Cracking Sendmail crackaddr
Still a challenge for automated program analysis?

Name Lastname < name@mail.org > ()()()()()()()()() ... ()()()

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Sendmail crackaddr Bug

Discovered 2003 by Mark Dowd
Buffer overflow in an email address parsing function of Sendmail. Consists of a parsing loop using a state machine. 
\sim500\ LOC
Sendmail crackaddr Bug

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**Bounty for Static Analyzers since 2011 by Halvar Flake**

Halvar extracted a smaller version of the bug as an example of a hard problem for static analyzers. 
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Sendmail crackaddr Bug

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Bounty for Static Analyzers since 2011 by Halvar Flake
Halvar extracted a smaller version of the bug as an example of a hard problem for static analyzers. ~50 LOC

Since then . . .
Various talks at security conferences and a paper presenting a static analysis of the example. The solutions however required manual specification of the loop invariant.
Halvar likes to challenge people!

Halvar gave us the challenge some years ago: “The tool should automatically (i.e. without hints provided by the user) show that the vulnerable version has a bug and the fixed version is safe.”

We were sure our analyzer could not yet handle it so did not look into it.

Last year we gave it a try and it suddenly worked :).
Let’s see the bug details ...
Sendmail Bug Code

```c
#define BUFFERSIZE 200
#define TRUE 1
#define FALSE 0

int copy_it (char *input, unsigned int length) {
    char c, localbuf[BUFFERSIZE];
    unsigned int upperlimit = BUFFERSIZE - 10;
    unsigned int quotation = roundquote = FALSE;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if ((c == '<') && (!quotation)) {
            quotation = TRUE; upperlimit--;
        }
        if ((c == '>') && (quotation)) {
            quotation = FALSE; upperlimit++;
        }
        if ((c == '(') && (!quotation) && !roundquote) {
            roundquote = TRUE; upperlimit--; // decrementation was missing in bug
        }
        if ((c == ')') && (!quotation) && roundquote) {
            roundquote = FALSE; upperlimit++;
        }
        // If there is sufficient space in the buffer, write the character.
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (roundquote) {
        localbuf[outputIndex] = '>'; outputIndex++;
    }
    if (quotation) {
        localbuf[outputIndex] = '>'; outputIndex++;
    }
}
```
We need to verify that \( \text{outputIndex} < \text{upperlimit} < \text{BUFFERSIZE} \) always holds in the good version.

In the bad version, \( \text{upperlimit} \) can be steadily incremented and a write outside of the stack allocated buffer can be triggered.
Sendmail Bug Analysis

Why are these 50 LOC hard to analyze?

• each iteration reads/writes one character; 201 loop iterations to trigger the bug
• paths through the loop dependent on the input: () < > combined with the last if-condition; 10 different paths
• a naïve state space exploration in worst case would need to visit around $2 \times 5^{201} \approx 2^{664}$ paths to find the bug!
• to naïvely prove the absence of the bug we would need to test all the possible input strings e.g. with lengths from 0 to $65535 = \text{UINT\_MAX}$; around $10^{65535} \approx 2^{217702}$ paths that need to be tested!
Why are these 50 LOC hard to analyze?

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Sendmail Bug Analysis

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  \( 2 \times 5^{201} \approx 2^{664} \) paths to find the bug!
- to naïvely prove the absence of the bug we would need to test all the possible input strings
e.g. with lengths from 0 to 65535 = UINT_MAX
  \( \leadsto \) around \( 10^{65535} \approx 2^{217702} \) paths that need to be tested!
Sendmail Bug Analysis

On the other hand . . . !

- finding the bug requires just finding 1 of the faulty paths!
- smarter tools combine many paths together and reason about all of them at once (abstraction)!

But unfortunately:
- abstraction might introduce imprecision and false positives;
- the non-vulnerable version is flagged as vulnerable, too, by an imprecise analyzer
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Sendmail Bug Analysis

On the other hand . . . !

• finding the bug requires just finding 1 of the faulty paths!
• smarter tools combine many paths together and reason about all of them at once (abstraction)!

But unfortunately

• abstraction might introduce imprecision and false positives
• \(\sim\) the non-vulnerable version is flagged as vulnerable, too, by an imprecise analyzer
Let’s introduce one abstraction technique in more detail ...
Abstract Interpretation Primer

Static program analysis using abstract interpretation

- use abstract domains to over-approximate concrete states
- abstract transformers simulate the concrete program semantics on the abstract state
- perform a fixpoint computation to infer invariants for each program point
- merge over all paths over-approximates all possible program executions (soundness)
- precision depends on the abstraction (completeness)
- for termination widening is necessary (introduces imprecision)
Some examples of concrete values and their abstractions ...
Sets of Concrete Values and their Abstractions

Concrete Points

$\pm x = c$

Constraints:

$x = 2 \land y = 6$
$\lor x = 3 \land y = 5$
$\lor x = 3 \land y = 7$
$\lor x = 3 \land y = 8$
$\lor \ldots$

Intervals

$\pm x \leq c$

Constraints:

