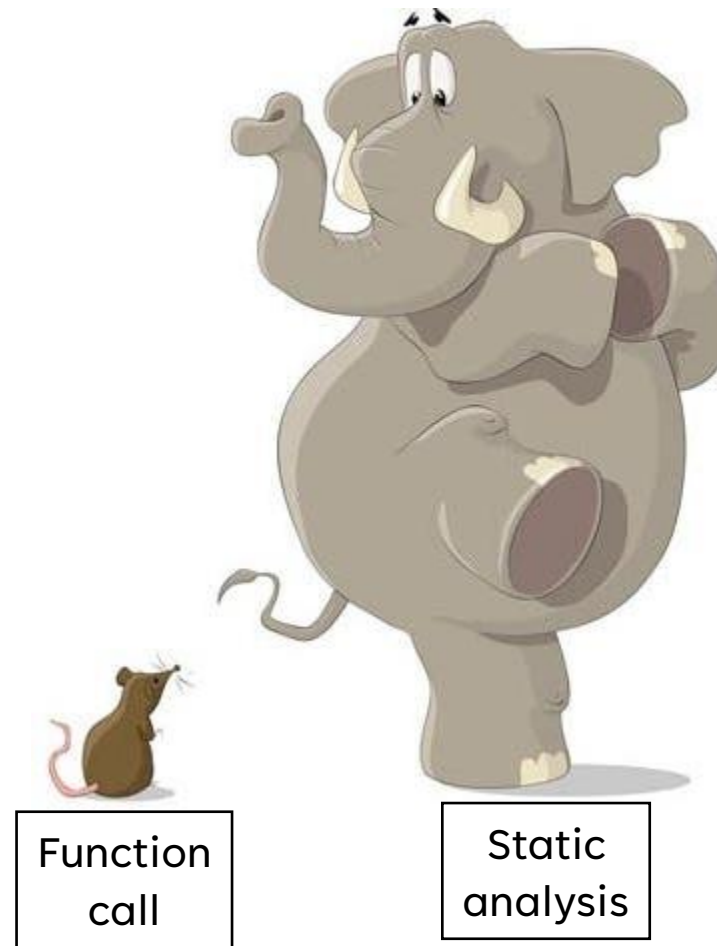
WORST-CASE ASSUMPTIONS

NAÏVE APPROACH

CREATE SIMPLE, “SAFE” OVER-APPROXIMATION

What constitutes “being safe”
depends on your analysis

- **Example 1, confidentiality:** Assume a function call tags all reachable data as confidential
- **Example 2, integrity:** Assume a function call tags all reachable data as untrusted



WORST-CASE ASSUMPTIONS

NAÏVE APPROACH

OUR GENERAL PHILOSOPHY:
“DO NO HARM” GUARANTEES

Recall our notions of soundness and completeness:

- Sound: no false positives (“tells no lie”)
- Complete: no false negatives (“omits no truth”)

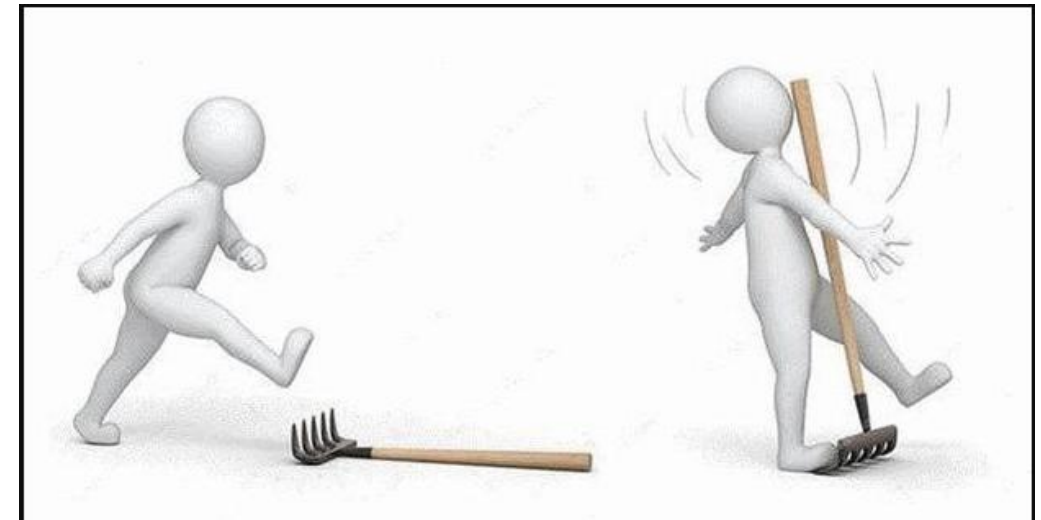
“BEING SAFE” REQUIRES
FORMULATING ANALYSIS GOAL

bug hunting:

- Report buggy programs
- Safe means complete analysis

program verification:

