Buffer Overrun Detection via Static Analysis

Vinod Ganapathy
University of Wisconsin

Introduction

- Buffer Overruns:
  - Easily exploitable class of vulnerabilities
  - Large number of systems are vulnerable
- Inadequate bounds checking
- CERT:
  - 9 out of 19 vulnerabilities since July '02
  - BIND, Kerberos, SSH, OpenSSL

WiSA BO-Tool

- Addresses the Buffer Overrun Problem
- Features:
  - *Statically* analyzes code for vulnerabilities
    - Vulnerabilities can be caught before deployment
  - Uses *points-to* information
    - Complicated dependencies can be tracked
  - Is designed to *scale* to large programs

Overview of Talk

- Related Work
- Tool Architecture
  - Constraint Generation
  - Constraint Solving
- Results
- Goals

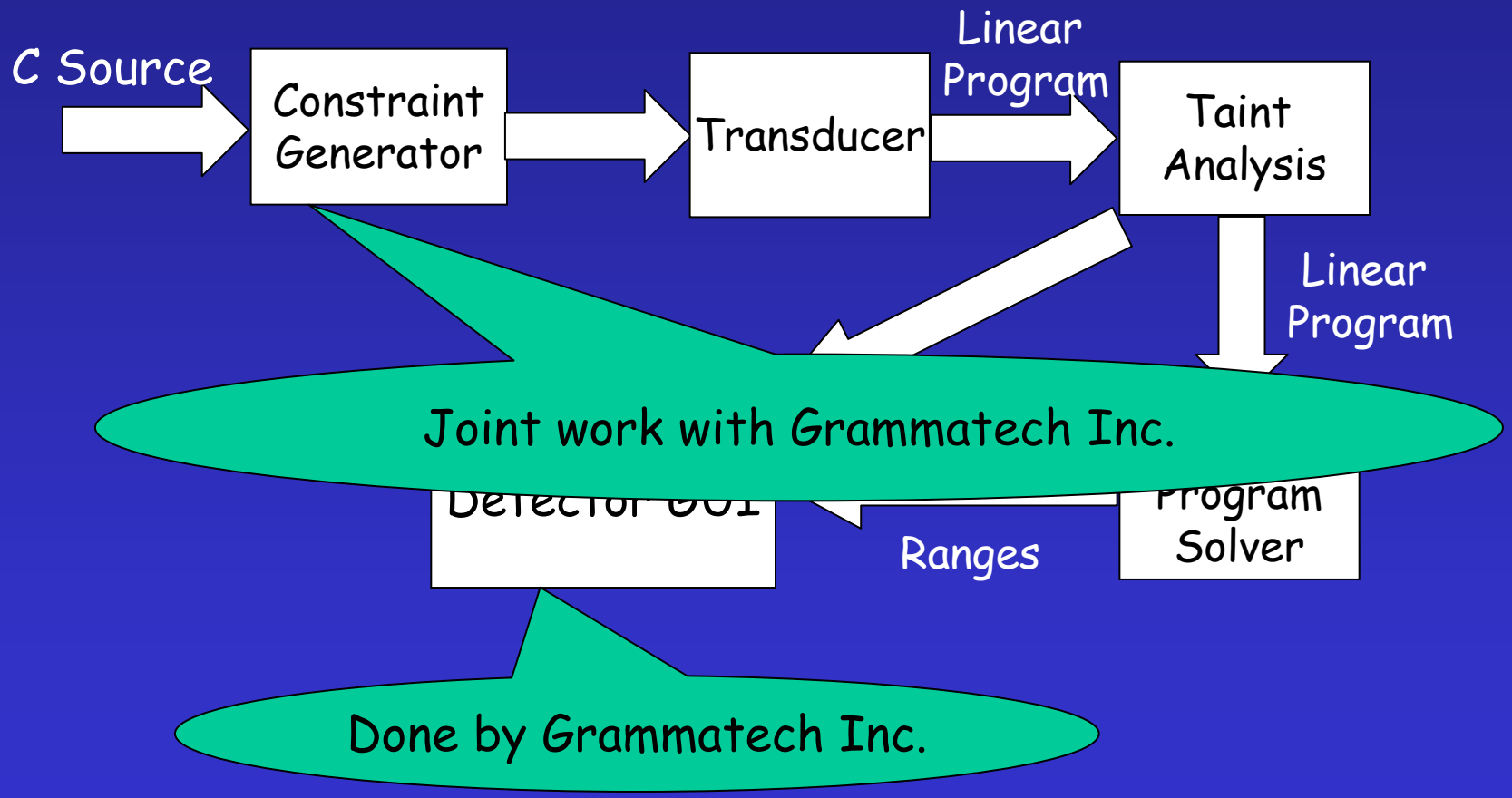
Related Work

- 'Fat' Pointers:
  - Static + Dynamic Analysis
  - SafeC (Wisconsin: Austin et.al.)
  - CCured (Berkeley: Necula et.al.)
- StackGuard:
  - Place 'canary' on the stack
  - Dynamic Analysis: High runtime overhead

Related Work

- BOON: (Berkeley: Wagner et.al.)
  - Closest relative to our work
  - Static Analysis
  - But, no points-to information used
  - Yet, good results

