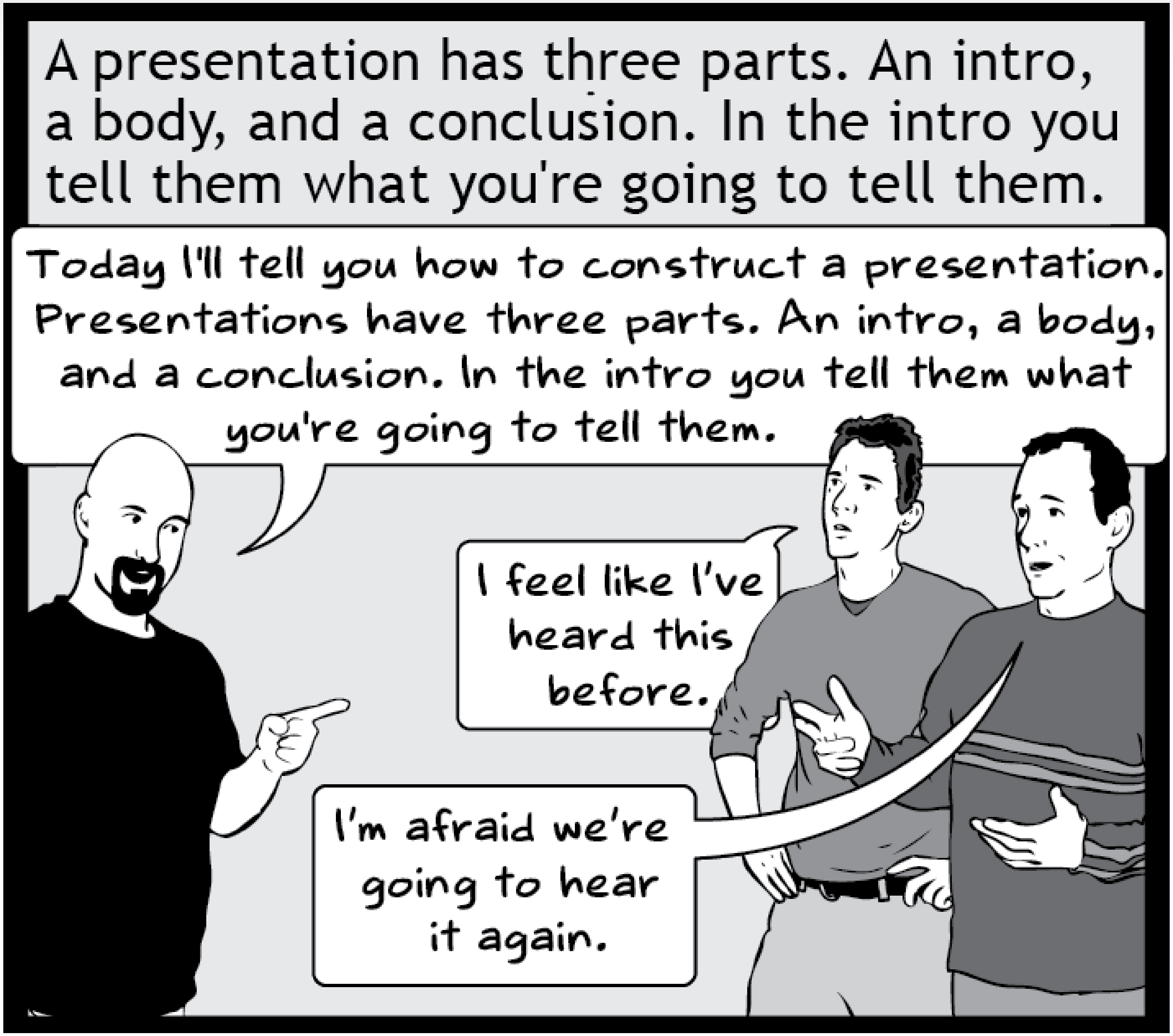
coverity®

A Synopsys Company

CS403 Guest Lecture Static Analysis

Eric Lippert


A presentation has three parts. An intro, a body, and a conclusion. In the intro you tell them what you're going to tell them.
Today I'll tell you how to construct a presentation. Presentations have three parts. An intro, a body, and a conclusion. In the intro you tell them what you're going to tell them.
I feel like I've heard this before.
I'm afraid we're going to hear it again.