- Report clean programs
- Safe means sound analysis



ANYTHING THAT **CAN** GO WRONG
WILL GO WRONG

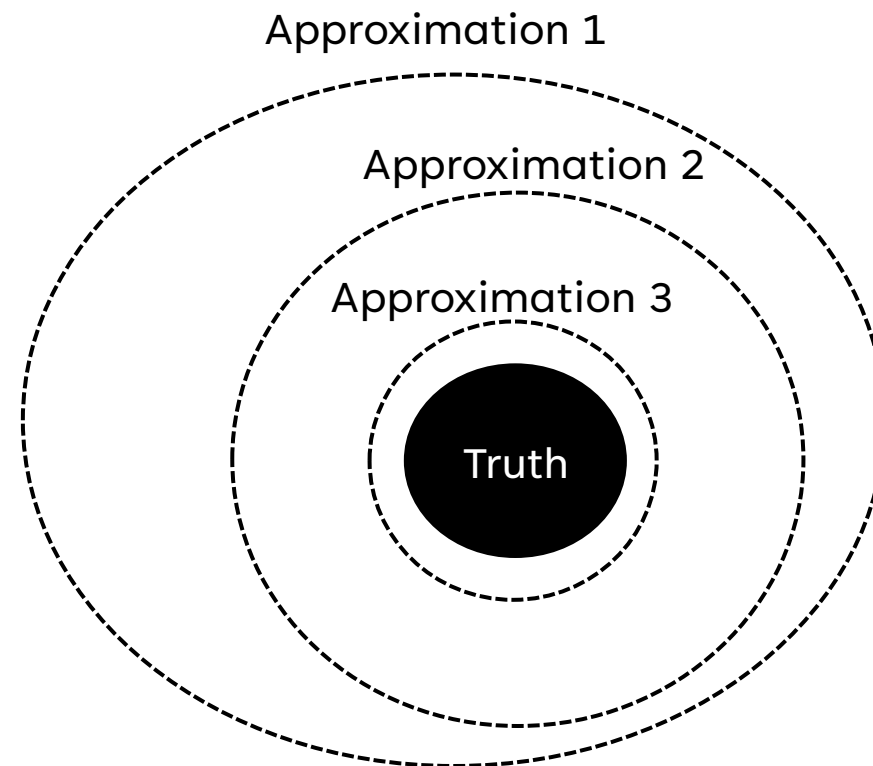
- MURPHY'S LAW

TIGHTENING THE BOUNDS

NAÏVE APPROACH

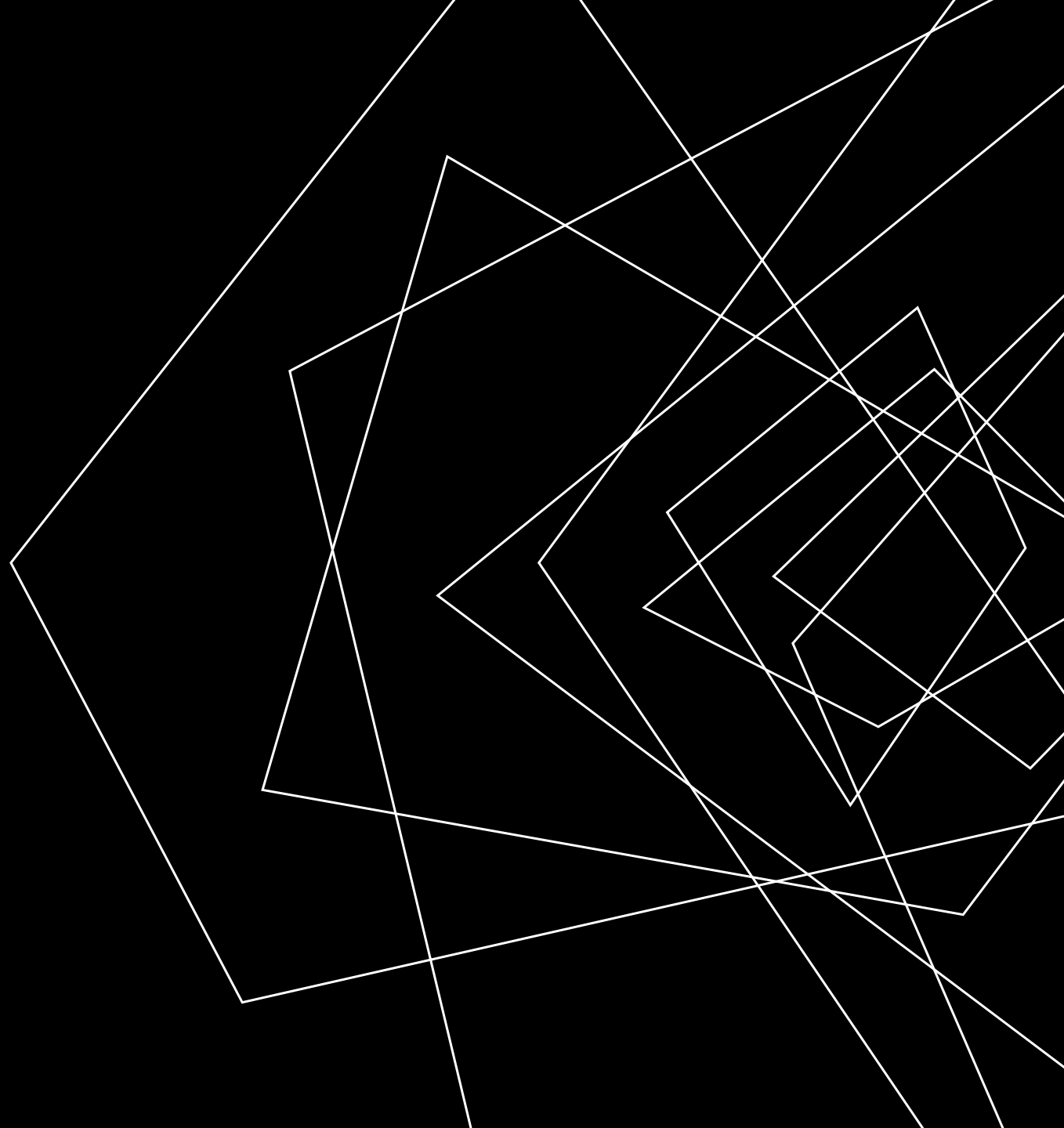
ATTEMPT TO GET TIGHTER AND TIGHTER
BOUNDS RETAINING COMPLETENESS

Address areas of imprecision that are only adding
false positives.