BO-Tool Architecture



Enhancements since July'02

- Taint Analysis and Pre-solve
- Ability to handle all kinds of Linear Programs
- Detector GUI with trace-back
- Other kinds of solvers

Constraint Generation

- Constraint Generator + Transducer
- Input: C source code
- Output: Linear Program
- Basic Idea:
  - Treat buffers as abstract data types
  - Reflect changes in buffers by changing associated buffer variables

Constraint Generation

- Four variables for each string buffer

  `buf_len_max, buf_len_min`

  `buf_alloc_max, buf_alloc_min`

- Operations on a buffer

  `strcpy(target, source)`

  `target_len_max >= source_len_max`

  `target_len_min <= source_len_min`

Constraint Generation

- Source code fed to Codesurfer
- Analysis is done by Codesurfer
- Various options available for program analysis

Constraint Generation

- Options Available
  - *Flow Sensitive* Analysis:
    - Respect Program order
  - *Flow Insensitive* Analysis:
    - Do not respect program order
  - *Context-Sensitive* modeling of functions:
    - Differentiate Information between call-sites
  - *Context-Insensitive* modeling of functions:
    - Merge Information across call-sites

Constraint Generation

- Current Model:
  - Flow Insensitive Analysis
  - Context-sensitive modeling for some library functions
  - Context-insensitive for the rest
- Pros and Cons:
  - ☺ Faster and Easier Analysis
  - ☺ Smaller space requirements
  - ☹ Lower Precision => Higher False Positives

The Solver

- Abstract Problem:
  - Given a set of constraints on `min` and `max` variables
  - Get tightest possible fit satisfying the constraints
- Our approach:
  - Model and solve as a linear program

Why Linear Programming?

- Rich literature available
  - Solutions to problems readily available
- Commercial solvers available
  - No need to build our own solver
  - Highly optimized code => faster solves
- Known to scale to large problem sizes
  - One of our initial goals

The Solver

- Consists of various phases:
  - Taint Analysis
  - Pre-solve value inference
    - Obtain solution based on constraint analysis
    - a >= 4 and a >= 3 imply a >= 4
    - Mainly an optimization to speed up LP solver
  - Linear Program Solver

Taint Analysis

- Objective: serve as a pre-solve step
- Search constraints for variables that
  - Are entered by the user:
    - `sprintf(buf, "%s", argv[1])`
  - Are un-initialized (incomplete modeling)
    - e.g. Library function that has not been modeled
- Helps reduce the Linear Program size

Linear Programming

- A set of constraints C
- Subject to: An objective function F
- Example:

```
Maximize: x
Subject to:
   x <= 3
```

Linear Program Solver

- In our case:
  - Constraints are available
  - Goal: Obtain values for buffer bounds
- Modeling as a Linear Program

Minimize: max variable

Subject to:

Set of Constraints

Least Upper Bound

And

Maximize: min variable

Subject to:

Set of Constraints

Greatest Lower Bound

Linear Program Solver

- The Solution to an LP can be:
  - Optimal
  - Unbounded
  - Infeasible (constraint set is infeasible)

Linear Program Solver

- Optimal:
  - All constraints are satisfied
  - Objective function is optimized
- Value of buffer variable = solution
- Example:

```
Minimize: buf_len_max
buf_len_max >= 3
```

Linear Program Solver

- Unbounded
  - Infinitely many solutions exist
- Example:

```
Minimize: var_max
var_max - var2_max >= 4
```

- Solution: set variable value to ∞/-∞

Linear Program Solver

- Infeasible:
  - No solution exists => Bad news for us
- Example:

```
Minimize: var
var >= 5
var <= 3
```

- Does this case arise?
  - Yes! And very often!