$2 \leq x \land x \leq 8$
$\land 2 \leq y \land y \leq 8$

Interval Sets

$\lor_i (l_i \leq x \land x \leq u_i)$

Polyhedra

$\sum_i a_i x_i \leq c$

Constraints:

$2 \leq x \land x \leq 5$
$\lor 7 \leq x \land x \leq 8$
$\lor 2 \leq y \land y \leq 3$
$\lor 5 \leq y \land y \leq 8$
Sets of Concrete Values and their Abstractions

Concrete Points
\[ \pm x = c \]

Constraints:
\[ x = 2 \land y = 1 \]
\[ x = 8 \land y = 5 \]

Concrete Points

Affine Equalities
\[ \sum_i a_i x_i = c \]

Constraints:
\[ 2x - 3y = 3 \]

Congruences
\[ x \equiv b \pmod{a} \]

Constraints:
\[ x \equiv 2 \pmod{3} \]
\[ y \equiv 1 \pmod{2} \]
Some examples of operations on abstractions ...
Some Operations on Intervals

Arithmetics:

\[ [0, 100] + [1, 2] = [1, 102] \]
\[ [0, 100] - [1, 2] = [-2, 99] \]

Tests or Assumptions, Meet \( \sqcap \)

Merge of paths, Join \( \sqcup \)
Widening and Narrowing

To analyze loops in less steps than the real iterations count ... and especially always analyze loops in finitely many steps.

Termination of Analysis!
Widening and Narrowing on Intervals

```c
int x = 1;
int y = 1;
// shown x, y values
// are at loop head
while (x <= 6) {
    x = x + 1;
    y = y + 2;
}
```

1st Iteration

2nd Iteration: □ join

3rd Iteration: ▽ widening

4th Iteration: ∆ narrowing

1st Iteration

2nd Iteration

3rd Iteration

4th Iteration
Abstract Interpretation

Good introduction and overview material:

- A gentle Introduction to Formal Verification of Computer Systems by Abstract Interpretation, P. Cousot and R. Cousot, 2010

- Abstract Interpretation Based Formal Methods and Future Challenges, P. Cousot, 2001

- Abstract Interpretation: Past, Present and Future, P. Cousot and R. Cousot, 2014
Now to our Analyzer “Bindead” ...
Analyzer Features

Analysis of binaries using abstract interpretation

- analyze machine code from disassembled executables
- translate machine code to intermediate language (RREIL)
- abstract transformers for instruction semantics of RREIL
- perform a reachability analysis to infer jump targets and
- use abstract domains to infer memory bounds and flag out-of-bounds accesses

Project page: https://bitbucket.org/mihaila/bindead
Analyzer Overview

- disassembler frontend produces RREIL for the analysis
- RREIL gets transformed to simpler languages for the abstract domains
- fixpoint and disassembly process are intertwined
- modular construction using co-fibered abstract domains
- domains stack is a partially reduced product of domains
- for interprocedural analysis we use either call-string or a summarization approach
... and what is needed to solve the Sendmail Example
# define BUFFERSIZE 200
#define TRUE 1
#define FALSE 0

prove memory correctness for all possible concrete inputs!

int copy_it (char *input, unsigned int length) { *
    input[i] ∈ [−∞, +∞], length ∈ [0, +∞]
    char c, localbuf[BUFFERSIZE];
    unsigned int upperlimit = BUFFERSIZE - 10;
    unsigned int quotation = roundquote = FALSE;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if ((c == '<') && (!quotation)) {
            quotation = TRUE; upperlimit--;
        }
        if ((c == '>') && (quotation)) {
            quotation = FALSE; upperlimit++;
        }
        if ((c == '(') && (!quotation) && !roundquote) {
            roundquote = TRUE; upperlimit--; // decrementation was missing in bug
        }
        if ((c == ')') && (!quotation) && roundquote) {
            roundquote = FALSE; upperlimit++;
        }
        // If there is sufficient space in the buffer, write the character.
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c; prove that outputIndex < BUFFERSIZE holds
            outputIndex++;
        }
    }
    if (roundquote) { prove that invariant outputIndex < BUFFERSIZE holds
        localbuf[outputIndex] = ')'; outputIndex++; }
    if (quotation) { prove that invariant outputIndex < BUFFERSIZE holds
        localbuf[outputIndex] = '>'; outputIndex++; }
}
Sendmail Code Revisited (Problems and Ideas)

```c
#define BUFFERSIZE 200
#define TRUE 1
#define FALSE 0

int copy_it (char *input, unsigned int length) {
  char c, localbuf[BUFFERSIZE];
  unsigned int upperlimit = BUFFERSIZE - 10;
  unsigned int quotation = roundquote = FALSE;
  unsigned int inputIndex = outputIndex = 0;  inputIndex ∈ [0, 0], outputIndex ∈ [0, 0]

  while (inputIndex < length) {
    c = input[inputIndex++];  inputIndex ∈ [1, 1]
    if ((c == '<') && (!quotation)) {
      quotation = TRUE; upperlimit--;
    }
    if ((c == '>') && (quotation)) {
      quotation = FALSE; upperlimit++;
    }
    if ((c == '(') && (!quotation) && !roundquote) {
      roundquote = TRUE;  upperlimit--; // decrementation was missing in bug
    }
    if ((c == ')') && (!quotation) && roundquote) {
      roundquote = FALSE; upperlimit++;
    }
    // If there is sufficient space in the buffer, write the character.
    if (outputIndex < upperlimit) {
      localbuf[outputIndex] = c;  prove that outputIndex < BUFFERSIZE holds
      outputIndex++;  outputIndex ∈ [1, 1]
    }
  }
  // if there is sufficient space in the buffer, write the character.
  if (roundquote) {
    localbuf[outputIndex] = ' '); outputIndex++;
  }
  if (quotation) {
    localbuf[outputIndex] = '> '); outputIndex++;
  }
}
```