LECTURE OUTLINE

- Abject Pessimism
- ICFGs
- Context-Sensitivity
- Summary Functions

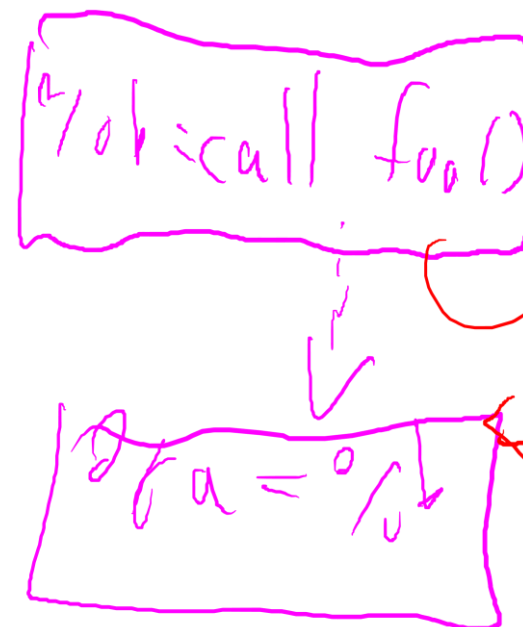
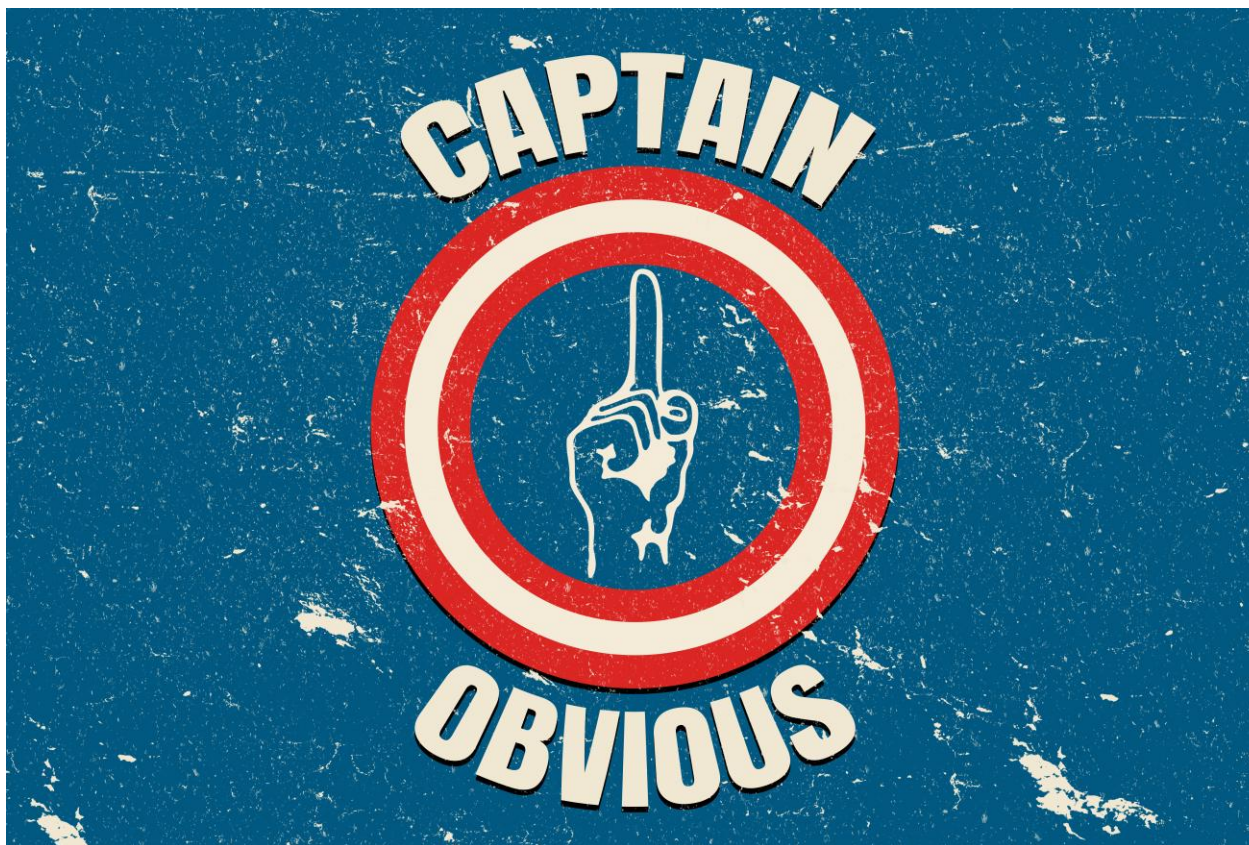


THE OBVIOUS INTERPROCEDURAL SOLUTION

INTERPROCEDURAL ANALYSIS: ICFGs

JUST ADD EDGES FROM A CALL SITE TO THE CALLEE

Builds the interprocedural control flow graph (ICFG) aka “supergraph”