Infeasible LPs

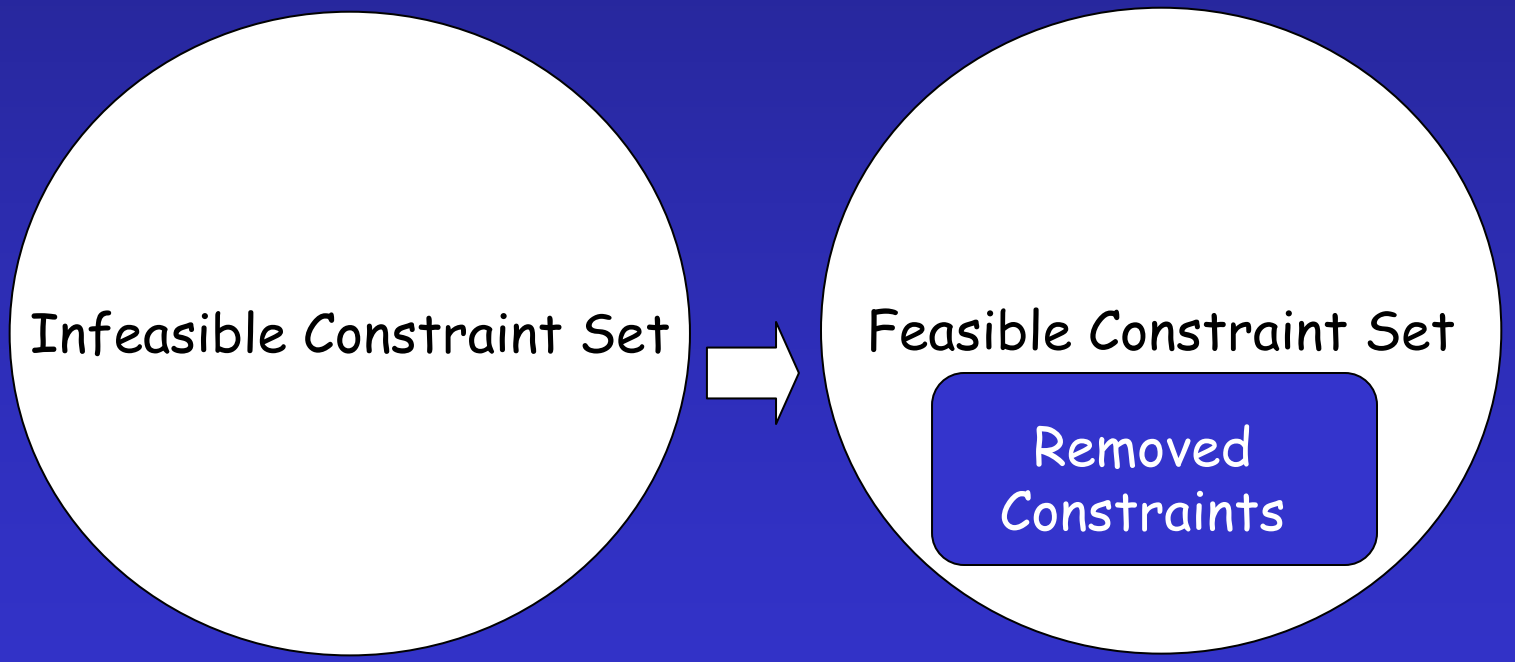
- Common Program construct:

  `i=i+1` -> loop iteration, pointer arithmetic

- Convert this to an LP constraint:

```
i'_max >= i_max + 1
i_max  >= i'_max
i'_min <= i_min + 1
i_min  <= i'_min
```

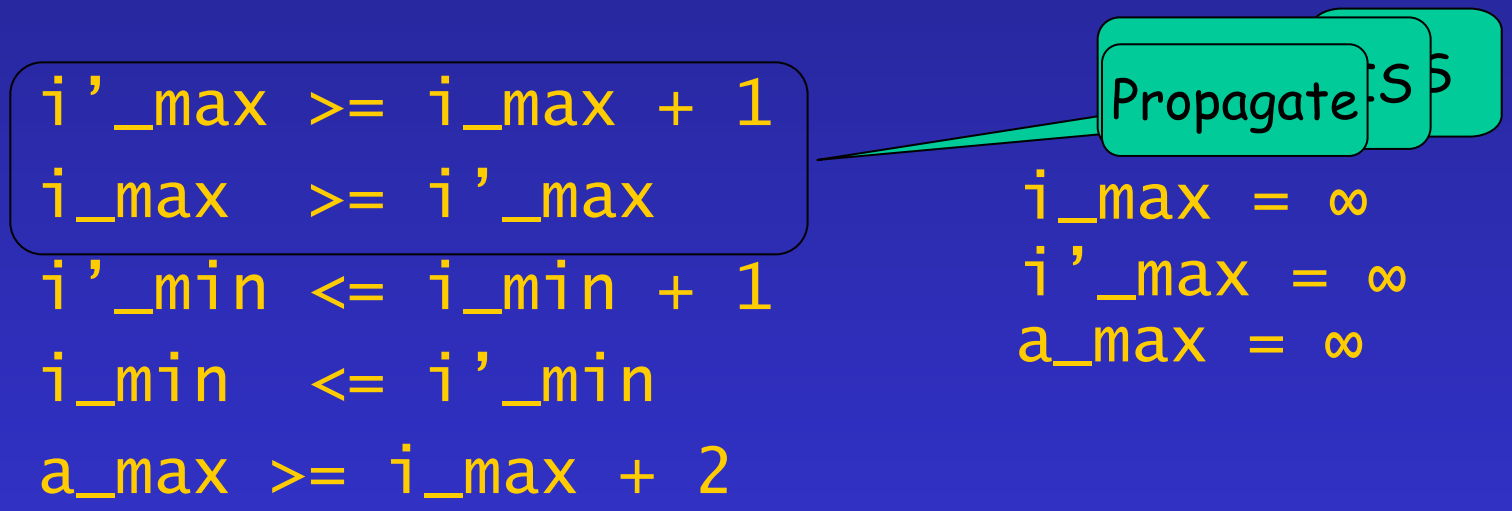
Solving Infeasible LPs



Solving Infeasible LPs

- Optimization literature to the rescue
- Problem of IIS detection
  - IIS = Irreducibly Inconsistent Set
  - Smallest set of constraints such that
    - The constraint set is infeasible
    - Any subset of the constraint set is feasible
- Algorithms available to identify IISs