Introduction

- Who is this guy? What does he do? Why is he here?
- Let's play Spot the Defect!
- How can we automate defect spotting?
- Improving the Joel Test

coverity®
A Synopsys Company

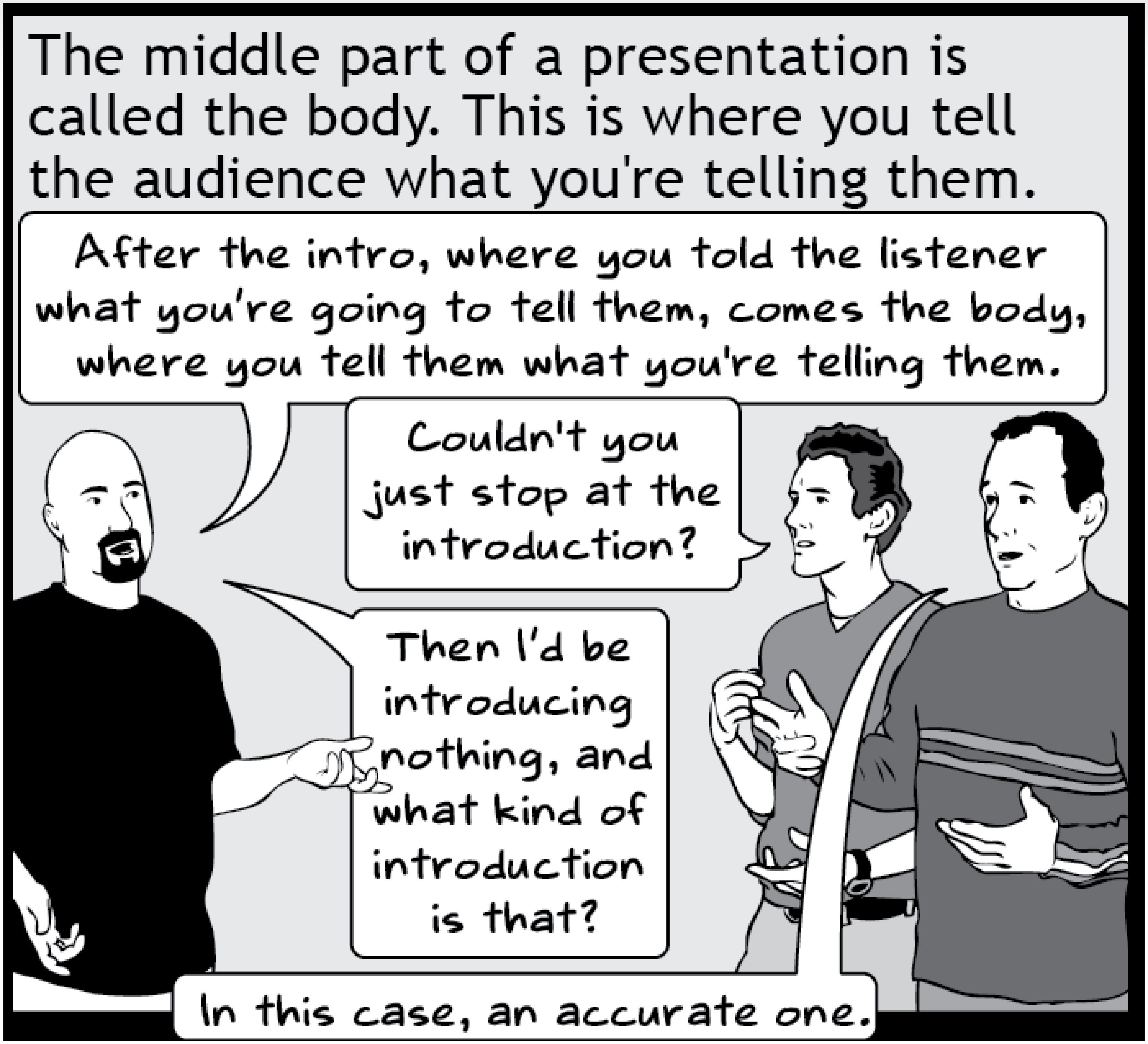
Who is this guy?