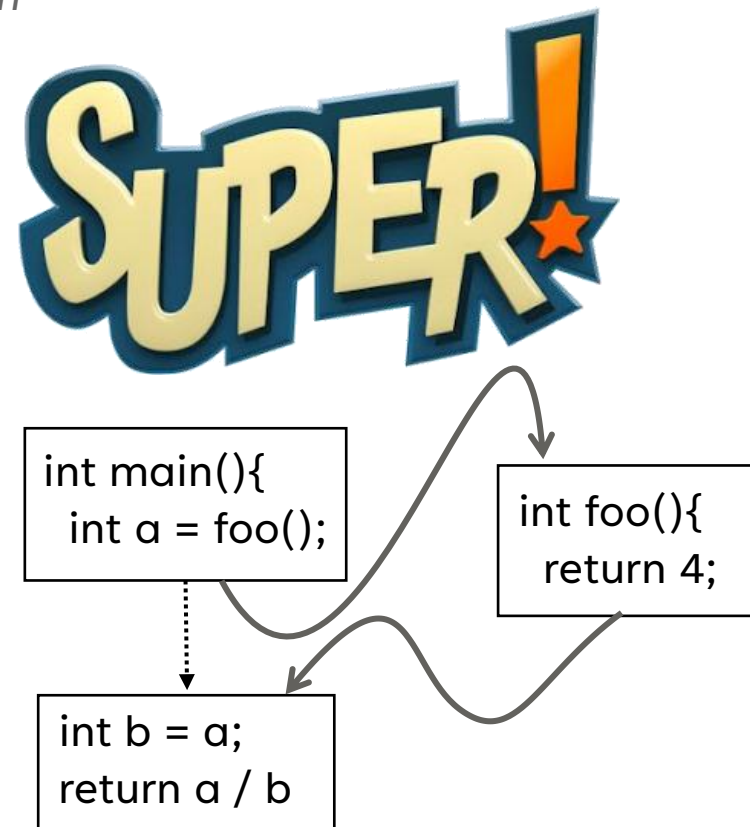
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Builds the interprocedural control flow graph (ICFG) aka “supergraph”

```
1 int foo(){  
2     return 4;  
3 }  
4  
5 int main(){  
6     int a = foo();  
7     int b = a;  
8     return a / b;  
9 }
```



COST/BENEFIT OF SUPERGRAPHS

INTERPROCEDURAL ANALYSIS: ICFGs

BENEFITS OF ICFGs

Better than object pessimism!

Minimal modification to intraprocedural algorithms

COSTS OF ICFGs

May not be obvious what the callee is

Naïvely leads to some erroneous paths



COST/BENEFIT OF SUPERGRAPHS

INTERPROCEDURAL ANALYSIS: ICFGs

COSTS OF ICFGs

May not be obvious what the callee is

We can separate that concern into a call graph analysis

CALL GRAPHS

INTERPROCEDURAL ANALYSIS: ICFGs

COSTS OF ICFGs

May not be obvious what the callee is

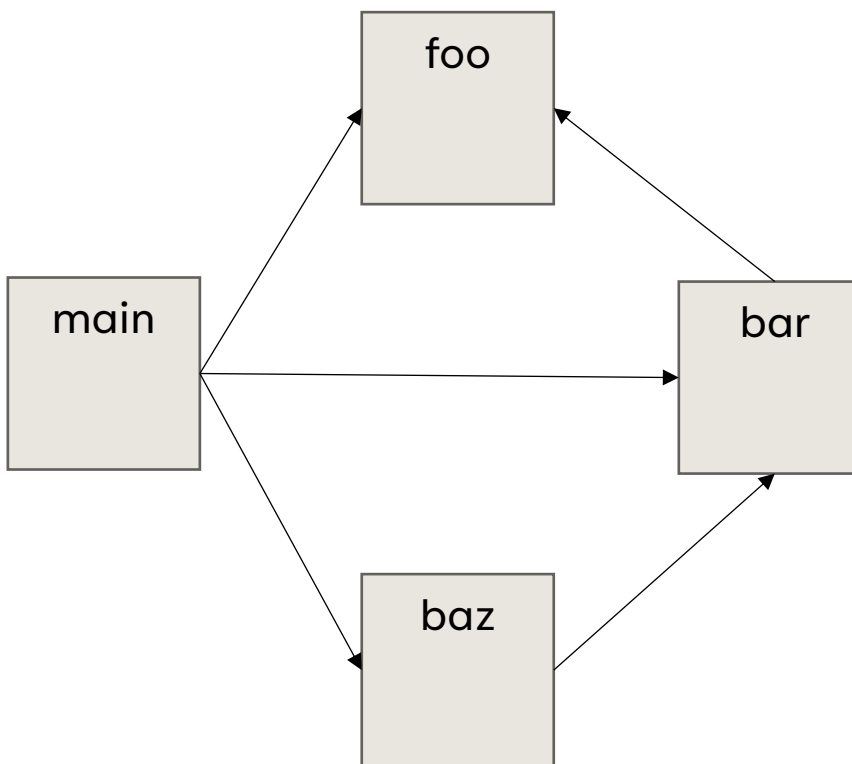
We can separate that concern into a call graph analysis

Simple call graph:

connect caller functions to callee functions

- Node: function
- Edge: function call

```
1 int foo(){ return 1; }
2 int bar(){ return foo() + 2; }
3 int baz(){ return bar() + 3; }
4
5 int main(int argc){
6     int a;
7     if (argc > 2){
8         foo();
9     } else {
10        bar();
11    }
12    int b = baz();
13    return a / b;
14
15 }
```