Solving Infeasible LPs



Solving Infeasible LPs

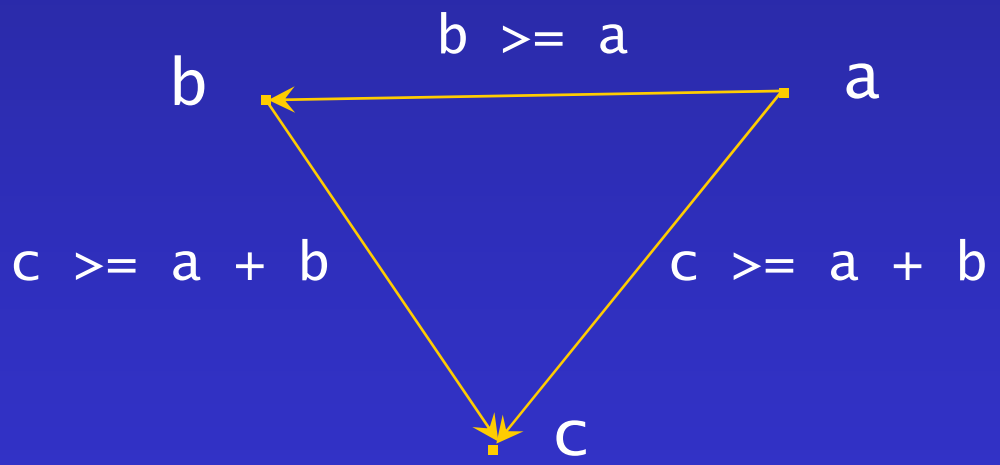
- Heuristic:
  - Identify IISs
  - Set variable values to ∞/-∞
  - Ripple effect through constraint set
- Investigation underway (with Michael Ferris)
  - How effective is this heuristic?
  - Do we set more variables to ∞/-∞ than required?

Other kinds of Solvers

- Hierarchical Solver
- Draw constraint dependency graph
- Identify SCCs
- Solve each SCC
- Propagate values

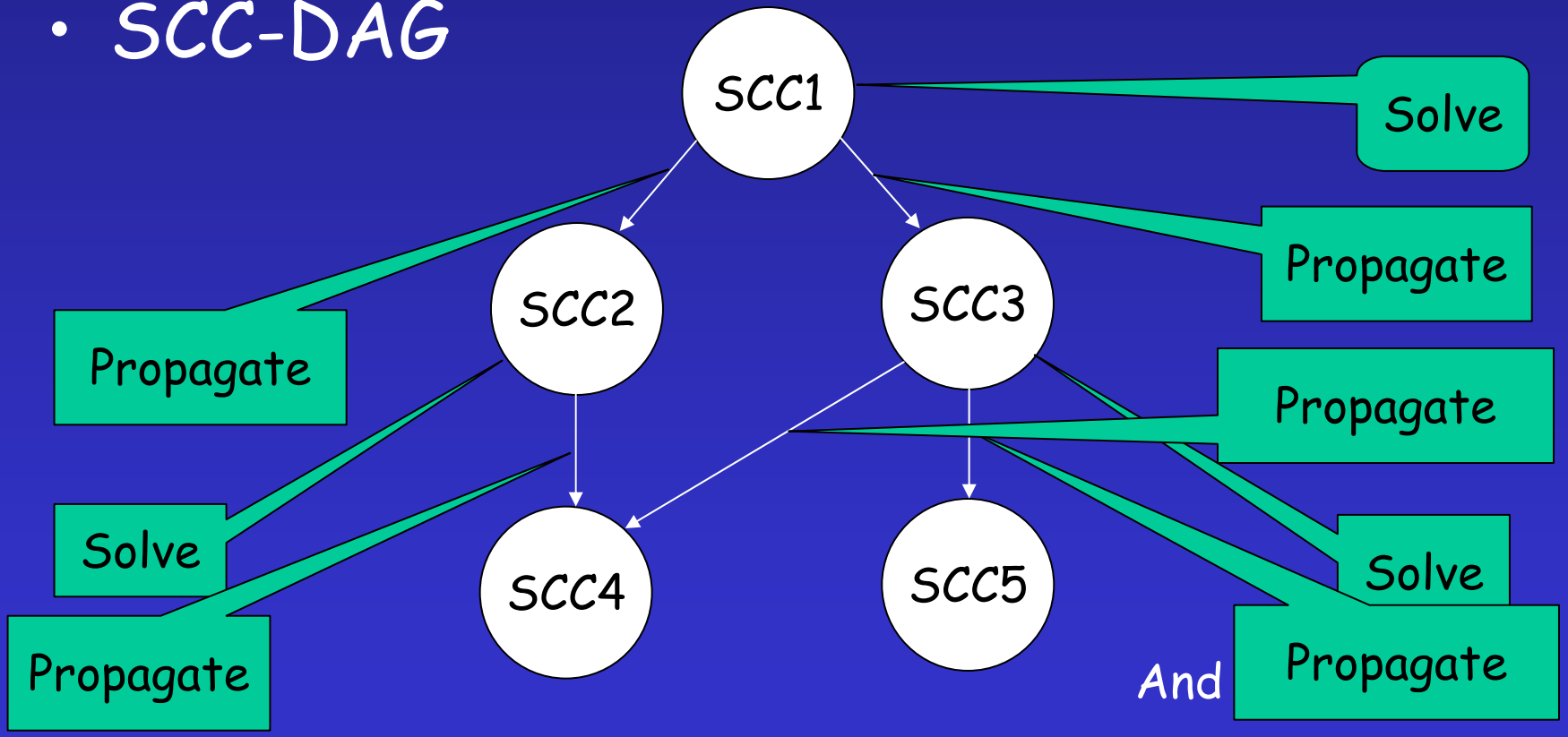
Dependency Graph

```
c >= a + b, b >= a, a >= 2
```