prove that invariant outputIndex < BUFFERSIZE holds
# define BUFFERSIZE 200
# define TRUE 1
# define FALSE 0

int copy_it (char *input, unsigned int length) {
    char c, localbuf[BUFFERSIZE];
    unsigned int upperlimit = BUFFERSIZE - 10;
    unsigned int quotation = roundquote = FALSE;
    unsigned int inputIndex = outputIndex = 0;  \inputIndex ∈ [0, 0], \outputIndex ∈ [0, 0]

    while (inputIndex < length) {  \n        c = input[inputIndex++];  \inputIndex ∈ [0, +∞], \outputIndex ∈ [0, +∞]

        if ((c == '<') && (!quotation)) {
            quotation = TRUE; upperlimit--;  \n        }

        if ((c == '>') && (quotation)) {
            quotation = FALSE; upperlimit++;
        }

        if ((c == '(') && (!quotation) && !roundquote) {
            roundquote = TRUE; upperlimit--;  // decrementation was missing in bug
        }

        if ((c == ')') && (!quotation) && roundquote) {
            roundquote = FALSE; upperlimit++;
        }

        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c; \prove that \outputIndex < \BUFFERSIZE holds
            outputIndex++; \outputIndex ∈ [1, 1]
        }  \proved: \outputIndex ∈ [0, 1]
    }

    if (roundquote) { \prove that invariant \outputIndex < \BUFFERSIZE holds
        localbuf[outputIndex] = '); outputIndex++; }

    if (quotation) { \prove that invariant \outputIndex < \BUFFERSIZE holds
        localbuf[outputIndex] = '>'; outputIndex++; }
}

```
Sendmail Code Revisited (Problems and Ideas)

```c
#define BUFFERSIZE 200
#define TRUE 1
#define FALSE 0

int copy_it (char *input, unsigned int length) {
    char c, localbuf[BUFFERSIZE];
    unsigned int upperlimit = BUFFERSIZE - 10; // upperlimit ∈ [190, 190]
    unsigned int quotation = roundquote = FALSE;
    unsigned int inputIndex = outputIndex = 0; // inputIndex ∈ [0, 0], outputIndex ∈ [0, 0]

    while (inputIndex < length) {
        c = input[inputIndex++]; // inputIndex ∈ [0, +∞], outputIndex ∈ [0, +∞]
        if ((c == '<') && (!quotation)) {
            quotation = TRUE; upperlimit--;
        }
        if ((c == '>') && (quotation)) {
            quotation = FALSE; upperlimit++;
        }
        if ((c == '(') && (!quotation) && !roundquote) {
            roundquote = TRUE; upperlimit--; // decrementation was missing in bug
        }
        if ((c == ')') && (!quotation) && roundquote) {
            roundquote = FALSE; upperlimit++;
        }

        // If there is sufficient space in the buffer, write the character.
        if (outputIndex < upperlimit) {
            if (roundquote) {
                localbuf[outputIndex] = c; // prove that outputIndex < BUFFERSIZE holds
                outputIndex++; outputIndex ∈ [1, 1]
            } else {
                localbuf[outputIndex] = c; // prove that outputIndex < BUFFERSIZE holds
                outputIndex++; outputIndex ∈ [1, 1]
            }
        }
    }
}
```
Sendmail Code Revisited (Problems and Ideas)

```c
#define BUFFERSIZE 200
#define TRUE 1
#define FALSE 0

int copy_it (char *input, unsigned int length) {
    char c, localbuf[BUFFERSIZE];
    unsigned int upperlimit = BUFFERSIZE - 10; // upperlimit ∈ [190,190]
    unsigned int quotation = roundquote = FALSE;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if ((c == '<') && (!quotation)) {
            quotation = TRUE; upperlimit--;
        } else: upperlimit ∈ [189,190]
        if ((c == '>') && (quotation)) {
            quotation = FALSE; upperlimit++;
        } else: upperlimit ∈ [189,191]
        if ((c == '(') && (!quotation) && !roundquote) {
            roundquote = TRUE; // decrementation was missing in bug
            upperlimit--; // decrementation was missing in bug
        } else: upperlimit ∈ [188,191]
        if ((c == ')') && (!quotation) && roundquote) {
            roundquote = FALSE; upperlimit++;
        } else: upperlimit ∈ [188,192]
        // If there is sufficient space in the buffer, write the character.
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
}
```

if (roundquote) {
    localbuf[outputIndex] = ')'; outputIndex++;
}
if (quotation) {
    localbuf[outputIndex] = '>'; outputIndex++;
}
```
# define BUFFERSIZE 200
# define TRUE 1
# define FALSE 0