CALL GRAPHS

INTERPROCEDURAL ANALYSIS: ICFGs

COSTS OF ICFGs

May not be obvious what the callee is

We can separate that concern into a call graph analysis

Better

~~Simple call graph:~~ **Call sites**

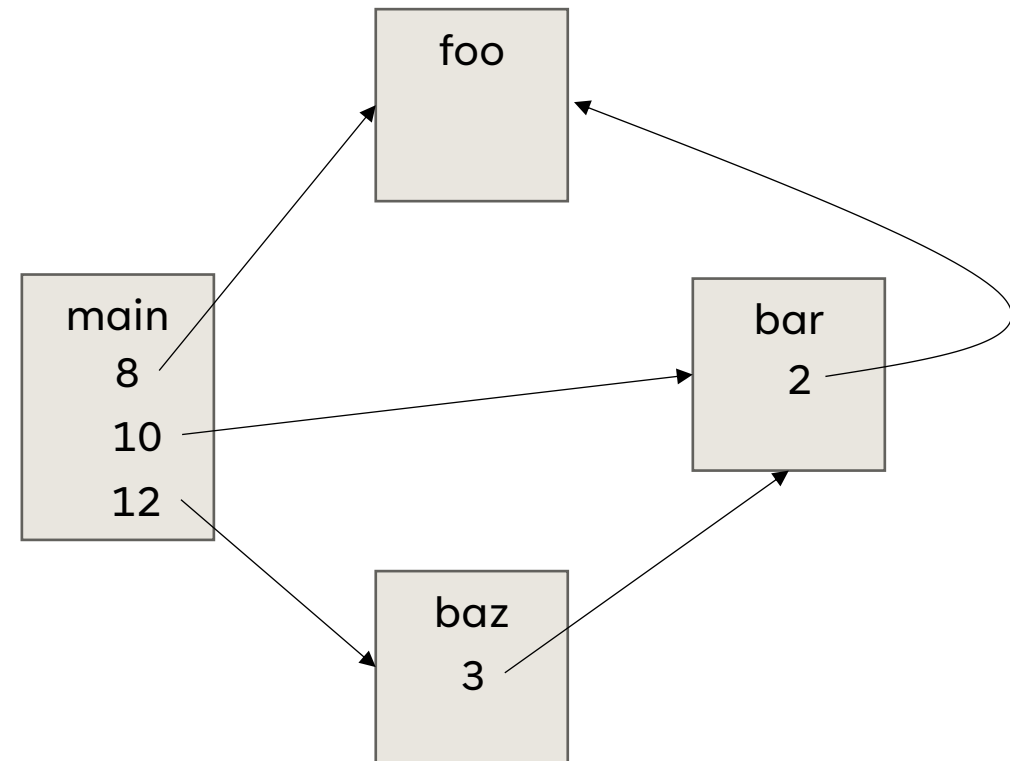
connect ~~caller functions~~ to callee functions

- Node: function **with nested call sites**
- Edge: function call

```

1 int foo(){ return 1; }
2 int bar(){ return foo() + 2; }
3 int baz(){ return bar() + 3; }
4
5 int main(int argc){
6     int a;
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13    return a / b;
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15 }

```



CALL GRAPHS

INTERPROCEDURAL ANALYSIS: ICFGs

COSTS OF ICFGs

May not be obvious what the callee is

We can separate that concern into a call graph analysis

In the case of imprecision, over-approximate behaviors

```
1 #include <dlfcn.h>
2
3 int main(int argc, char **argv) {
4     void *handle;
5     void (*fn)();
6
7     handle = dlopen (argv[1], RTLD_LAZY);
8     fn = dlsym(handle, argv[2]);
9     fn();
10 }
```

THE OTHER THING ABOUT SUPERGRAPHS

INTERPROCEDURAL ANALYSIS: ICFGs

COSTS OF ICFGs

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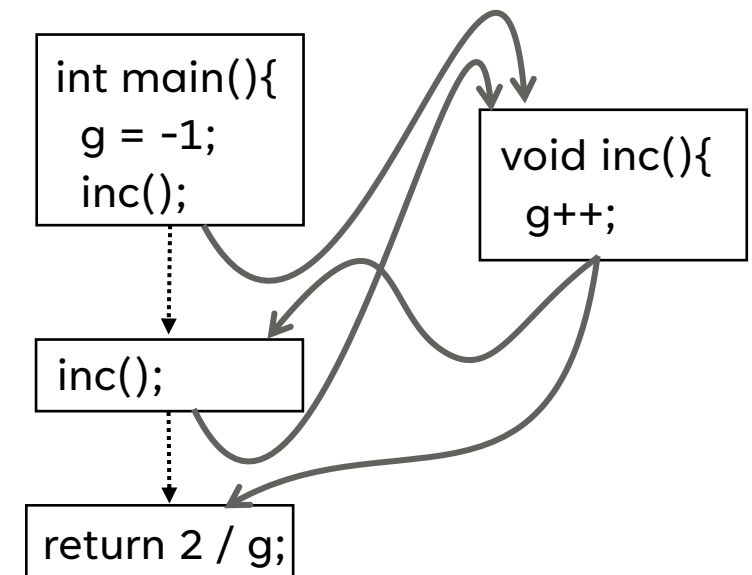
INTERPROCEDURAL ANALYSIS: ICFGs

May not be obvious what the callee is

In the case of imprecision, over-approximate behaviors

Naïvely leads to some impossible paths

```
1 int g;  
2  
3 void inc(){  
4     g++;  
5 }  
6  
7 int main(){  
8     g = -1;  
9     inc();  
10    inc();  
11    return 2 / g;  
12 }
```