Hierarchical Solver

- SCC-DAG

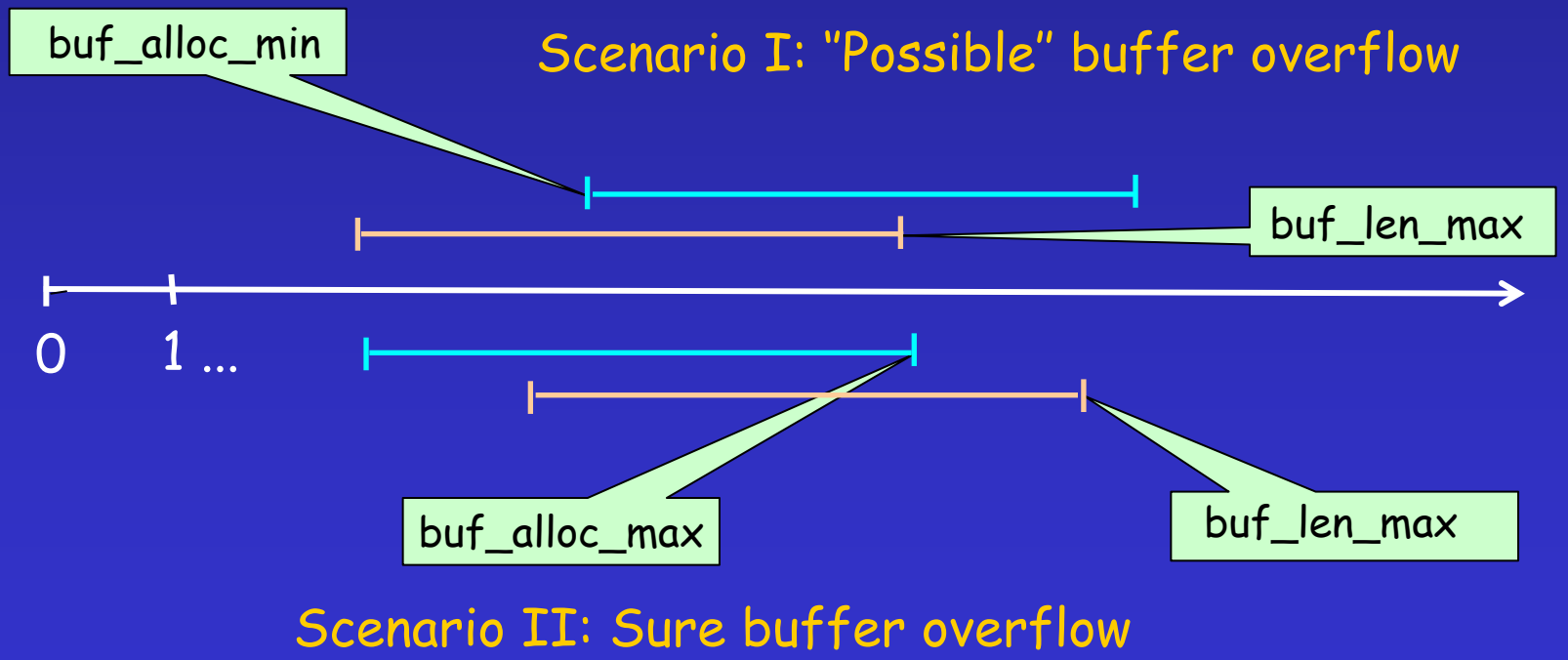


Hierarchical Solver

- Big LP broken down into smaller ones
- Can use different solvers for different SCCs
- Can solve in parallel (?)
- Status:
  - Most of the Infrastructure in place
  - To test on benchmarks