int copy_it (char *input, unsigned int length) {
    char c, localbuf[BUFFERSIZE];
    unsigned int upperlimit = BUFFERSIZE - 10; upperlimit ∈ [190, 190]
    unsigned int quotation = roundquote = FALSE;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) { widening \ removes bounds: upperlimit ∈ [−∞, +∞]
        c = input[inputIndex++];
        if ((c == '<') && (!quotation)) {
            quotation = TRUE; upperlimit--;
            □: upperlimit ∈ [189, 190]
        }
        if ((c == '>') && (quotation)) {
            quotation = FALSE; upperlimit++;
            □: upperlimit ∈ [189, 191]
        }
        if ((c == '(') && (!quotation) && !roundquote) {
            roundquote = TRUE; upperlimit--; // decrementation was missing in bug
            □: upperlimit ∈ [188, 191]
        }
        if ((c == ')') && (!quotation) && roundquote) {
            roundquote = FALSE; upperlimit++;
            □: upperlimit ∈ [188, 192]
        // If there is sufficient space in the buffer, write the character.
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (roundquote) {
        localbuf[outputIndex] = '\''; outputIndex++;
    }
    if (quotation) {
        localbuf[outputIndex] = '>'; outputIndex++;
    }
}
Sendmail Code Revisited (Problems and Ideas)

```c
#define BUFFERSIZE 200
#define TRUE 1
#define FALSE 0

int copy_it (char *input, unsigned int length) {
    char c, localbuf[BUFFERSIZE];
    unsigned int upperlimit = BUFFERSIZE - 10; upperlimit ∈ [190, 190]
    unsigned int quotation = roundquote = FALSE;
    unsigned int inputIndex = outputIndex = 0;

    while (inputIndex < length) { widening ▽ removes bounds: upperlimit ∈ [−∞, +∞]
        c = input[inputIndex++]; use relation with flag variables quotation and roundquote
        if ((c == '<') && (!quotation)) { to keep upperlimit bounded!
            quotation = TRUE; upperlimit--;
        } ▼: upperlimit ∈ [189, 190]
        if ((c == '>') && (quotation)) {
            quotation = FALSE; upperlimit++;
        } ▼: upperlimit ∈ [189, 191]
        if ((c == '(') && (!quotation) && !roundquote) {
            roundquote = TRUE; upperlimit--; // decrementation was missing in bug
        } ▼: upperlimit ∈ [188, 191]
        if ((c == ')') && (!quotation) && roundquote) {
            roundquote = FALSE; upperlimit++;
        } ▼: upperlimit ∈ [188, 192]
        // If there is sufficient space in the buffer, write the character.
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }

    if (roundquote) {
        localbuf[outputIndex] = '\''; outputIndex++;
    }

    if (quotation) {
        localbuf[outputIndex] = '\''; outputIndex++;
    }
}
```
Sendmail Code Revisited (Problems and Ideas)

```c
#define BUFFERSIZE 200
#define TRUE 1
#define FALSE 0

int copy_it (char *input, unsigned int length) {
    char c, localbuf[BUFFERSIZE];
    unsigned int upperlimit = BUFFERSIZE - 10;
    unsigned int quotation = roundquote = FALSE; // quotation ∈ [0, 0], roundquote ∈ [0, 0]
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if ((c == '<') && (!quotation)) {
            quotation = TRUE; upperlimit--;
        } // : quotation ∈ [0, 1]
        if ((c == '>') && (quotation)) {
            quotation = FALSE; upperlimit++;
        } // : quotation ∈ [0, 1]
        if ((c == '(') && (!quotation) && !roundquote) {
            roundquote = TRUE; upperlimit--; // decrementation was missing in bug
        } // : quotation ∈ [0, 1], roundquote ∈ [0, 1]
        if ((c == ')') && (!quotation) && roundquote) {
            roundquote = FALSE; upperlimit++;
        } // : quotation ∈ [0, 1], roundquote ∈ [0, 1]
        // If there is sufficient space in the buffer, write the character.
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (roundquote) {
        localbuf[outputIndex] = '
        outputIndex++; }
    if (quotation) {
        localbuf[outputIndex] = '>' ; outputIndex++; }
    }
```
Sendmail Code Revisited (Problems and Ideas)

```c
#define BUFFERSIZE 200
#define TRUE 1
#define FALSE 0

int copy_it (char *input, unsigned int length) {
    char c, localbuf[BUFFERSIZE];
    unsigned int upperlimit = BUFFERSIZE - 10;
    unsigned int quotation = roundquote = FALSE; /* quotation ∈ [0,0], roundquote ∈ [0,0] */
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) { /* removes bounds: quotation ∈ [0, +∞], roundquote ∈ [0, +∞] */
        c = input[inputIndex++];
        if ((c == '<') && (!quotation)) {
            quotation = TRUE; upperlimit--;
        } /* quotation ∈ [0,1] */
        if ((c == '>') && (quotation)) {
            quotation = FALSE; upperlimit++;
        } /* quotation ∈ [0,1] */
        if ((c == '(') && (!quotation) && !roundquote) {
            roundquote = TRUE; upperlimit--; /* decrementation was missing in bug */
        } /* quotation ∈ [0,1], roundquote ∈ [0,1] */
        if ((c == ')') && (!quotation) && roundquote) {
            roundquote = FALSE; upperlimit++;
        } /* quotation ∈ [0,1], roundquote ∈ [0,1] */
        // If there is sufficient space in the buffer, write the character.
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (roundquote) {
        localbuf[outputIndex] = ')'; outputIndex++;
    }
    if (quotation) {
        localbuf[outputIndex] = '>'; outputIndex++;
    }
}
```
Sendmail Code Revisited (Problems and Ideas)

```c
#define BUFFERSIZE 200
#define TRUE 1
#define FALSE 0

int copy_it (char *input, unsigned int length) {
    char c, localbuf[BUFFERSIZE];
    unsigned int upperlimit = BUFFERSIZE - 10;
    unsigned int quotation = roundquote = FALSE; quotation ∈ [0, 0], roundquote ∈ [0, 0]
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++]; delay widening until flags and relations stable!
        if ((c == '<') && (!quotation)) {
            quotation = TRUE; upperlimit--;
            } □: quotation ∈ [0, 1]
        if ((c == '>') && (quotation)) {
            quotation = FALSE; upperlimit++;
            } □: quotation ∈ [0, 1]
        if ((c == '(') && (!quotation) && !roundquote) {
            roundquote = TRUE; upperlimit--; // decrementation was missing in bug
            } □: quotation ∈ [0, 1], roundquote ∈ [0, 1]
        if ((c == ')') && (!quotation) && roundquote) {
            roundquote = FALSE; upperlimit++;
            } □: quotation ∈ [0, 1], roundquote ∈ [0, 1]
        // If there is sufficient space in the buffer, write the character.
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        } □: outputIndex ∈ [0, upperlimit]
        }
        if (roundquote) {
            localbuf[outputIndex] = '');?></outputIndex++;
        } □: outputIndex ∈ [0, inputIndex + 10]
        if (quotation) {
            localbuf[outputIndex] = '>'; outputIndex++;
        } □: outputIndex ∈ [0, inputIndex + 10]
    }
```
Stack of Required Domains