- Compiler developer / language designer at Microsoft from 1996 through 2012
  - Visual Basic, VBScript, JScript, VS Tools for Office, C♯ / Roslyn
- C# analysis architect at Coverity since January 2013
  - I will use “we” inconsistently
- I have no formal background in static analysis
  - I take an engineering rather than academic approach

About Coverity

- Founded in 2003
  - Spun off of a Stanford Ph.D. research project
  - We do static analysis of C/C++, C♯ and Java codebases looking for quality and security defects
- ~3×10^2 employees
- ~ 1.2×10^3 customers
  - Consumer electronics, telecommunications, software, aerospace, medical devices…
- ~ 5×10^9 lines of code regularly scanned
- Development offices in San Francisco, Calgary and Seattle
- Growing quickly
- Purchased by Synopsys about five minutes ago

coverity®
A Synopsys Company



coverity®
A Synopsys Company

Spot the defect, round one (C#)

```
static int M(string s, int x, int y)
{
  int z = 0;
  if (s != null && x < y || s.Length > 0)
    z = x + y - s.Length;
  return z;
}
```

Spot the defect, round one (C#)

```
static int M(string s, int x, int y)
{
  int z = 0;
  if (s != null && x < y || s.Length > 0)
```

&& is of higher precedence than ||.

If the null check results in false then the right side of the || executes, and asks for the length of a null string, which throws.

The || could be parenthesized, but frankly this code looks like it ought to be rewritten to make the intention more clear in the first place.

Coverity's static analyzer determines that there is a control flow path in which a known-to-be-null value of reference type is dereferenced.

coverity
A Synopsys Company

Life is terrible

- C was designed for a world of slow machines with tiny memory and was a massive improvement over assembly.
  - We don't live in that world anymore, but we still use C.
- Even modern type-safe, memory-safe languages like C# and Java permit the developer to write horrid bugs.
  - No one has made a pragmatic language yet that prevents mistakes.
- Cost of fixing a defect rises exponentially:
  - Fixed while typing code in: ~$1
  - Fixed after developer testing ~$10
  - Fixed after unit testing: ~$100
  - Fixed after integration testing: ~$1000
  - Fixed after shipping: **arbitrarily expensive**
- We can use software to mitigate the disasters caused by software

Enter static analysis

- **Static** analysis is any analysis of a program based solely on its source code or object code
  - **dynamic** analysis examines code as it is executing
- Compilers are static analyzers
  - Compiler errors tell you when your program is illegal, not buggy.
  - Compiler warnings tell you about potential bugs…
  - … but are typically a fast, shallow analysis
- Many static analyzers exist for many reasons
  - Bug finding
  - Refactoring
  - Documentation
  - Software metrics
  - And so on

Jargon

- True positive: a report of a genuine flaw
- True negative: a non-report of a non-flaw
- False positive: a report of a non-flaw
- False negative: a non-report of a flaw
- Sound analysis: no false positives or negatives…
- … is impossible
- Our goal is not to find *all* defects or even *most* defects
- "Thank goodness we found that before our customers did!"
- How do we do this in practice?