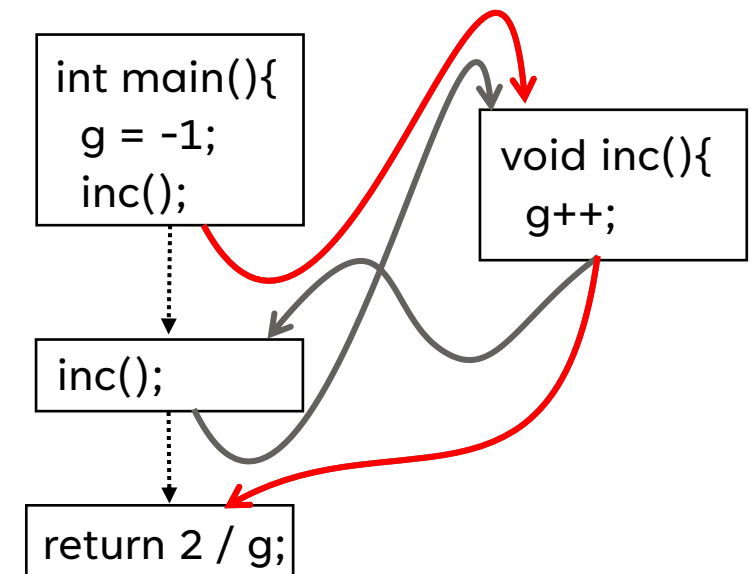
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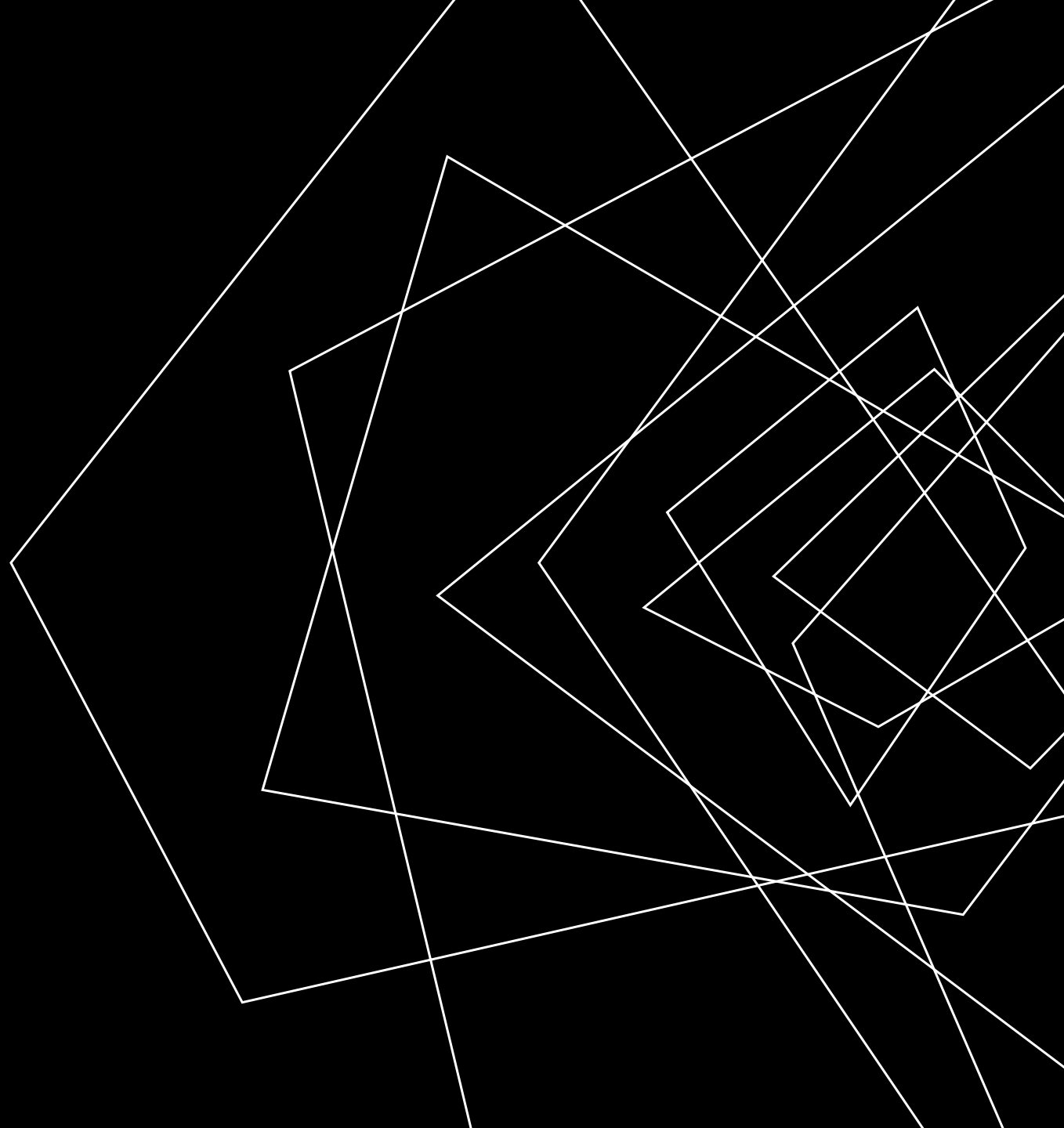
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```



LECTURE OUTLINE

- Abject Pessimism
- ICFGs
- Context-Sensitivity
- Summary Functions



(CALLING) CONTEXT SENSITIVITY

INTERPROCEDURAL ANALYSIS: ICFGs

THE PROBLEM IN THE SIMPLE SUPERGRAPH ANALYSIS

A lack of calling context (return to the wrong call site)

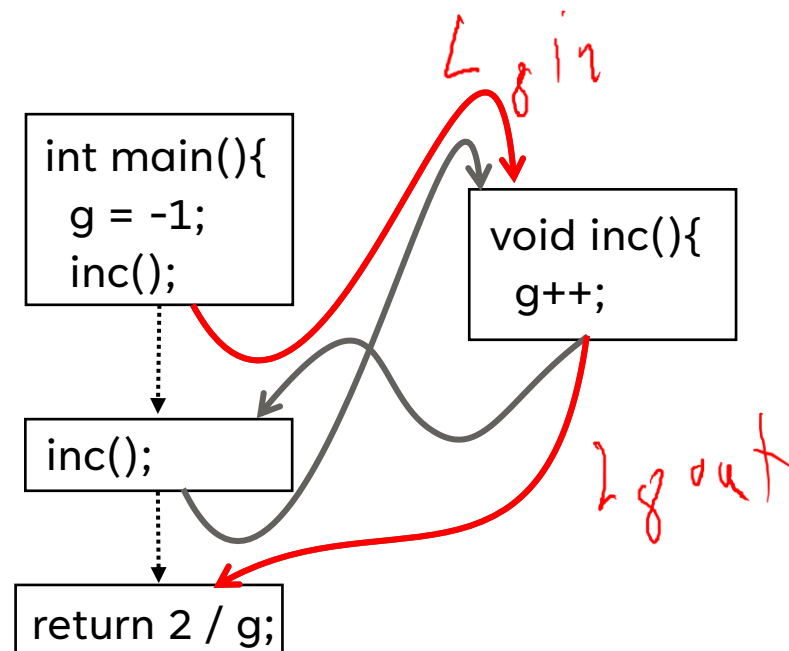
This provides another way to “tune” a flow analysis