To verify the code (disassembled from the binary) we used these abstract domains:

Adding more domains (e.g. predicates, congruences, octagons, polyhedra, interval-sets) improves the precision of the inferred bounds after widening but is not necessary to verify the code.
Solving Sendmail with Abstract Interpretation

A Walkthrough the Sendmail Analysis using Bindead
Analysis Steps and inferred Values

Lets analyze the code!

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            q = 1; upperlimit--;
        }
        if (... && (q)) {
            q = 0; upperlimit++;
        }
        if (... && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (... && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (rq) {
        localbuf[outputIndex] = '\0'; outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '>'; outputIndex++;
    }
}
```
1st iteration: infers the affine equality between the variables: $upperlimit + q + rq = 190$

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        inputIndex = 0, outputIndex = 0, length ∈ [−∞, +∞]
        c = input[inputIndex++];
        if (... && (!q)) { upperlimit = 190, q = 0, rq = 0
            q = 1; upperlimit--;
        }  □: $upperlimit + q = 190, upperlimit ∈ [189, 190], q ∈ [0, 1]
        if (... && (q)) {
            q = 0; upperlimit++;
        }
        if (... && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (... && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (rq) {
        localbuf[outputIndex] = '\''; outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '>' ; outputIndex++;
    }
}
```
Analysis Steps and inferred Values

1st iteration: infers the affine equality between the variables: $upperlimit + q + rq = 190$

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            q = 1; upperlimit--;
        } 
        if (... && (q)) {  // upperlimit = 189, q = 1, rq = 0 
            q = 0; upperlimit++;
        } ⊔: upperlimit + q = 190, upperlimit ∈ [189, 190], q ∈ [0, 1]
        if (... && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (... && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (rq) {
        localbuf[outputIndex] = '\''; outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '>'; outputIndex++;
    }
}
```
Analysis Steps and inferred Values

1st iteration: infers the affine equality between the variables: \( upperlimit + q + rq = 190 \)

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            q = 1; upperlimit--;
        }
        if (... && (q)) {
            q = 0; upperlimit++;
        }
        if (... && (!q) && !rq) {
            upperlimit = 190, q = 0, rq = 0
            rq = TRUE; upperlimit--;
        } // : upperlimit + q + rq = 190, upperlimit ∈ [189, 190], q ∈ [0, 1], rq ∈ [0, 1]
        if (... && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
}

if (rq) {
    localbuf[outputIndex] = ''; outputIndex++;
}
if (q) {
    localbuf[outputIndex] = '>'; outputIndex++;
}
```
1st iteration: infers the affine equality between the variables: upperlimit + q + rq = 190