Detector: Basic Idea

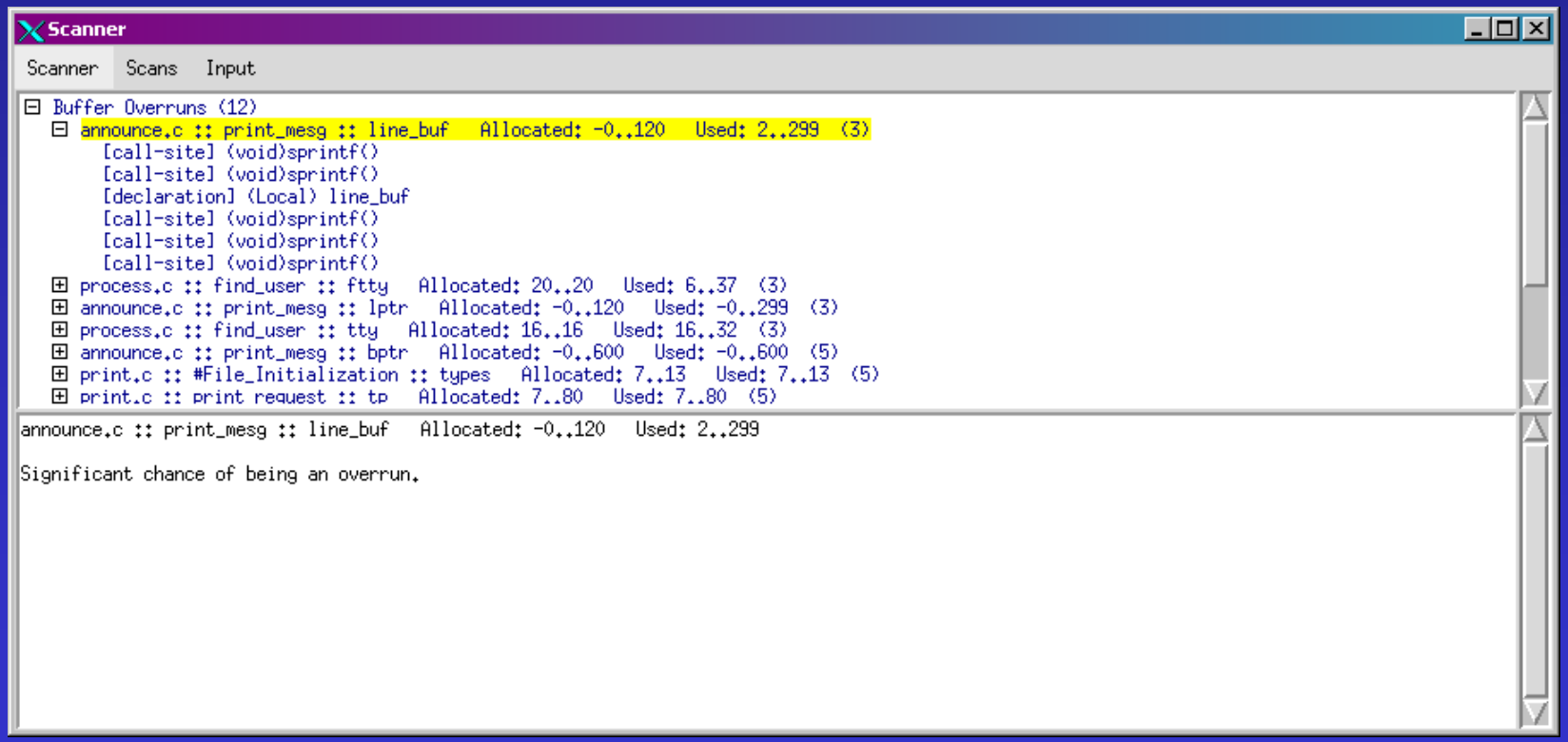
- Takes values from the LP solver
- Detects overruns based on the values



Detector Front End

- GUI built at Grammatech Inc.
- Allows trace-back:
  - Click on warning
  - Get to offending line on source code
  - Constraints also available for the more informed debugger
- Currently compiled for Linux

Detector Front End



Results

- 3 Benchmarks:
  - BSD Talk Daemon-4.2 (1000 lines)
  - WuFTP Daemon-2.5.0 (17000 lines)
  - Sendmail-8.7.6 (40000 lines)
- WuFTP Daemon: CERT-1999-13
- Sendmail-8.7.6: 1 known bug (BOON)
- Talk Daemon: ??

Results: Talk Daemon

- line_buf: [120..120] [2..299]
- Offending source code:

```
sprintf(line_buf[i], "…", var1, var2)
```

Could be as large as 256 bytes

- `snprintf` will solve the problem

Results: WuFTP Daemon

- `strcat(mapped_path, dir)`
- `mapped_path`: global array: 4096
- `dir`: there is a path to user input
- Result:

  `mapped_path` : [4096..4096] [-∞,∞]

Results: Sendmail

- Unreported overrun: caught by BOON
- Off by one bug:
  - BOON gets it as:
    - `dfname`: [20..20] [-∞..257]
  - We get it as:
    - `dfname`: [20..20] [-∞..∞]

Current Status

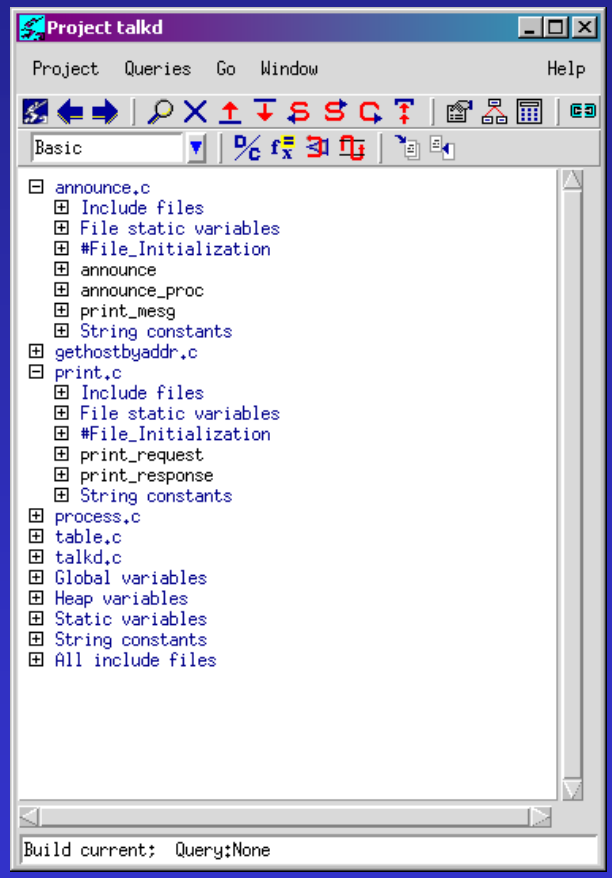
- Alpha version ready and working
- Acceptably quick:
  - Sendmail ~2 hours
  - Wuftpd, TalkD < 5 minutes
- User friendly GUI for trace-back