coverity®
A Synopsys Company

First, determine what code to analyze

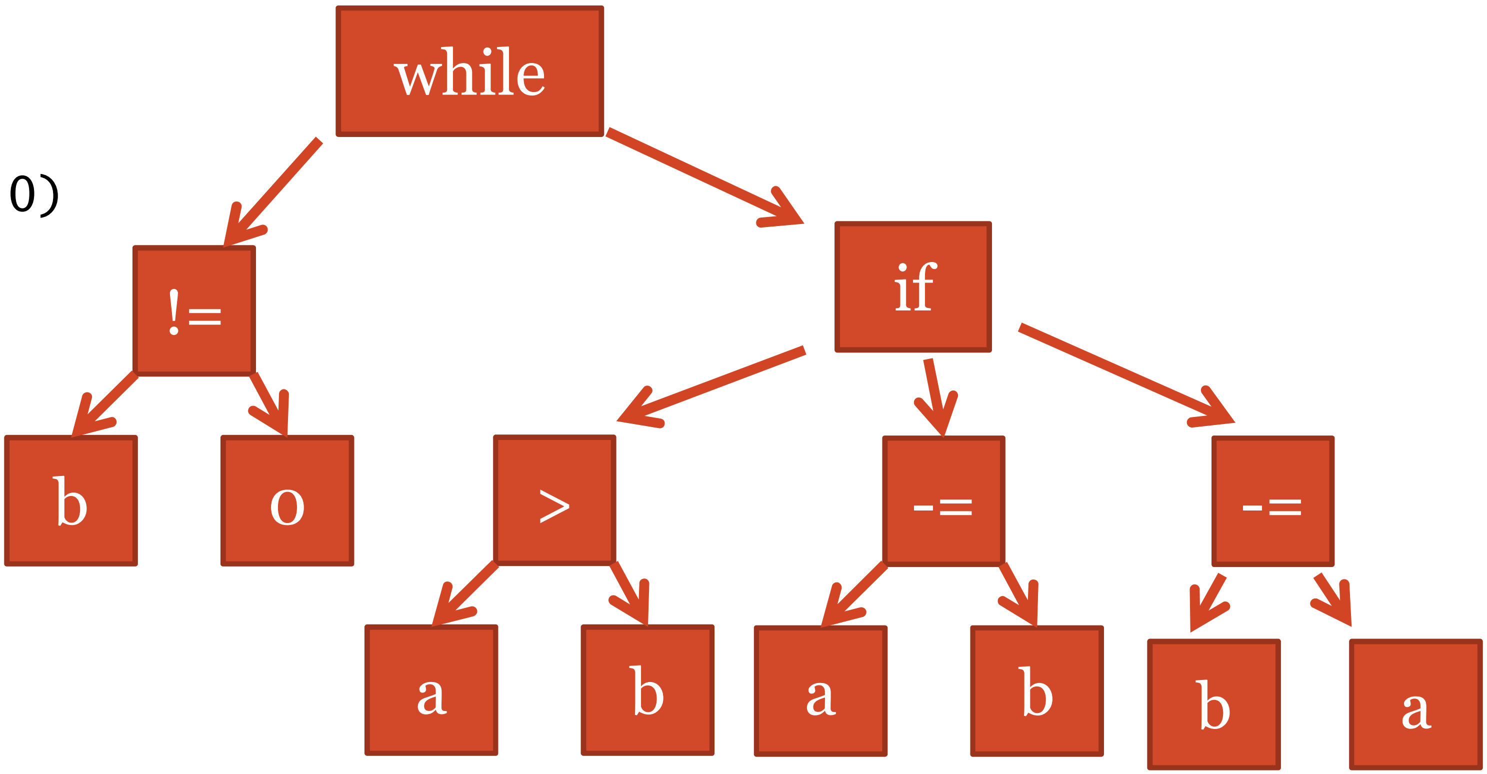
- Bad: make the customer say what they want to analyze
- Good: figure it out by watching a build
- You run a clean build of whatever you want analyzed using the build capture tool to launch the build
- The tool registers itself as a debugger and/or profiler of the build process
- Invocations of compilers are detected and logged to a temporary directory
- Now we know everything about the build.
- Capture of centralized nightly build is common, but not the only possible workflow.