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            q = 1; upperlimit--;
        }
        if (... && (q)) {
            q = 0; upperlimit++;
        }
        if (... && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (... && (!q) && rq) { upperlimit = 189, q = 0, rq = 1
            rq = 0; upperlimit++;
        } \[ upperlimit + q + rq = 190, upperlimit \in [189, 190], q \in [0, 1], rq \in [0, 1] \]
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (rq) {
        localbuf[outputIndex] = ''; outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '>' ; outputIndex++;
    }
}
```
Analysis Steps and inferred Values

1st iteration: infers the affine equality between the variables: \( upperlimit + q + rq = 190 \)

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            q = 1; upperlimit--;
        }
        if (... && (q)) {
            q = 0; upperlimit++;
        }
        if (... && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (... && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) { // upperlimit ∈ [189, 190], outputIndex = 0
            localbuf[outputIndex] = c;
            outputIndex++;
        }  // outputIndex ∈ [189, 190], upperlimit ∈ [0, 1]
    }
    if (rq) {
        localbuf[outputIndex] = '\''; outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '>'; outputIndex++;
    }
}
```
Analysis Steps and inferred Values

2nd iteration: widening $\nabla$ suppressed by the “delayed widening” domain because of the flag assignments. Join $\sqcup$ performed instead. We analyze the loop again with still valid equality: $\text{upperlimit} + q + rq = 190$

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            upperlimit + rq = 190, upperlimit ∈ [189, 190], q = 0, rq ∈ [0, 1]
            q = 1; upperlimit--;
        }  \[upperlimit + q + rq = 190, upperlimit ∈ [188, 190], q ∈ [0, 1], rq ∈ [0, 1]\n        if (... && (q)) {
            q = 0; upperlimit++;
        }
        if (... && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (... && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (rq) {
        localbuf[outputIndex] = '\''; outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '>'; outputIndex++;
    }
}
```
Analysis Steps and inferred Values

2nd iteration: widening $\nabla$ suppressed by the “delayed widening” domain because of the flag assignments. Join $\sqcup$ performed instead. We analyze the loop again with still valid equality: $\text{upperlimit} + q + rq = 190$

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            q = 1; upperlimit--;
        }
        if (... && (q)) {  $\text{upperlimit} = 189, \text{upperlimit} \in [188, 189], q = 1, rq \in [0, 1]$  
            q = 0; upperlimit++;
        }  $\sqcup: \text{upperlimit} + q + rq = 190, \text{upperlimit} \in [188, 190], q \in [0, 1], rq \in [0, 1]$  
        if (... && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (... && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (rq) {
        localbuf[outputIndex] = '\''; outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '>'; outputIndex++;
    }
}
```
Analysis Steps and inferred Values

2nd iteration: widening $\nabla$ suppressed by the “delayed widening” domain because of the flag assignments. Join $\sqcup$ performed instead. We analyze the loop again with Still valid equality: $upperlimit + q + rq = 190$

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            q = 1; upperlimit--;}
        if (... && (q)) {
            q = 0; upperlimit++;
        }
        if (... && (!q) && !rq) {
            $upperlimit = 190, q = 0, rq = 0$
            rq = TRUE; $upperlimit--;$
        $\sqcup: upperlimit + q + rq = 190, upperlimit \in [188, 190], q \in [0, 1], rq \in [0, 1]$
        if (... && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (rq) {
        localbuf[outputIndex] = ''); outputIndex++; }
    if (q) {
        localbuf[outputIndex] = '>'; outputIndex++; }
}
```
Analysis Steps and inferred Values

2nd iteration: widening $\nabla$ suppressed by the “delayed widening” domain because of the flag assignments. Join $\sqcap$ performed instead. We analyze the loop again with still valid equality: $upperlimit + q + rq = 190$

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            q = 1; upperlimit--;
        }
        if (... && (q)) {
            q = 0; upperlimit++;
        }
        if (... && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (... && (!q) && rq) {
            upperlimit = 189, q = 0, rq = 1
            rq = 0; upperlimit++;
        } $\sqcap$: $upperlimit + q + rq = 190$, $upperlimit \in [188, 190]$, $q \in [0, 1]$, $rq \in [0, 1]$
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (rq) {
        localbuf[outputIndex] = ''); outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '>'); outputIndex++;
    }
}```
Analysis Steps and inferred Values

2nd iteration: widening $\nabla$ suppressed by the “delayed widening” domain because of the flag assignments. Join $\sqcap$ performed instead. We analyze the loop again with still valid equality: $\textit{upperlimit} + q + rq = 190$

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (...) && (!q)) {
            q = 1; upperlimit--;
        }
        if (...) && (q)) {
            q = 0; upperlimit++;
        }
        if (...) && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (...) && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) { upperlimit $\in$ [188, 190], outputIndex $\in$ [0, 1]
            localbuf[outputIndex] = c;
            outputIndex++;
        } \sqcap: upperlimit $\in$ [188, 190], outputIndex $\in$ [0, 2]
    }
    if (rq) {
        localbuf[outputIndex] = '\''; outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '>'; outputIndex++;
    }
}
```
3rd iteration: now widening \( \nabla \) is applied using the widening threshold: \( \text{outputIndex} - 1 < \text{upperlimit} \).
Widening changes the lower bound of \( \text{upperlimit} \) but reduction with the equality \( \text{upperlimit} + q + rq = 190 \) restores it.