Next in line…

- The challenge: BIND ~50000 lines
  - Highly vulnerable
  - 4 CERT advisories in 2 years
- Hierarchical Solver results
- Context Sensitivity through summary functions
- Timeline: completion by mid-April

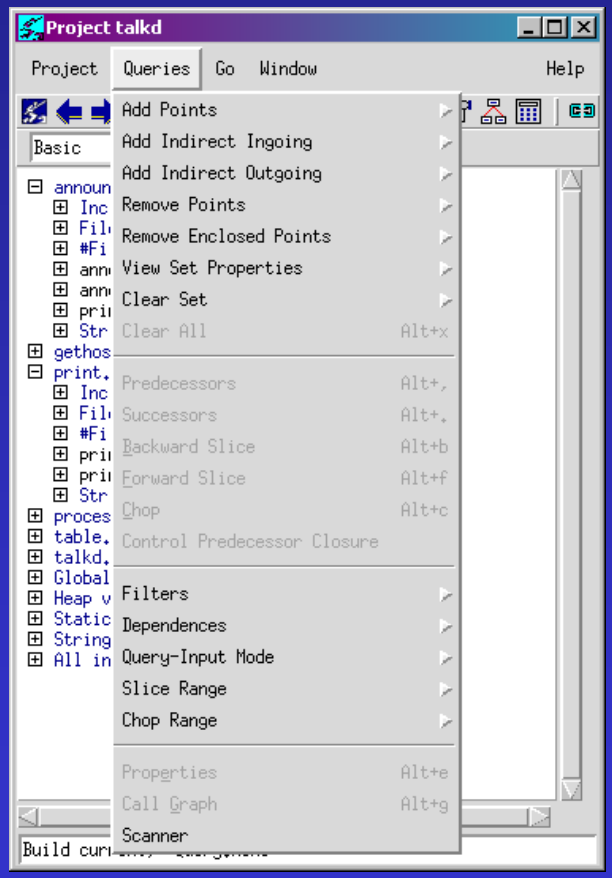
Tool Demo: TalkD