coverity®
A Synopsys Company

Second, find the defects

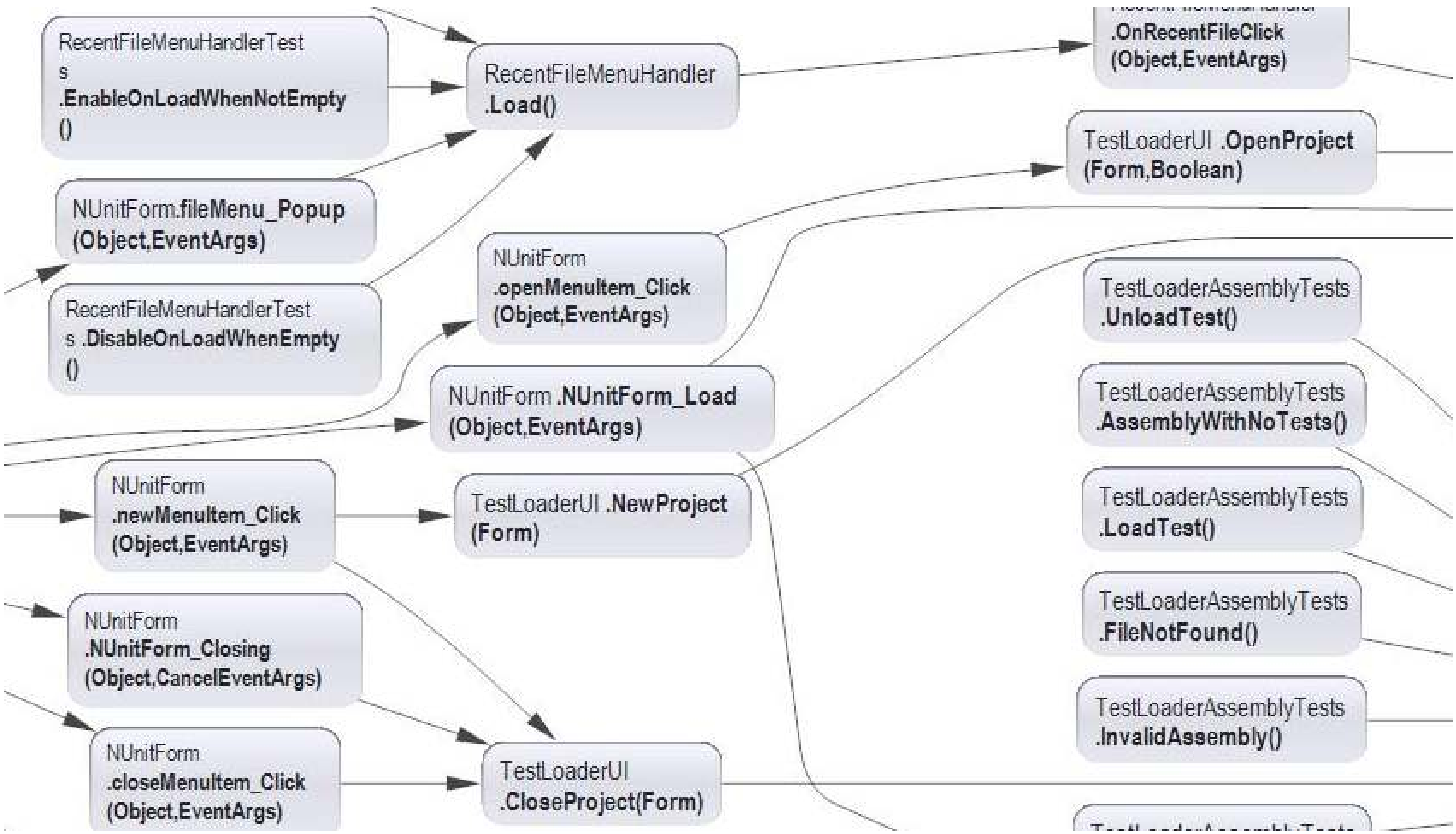
- Run all the source code through our own C / C++ / C# / Java compiler front end, as appropriate
  - Abstract syntax trees and source code persisted into a temporary directory

```
while (b != 0)
  if (a > b)
    a -= b;
  else
    b -= a;
```



coverity
A Synopsys Company

Compute call graph, topo-sort it



coverity
A Synopsys Company

Summarize the callees

- Now that we have an acyclic **inter**procedural call graph we traverse the graph from leaves (callees) to roots (callers)
- As we traverse the graph each method is *summarized*.
  - "M(string x) dereferences its argument"
  - "OpenFile() returns a newly-allocated Stream object"
  - "Foo() uses value equality on an object of type Bar five times"
  - And so on.
- Method calls can be treated as though they had the actions described in their summaries
- Now we have enough information to find defects

Analyze each method body

- "Checkers" are FSMs whose input is a sequence of AST nodes, either in syntactic order or path order.
- Always run cheap path-insensitive analysis first
  - There can be thousands of paths through a method
  - Anything that makes analysis cheaper is goodness
- If any potential defect is found the method is analyzed again, this time with **intra**procedural path-sensitivity
- **False-path-pruning** algorithms ensure defects found only on impossible paths are suppressed.
- The vast majority of lines of code are **not** defective
  - One defect per KLOC is typical

coverity® A Synopsys Company

False path pruning

- Defects found on "impossible" paths are likely false positives (and make us look dumb)
- We use many techniques to determine if a defect is on a false path.
  - Integer interval inequality
  - Nullity tracking
  - SAT / SMT solving
  - Many secret proprietary heuristic techniques
  - Coming soon: collection invariants

Third, present the defects

- Finding defects is hard
- Presenting defects so that the developer understands them well enough to fix them is even harder
  - It is easy for skeptical, overworked, defensive developers to assume a convoluted series of events that leads to a defect is impossible
- But before we get into that…