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) { \( \text{upperlimit} + rq = 190 \), \( \text{upperlimit} \in [189, 190] \), \( q = 0 \), \( rq \in [0, 1] \)
            q = 1; upperlimit--;
        } \( \nabla : \text{upperlimit} + q + rq = 190 \), \( \text{upperlimit} \in [188, 190] \), \( q \in [0, 1] \), \( rq \in [0, 1] \)
        if (... && (q)) {
            q = 0; upperlimit++;
        }
        if (... && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (... && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
        if (rq) {
            localbuf[outputIndex] = '; outputIndex++;
        }
        if (q) {
            localbuf[outputIndex] = '>'; outputIndex++;
        }
    }
}
```
3rd iteration: now widening $\nabla$ is applied using the widening threshold: $outputIndex - 1 < upperlimit$.
 Widening changes the lower bound of $upperlimit$ but reduction with the equality $upperlimit + q + rq = 190$ restores it.

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            q = 1; upperlimit--;
        }
        if (... && (q)) { $upperlimit + rq = 189$, $upperlimit \in [188, 189]$, $q = 1$, $rq \in [0, 1]$
            q = 0; upperlimit++;
        }  $\sqcup : upperlimit + q + rq = 190$, $upperlimit \in [188, 190]$, $q \in [0, 1]$, $rq \in [0, 1]$
        if (... && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (... && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (rq) {
        localbuf[outputIndex] = ')'; outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '>'; outputIndex++;
    }
}
```
Analysis Steps and inferred Values

3rd iteration: now widening $\nabla$ is applied using the widening threshold: $outputIndex - 1 < upperlimit$. Widening changes the lower bound of $upperlimit$ but reduction with the equality $upperlimit + q + rq = 190$ restores it

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            q = 1; upperlimit--;
        }
        if (... && (q)) {
            q = 0; upperlimit++;
        }
        if (... && (!q) && !rq) {
            upperlimit = 190, q = 0, rq = 0
            rq = TRUE; upperlimit--;
        }  \[ upperlimit + q + rq = 190, upperlimit \in [188, 190], q \in [0, 1], rq \in [0, 1] \]
        if (... && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (rq) {
        localbuf[outputIndex] = '\''; outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '>'; outputIndex++;
    }
}
```
3rd iteration: now widening $\nabla$ is applied using the widening threshold: $\text{outputIndex} - 1 < \text{upperlimit}$. Widening changes the lower bound of $\text{upperlimit}$ but reduction with the equality $\text{upperlimit} + q + rq = 190$ restores it.

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            q = 1; upperlimit--;
        }
        if (... && (q)) {
            q = 0; upperlimit++;
        }
        if (... && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (... && (!q) && rq) {
            upperlimit = 189, q = 0, rq = 1
            rq = 0; upperlimit++;
        }  \[ upperlimit + q + rq = 190, upperlimit \in [188, 190], q \in [0,1], rq \in [0,1] \]
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (rq) {
        localbuf[outputIndex] = '\''; outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '\>'; outputIndex++;
    }
}
```
3rd iteration: now widening ∇ is applied using the widening threshold: outputIndex − 1 < upperlimit. Widening changes the lower bound of upperlimit but reduction with the equality upperlimit + q + rq = 190 restores it.

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (...) && (!q)) {
            q = 1; upperlimit--;
        }
        if (...) && (q)) {
            q = 0; upperlimit++;
        }
        if (...) && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (...) && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) {
            upperlimit ∈ [188, 190], outputIndex ∈ [0, 189]
            localbuf[outputIndex] = c;
            outputIndex++;
        } /* upperlimit ∈ [188, 190], outputIndex ∈ [0, 190] */
    }
    if (rq) {
        localbuf[outputIndex] = '); outputIndex++;
    }
    if (q) {
        localbuf[outputIndex] = '>'); outputIndex++;
    }
}
```
Analysis Steps and inferred Values

4th iteration: loop is stable; outside of the loop body the value of `outputIndex` is still bounded!