Step 1: Build the source code using Codesurfer



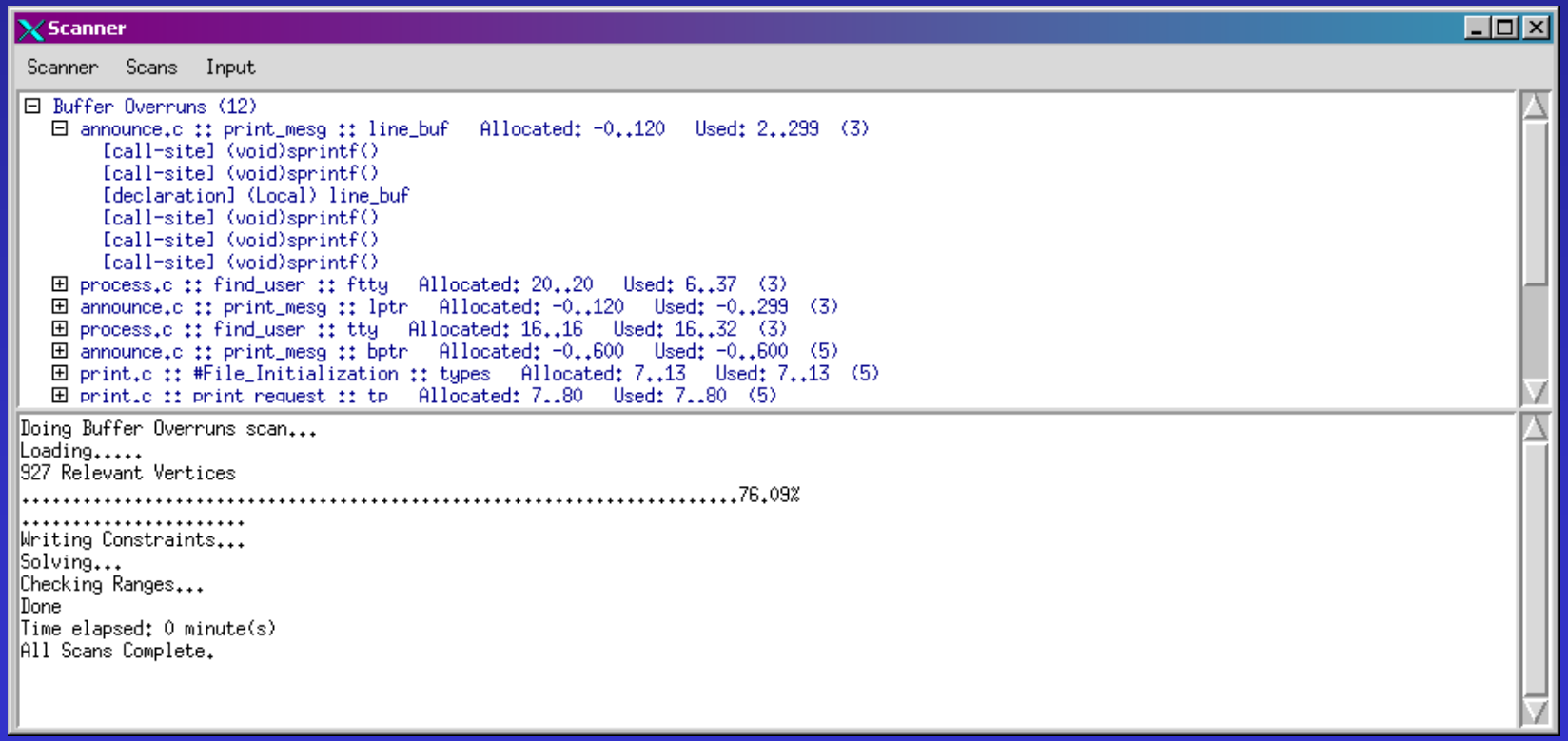
Tool Demo: TalkD

Step 2: Invoke the Buffer Overrun Analyzer

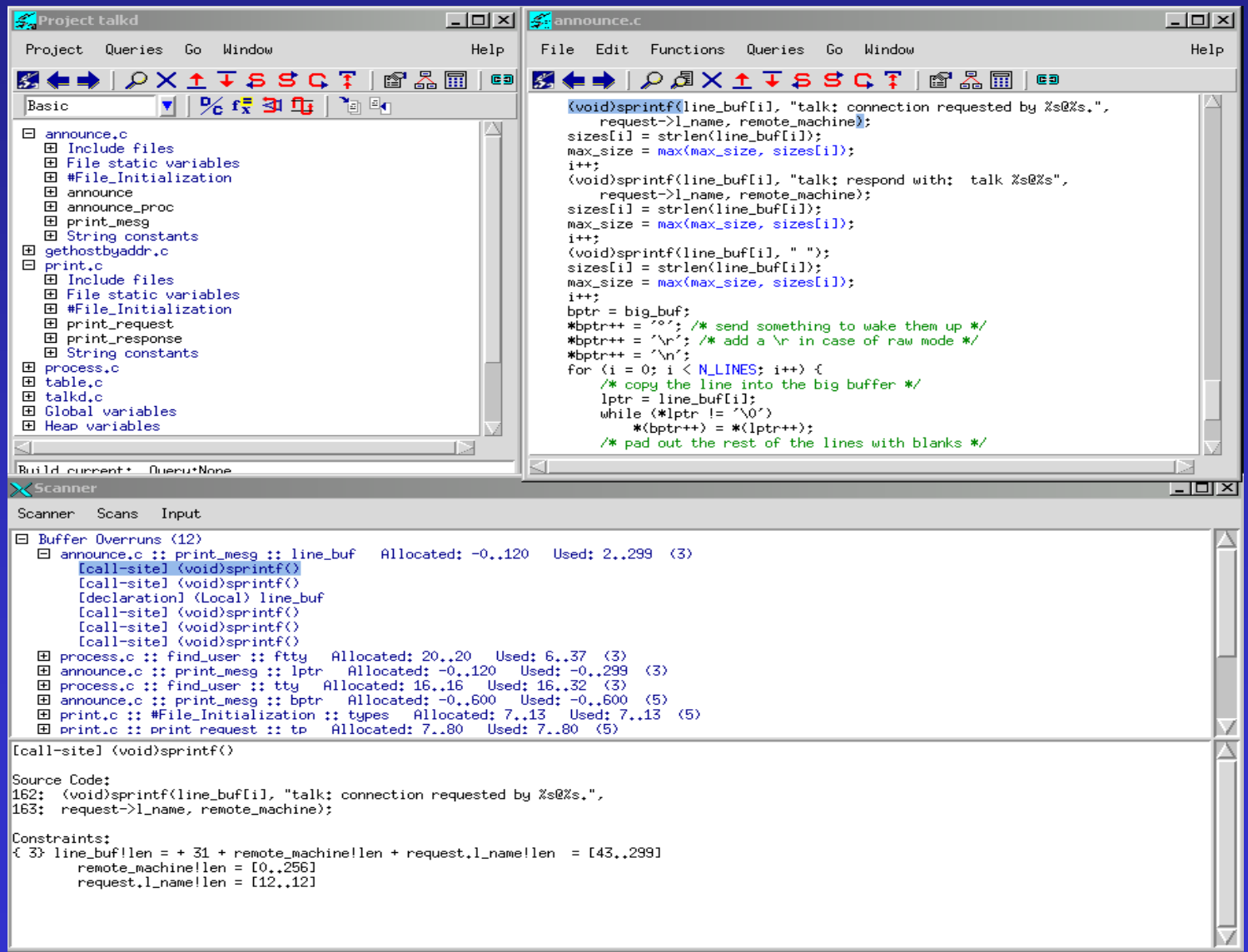


Tool Demo: TalkD

Step 3: Follow the warnings to source code lines



Tool Demo: TalkD



Thank You!

Questions?