Spot the defect, round 2 (C#)

```
bool linkToDatabase =
   (attr != null && attr.i_database == null) ?
     true :
     !isMigrating;
if (linkToDatabase)
{
  Db4oDatabase db = container.Identity();
  if (db == null)
  {
    attr = null;
  }
  else if (attr.i_database == null)
  {
```

coverity®
A Synopsys Company

Forward-Null: ~800 / MLOC

1. **var_compare_op:** Comparing `attr` to null implies that `attr` might be null.

```
bool linkToDatabase = (attr != null && attr.i_database == null) ? true : !isMigrating;
```

2. Condition `linkToDatabase`, taking true branch

```
if (linkToDatabase)
{
        Db4oDatabase db = ((IInternalObjectContainer)container).Identity();
```

3. Condition `db == null`, taking false branch

```
        if (db == null)
        {
                attr = null;
        }
        else
        {
```

CID 14146 (#1 of 1): Dereference after null check (FORWARD_NULL)

4. **null_field_access:** Accessing field of null object `attr`.

```
                if (attr.i_database == null)
                {
                        attr.i_database = db;
                        if (container is LocalObjectContainer)
                        {
                                attr.i_uuid = container.GenerateTimeStampId();
                                doAddIndexEntry = true;
```

coverity® A Synopsys Company

Improving the Joel Test

- You recently learned about my buddy Joel's famous 12 point test: do you have source control, easy builds, daily builds, bug tracking, aggressive bug fixing, schedules, specifications, quiet offices, **software tools**, testers, technical interviews, ad hoc usability testing?
- That "the best tools money can buy" item is a little vague.
- Source control and bug tracking are tools but so important that they are called out as individual items.
- I want:

13. Do you use static analysis tools to find bugs during the development process?

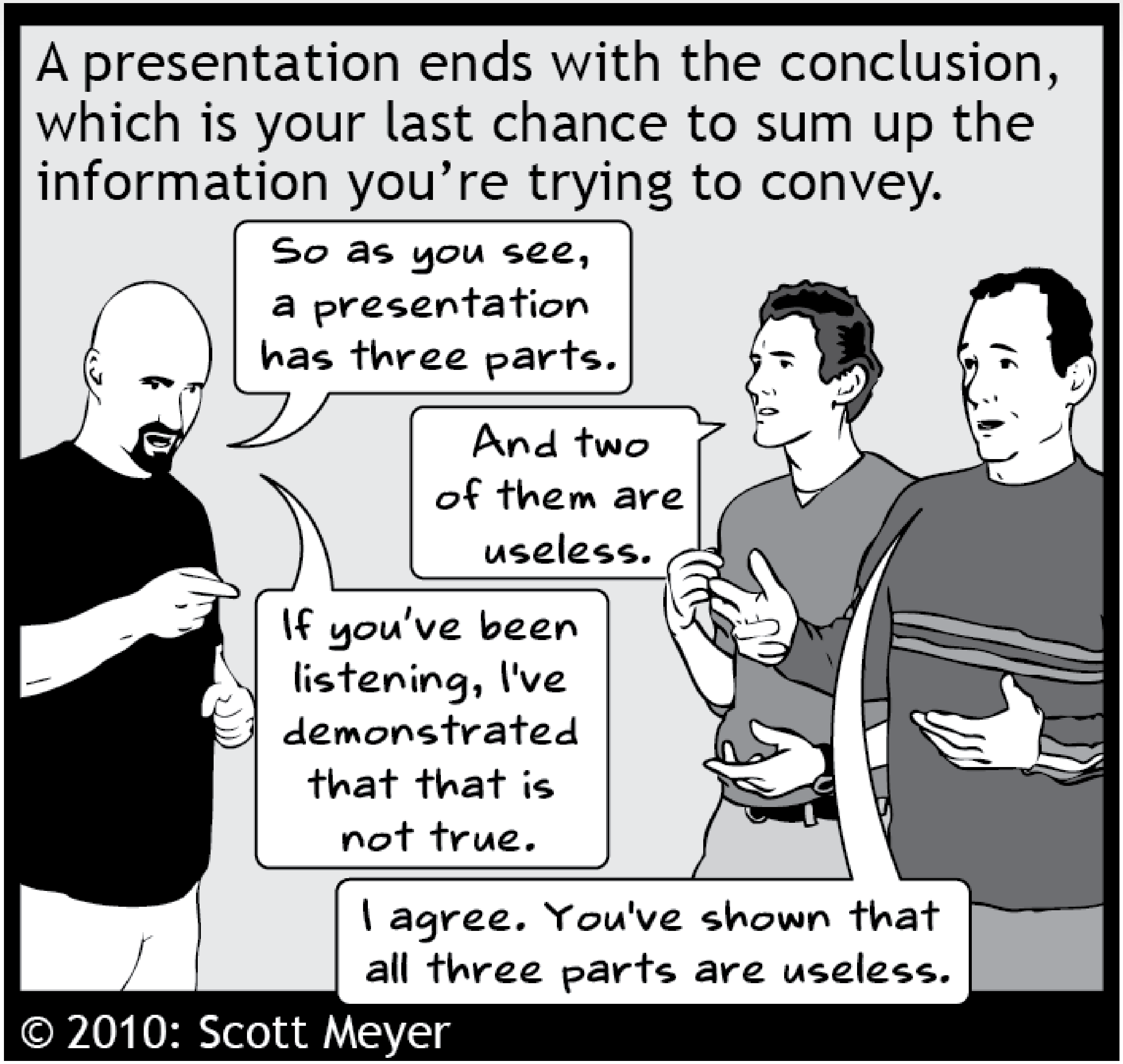
Spot the defect, round three (C#)

```
private int InternalCopyID(
  bool flipNegative, bool lenient, int id)
{
  if (flipNegative && id < 0)
  {
    id = -id;
  }
  int mapped = _mapping.MappedID(id, lenient);
  if (flipNegative && id < 0)
  {
    mapped = -mapped;
  }
  return mapped;
}
```