- Flow-sensitive vs Flow-insensitive
- Context-sensitive vs Context-insensitive

*tracks some
amount of
context*

```

1 int g;
2
3 void inc(){
4 }
5
6 int main(){
7     g = -1;
8     inc();
9     inc();
10    return 2 / g;
11 }
  
```



CALL STRINGS AND K-CFA

INTERPROCEDURAL ANALYSIS: ICFGs

HOW MUCH CONTEXT TO KEEP?

Obvious problem: can't distinguish between callers (context-insensitive analysis)

Obvious solution: Call strings

Keep track of the caller 1-CFA

Obvious problem: what about the caller's caller?

Obvious solution: keep track of the caller's caller? 2-CFA

“k-CFA popularized the idea of context-sensitive flow analysis.
[...] in the OO setting, where a 1- and 2-CFA analysis is
considered heavy but certainly possible”

- Might et al, Resolving and Exploiting the k-CFA Paradox

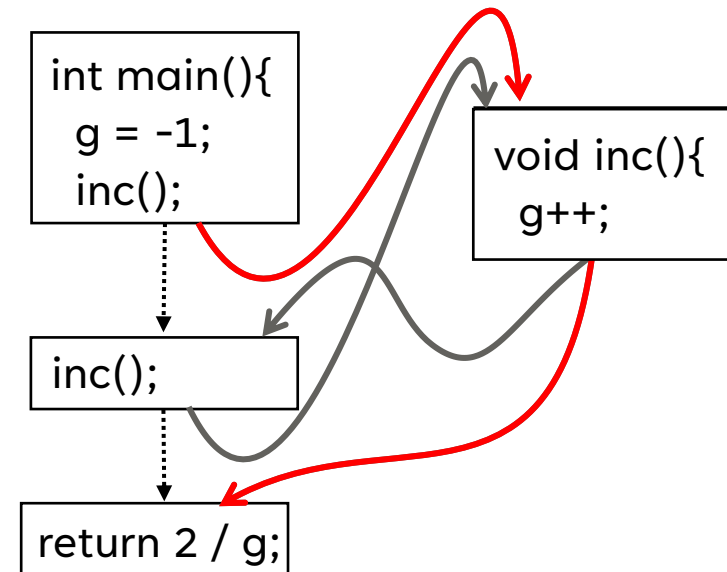
ANOTHER FORM OF CONTEXT SENSITIVITY

INTERPROCEDURAL ANALYSIS: CONTEXT-SENSITIVITY

A (PERHAPS) MORE CONCEPTUALLY STRAIGHTFORWARD APPROACH...