```c
int copy_it (char *input, unsigned int length) {
    char c, localbuf[200];
    unsigned int upperlimit = 190;
    unsigned int q = rq = 0;
    unsigned int inputIndex = outputIndex = 0;
    while (inputIndex < length) {
        c = input[inputIndex++];
        if (... && (!q)) {
            q = 1; upperlimit--;
        }
        if (... && (q)) {
            q = 0; upperlimit++;
        }
        if (... && (!q) && !rq) {
            rq = TRUE; upperlimit--;
        }
        if (... && (!q) && rq) {
            rq = 0; upperlimit++;
        }
        if (outputIndex < upperlimit) {
            localbuf[outputIndex] = c;
            outputIndex++;
        }
    }
    if (rq) {
        outputIndex ∈ [0, 190]
        localbuf[outputIndex] = ')' outputIndex++;
    }
    if (q) {
        outputIndex ∈ [1, 191]
        localbuf[outputIndex] = '>' outputIndex++;
    }
}
```
Key Points

- Widening needs to be suppressed until the flag variables are stable to infer the equality relation with $upperlimit$.

- The inferred equality $upperlimit + q + rq = 190$ and reduction between domains results in more precise values for $upperlimit$; it recovers the precision loss of widening.
Key Points (continued)

• narrowing does not help here; instead the threshold \( outputIndex < upperlimit \) must be used for widening
  \( \sim \) \( outputIndex \) is also restricted outside of the loop for the following two writes to the buffer

• in the vulnerable version because of the missing decrementation the equality relation does not hold
  \( \sim \) \( upperlimit \) is unbounded after widening
Unfortunately

The original 500 LOC Sendmail Bug is more complex!
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- the code contains ~10 loops (nesting depth is 4) and gotos
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- lots of pointer arithmetic inside loops
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- the bugfix is not only one line but in more places
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The original 500 LOC Sendmail Bug is more complex!

- the code contains $\sim 10$ loops (nesting depth is 4) and gotos
- lots of pointer arithmetic inside loops
- uses string manipulating functions
- the bugfix is not only one line but in more places

$\sim$ we cannot yet automatically prove the invariant on that code; the non-vulnerable version is flagged as vulnerable, too
Now lets look how other tools fare on the simplified example ...
## Analysis Results of various Tools

Evaluated on the simplified Sendmail Crackaddr Example

<table>
<thead>
<tr>
<th>Tool</th>
<th>non-vuln.</th>
<th>vuln.</th>
<th>Techniques used</th>
<th>Input</th>
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<tbody>
<tr>
<td>Bindead</td>
<td>✓</td>
<td>✓</td>
<td>AI</td>
<td>binary</td>
</tr>
<tr>
<td>Jakstab</td>
<td></td>
<td>✓</td>
<td>AI</td>
<td>binary</td>
</tr>
<tr>
<td>Astrée</td>
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<td>AI</td>
<td>C</td>
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<td>✓</td>
<td>AI + MC</td>
<td>C</td>
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<td>Radamsa</td>
<td></td>
<td>✓</td>
<td>Fuzz</td>
<td>binary</td>
</tr>
</tbody>
</table>

m: manual hints from user required  
AI: Abstract Interpretation  
MC: Model Checking  
Fuzz: fuzz fuzz fuzz fuzz

Still to test: KLEE, S2E, BAP, Java Path Finder, Triton, PySymEmu, Moflow, Angr, McSema, OpenREIL, Bincoa, CodeSonar, Polyspace, Goanna, Clousot ...
Program analysis tools can infer surprisingly nice results. Here an invariant that shows the programmer’s intention.
Conclusion

Program analysis tools can infer surprisingly nice results. Here an invariant that shows the programmer’s intention:

- but the tools are quite complex
  - hard to understand and to reason about the results
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- but the tools are quite complex
  - hard to understand and to reason about the results
- if an expected invariant cannot be proved it is difficult to find out why and fix it
Program analysis tools can infer surprisingly nice results. Here an invariant that shows the programmer’s intention

- but the tools are quite complex
- hard to understand and to reason about the results
- if an expected invariant cannot be proved it is difficult to find out why and fix it
- however, being able to understand, use and debug an analyzer is key to building useful analyses!
- general adoption of static analyzers is an uphill battle :(
Demo!

Initializing ... demo

Project page:  https://bitbucket.org/mihaila/bindead
Demo!

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A Merci Beaucoup goes to ...

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All the tool developers of
Bindead, Astrée, TIS-Analyzer, Frama-C, Goblint, PAGAI, AFL, Radamsa, Jakstab, SeaHorn, CProver, HAVOC, KLEE, S2E, BAP, Java Path Finder, Triton, PySymEmu, Moflow, Angr, McSema, OpenREIL, Bincoa, CodeSonar, Polyspace, Goanna, Clousot, ...

Hackito Ergo Sum

2015
Some previous material on Sendmail Crackaddr

Presentations

• Checking the Boundaries of Static Analysis - Halvar Flake 2013
• Exploitation and State Machines - Halvar Flake 2012
• Exploit-Generation with Acceleration - Daniel Kröning et al. 2013
• Modern Static Security Checking of C/C++ Code - Julien Vanegue 2012
• Practical AI Applications to Information Security - Fyodor Yarochkin 2003

Papers and Web Resources

• TIS Analyzer Sendmail Crackaddr Analysis Report - Pascal Cuoq 2014
• Technical Analysis and Exploitation of Sendmail Bug - LSD 2003
• Sendmail Crackaddr CVE-2002-1337 - MITRE Co. 2003
• Remote Sendmail Header Processing Vulnerability - IBM ISS 2003