Dead code -- ~60 / MLOC

```
cond_at_most: Condition id < 0, taking true branch. Now the value of id is at most -1.
cond_at_least: Condition id < 0, taking false branch. Now the value of id is at least 0.
                if (flipNegative && id < 0)
                {
assignment: Assigning: id = -id.
                    id = -id;
                }
                int mapped = _mapping.MappedID(id, lenient);
at_least: At condition id < 0, the value of id must be at least 0.
dead_error_condition: The condition id < 0 cannot be true.
                if (flipNegative && id < 0)
                {
CID 14128 (#1 of 1): Logically dead code (DEADCODE)
dead_error_line: Execution cannot reach this statement mapped = -mapped;.
                    mapped = -mapped;
                }
                _target.WriteInt(mapped);
                return mapped;
            }
```

coverity
A Synopsys Company



Special thanks to Scott at BasicInstructions.net

coverity A Synopsys Company

Summing up

- Even good languages make it too easy to write bugs
- Bugs are easy to cause and hard to find, even for experts
- The earlier you find the bug, the cheaper it is to fix
- Static analysis tools do a lexical, grammatical, semantic, **inter**procedural control flow and **intra**procedural control flow analysis to find specific defect patterns…
- … and many heuristics to eliminate false positives
- Writing good defect presentations is a hard problem
- Use of static analysis tools is growing in industry, but are not yet considered must-haves
- The stuff you're learning is actually useful!

coverity®
A Synopsys Company

More information

- Learn about Coverity at **www.Coverity.com**
- Read “A Few Billion Lines Of Code Later”
- Find me on Twitter at **@ericlippert**
- Or read my C♯ blog at **www.EricLippert.com**
- Or ask me about C♯ at **www.StackOverflow.com**

coverity®

A Synopsys Company

Bonus: Round four, time permitting

```
if (defaultValue > maxValue)
  _defaultValue = maxValue;
else if (defaultValue < minValue)
  _defaultValue = minValue;
else
  _defaultValue = defaultValue;
if (value > maxValue)
  _value = maxValue;
else if (defaultValue < minValue)
  _value = minValue;
else
  _value = value;
```

coverity®
A Synopsys Company

Copy/paste error -- ~8 / MLOC

original: `defaultValue < minValue` looks like the original copy.

```
  else if (defaultValue < minValue)
  {
    _defaultValue = minValue;
  }
  else
  {
    _defaultValue = defaultValue;
  }
  _manual = manual;
  if (value > maxValue)
  {
    _value = maxValue;
  }
```

CID 19155 (#1 of 1): Copy-paste error (COPY_PASTE_ERROR)

copy_paste_error: `defaultValue` in `defaultValue < minValue` looks like a copy-paste error.

Should it say `value` instead?

```
  else if (defaultValue < minValue)
  {
    _value = minValue;
  }
  else
  {
    _value = value;
  }
}
```

coverity®
A Synopsys Company