Rather than complicating the edges, what if we cloned the nodes

```
1 int g;  
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ANOTHER FORM OF CONTEXT SENSITIVITY

INTERPROCEDURAL ANALYSIS: CONTEXT-SENSITIVITY

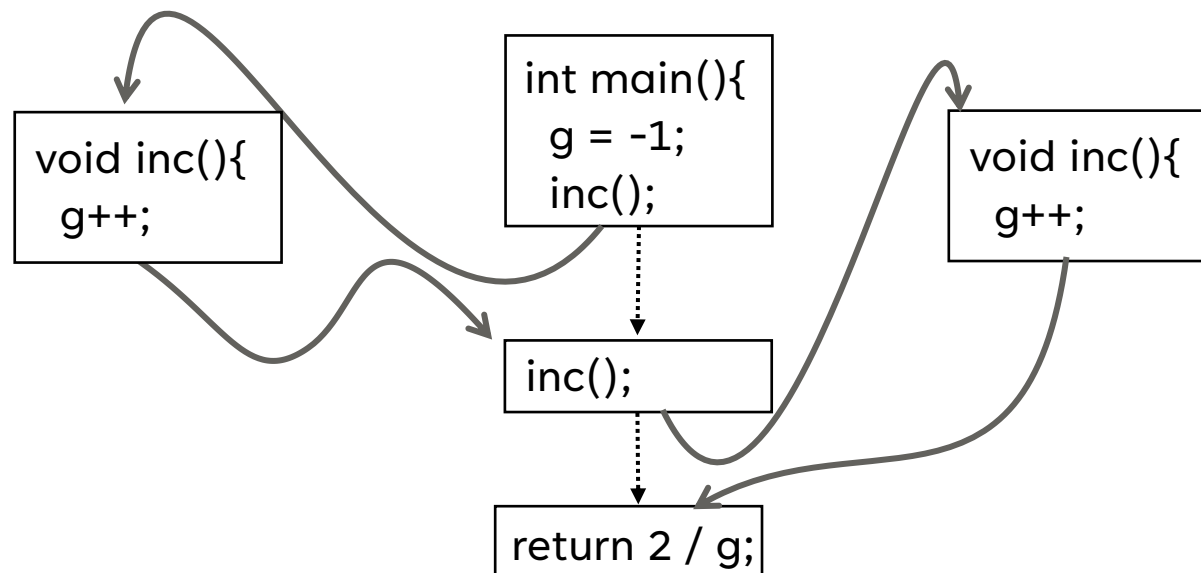
A (PERHAPS) MORE CONCEPTUALLY STRAIGHTFORWARD APPROACH...

Rather than complicating the edges, what if we cloned the nodes

“Exploded supergraph”: 1 clone per static call site

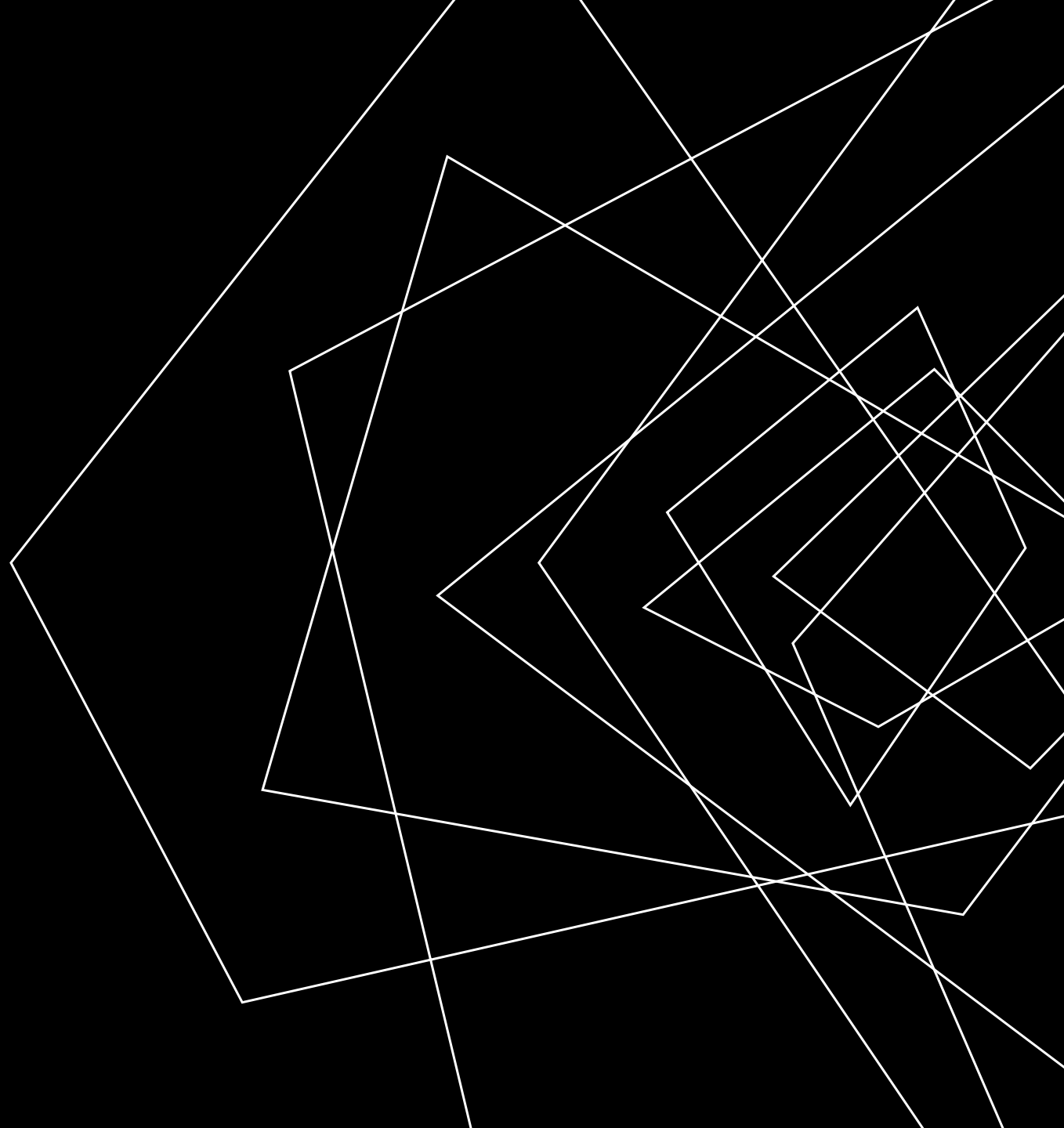
Still very much not foolproof

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1 int g;  
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SUMMARY FUNCTIONS

SUPERGRAPHS

BIG IDEA

Summarize callee analysis (rather than include it in the analysis)

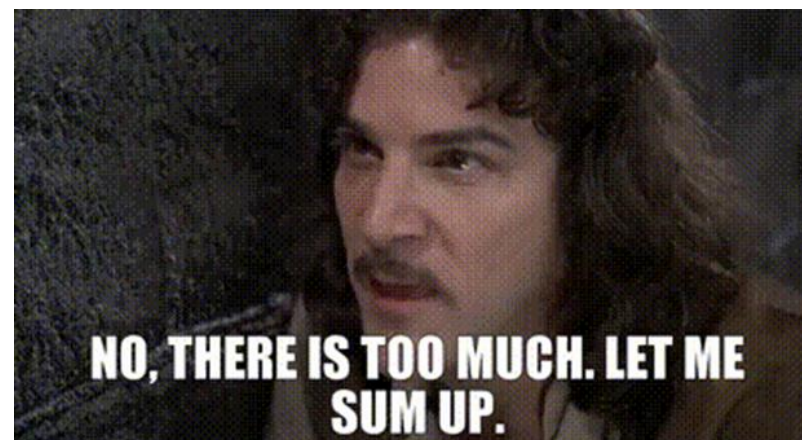
MANUAL MANIFESTATION

Ask the user to provide information

AUTOMATIC MANIFESTATION

Create a lightweight inference

- What variables are (transitively) modified as a result of a function call? GMOD
- What variables are (transitively) referenced as a result of a function call? GREF



WRAP-UP

