

Contemporary Automatic Program Analysis

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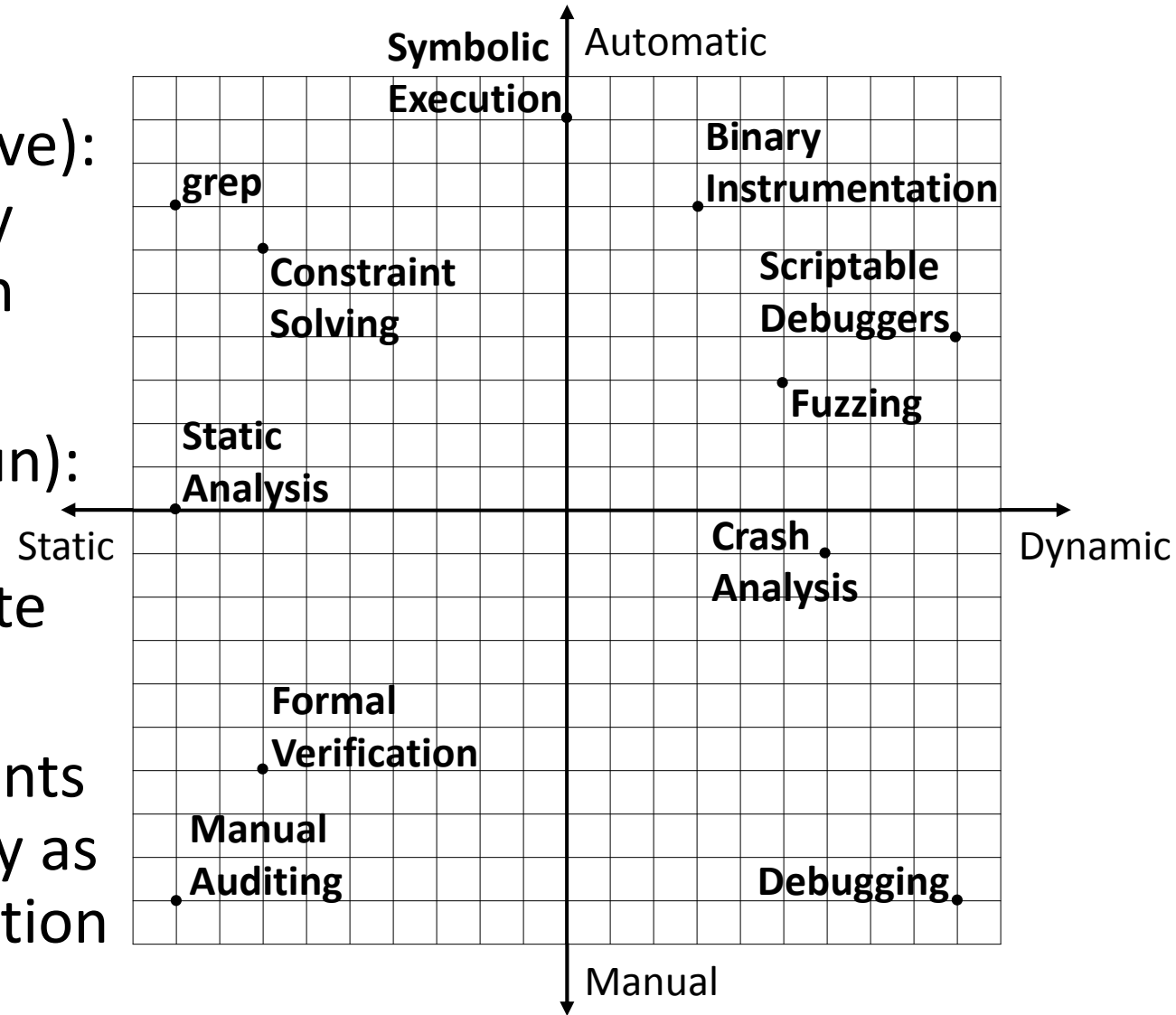
- Application Security | Large Organization
- NYU Polytechnic School of Engineering | <http://engineering.nyu.edu/>
- Cyber Security Awareness Week | <https://csaw.isis.poly.edu/>
- ISIS Laboratory | <http://www.isis.poly.edu/>
- Ghost in the Shellcode | <http://ghostintheshellcode.com/>
- Moderator | </r/netsec> | </r/vrd>
- NYSEC | <https://twitter.com/nysecsec>

Cyber Security Awareness Week

- <https://csaw.isis.poly.edu/>
- @CSAW_NYUPoly | <https://www.facebook.com/NYUPolyCSAW>
- Student-run @ NYU Polytechnic School of Engineering
- Six Competitions: CTF | HSF | ESC | Research | Policy | Quiz
- Cyber Security Career Fair
- THREADS: Security Automation
- Downtown Brooklyn, New York

Automatic Program Analysis

- au·to·mat·ic /,ô·tə'matik/ (adjective):
(of a device or process) working by
itself with little or no direct human
control
- pro·gram /'prô,gram,-grəm/ (noun):
a sequence of instructions that a
computer can interpret and execute
- a·nal·y·sis /ə'naləsis/ (noun):
detailed examination of the elements
or structure of something, typically as
a basis for discussion or interpretation

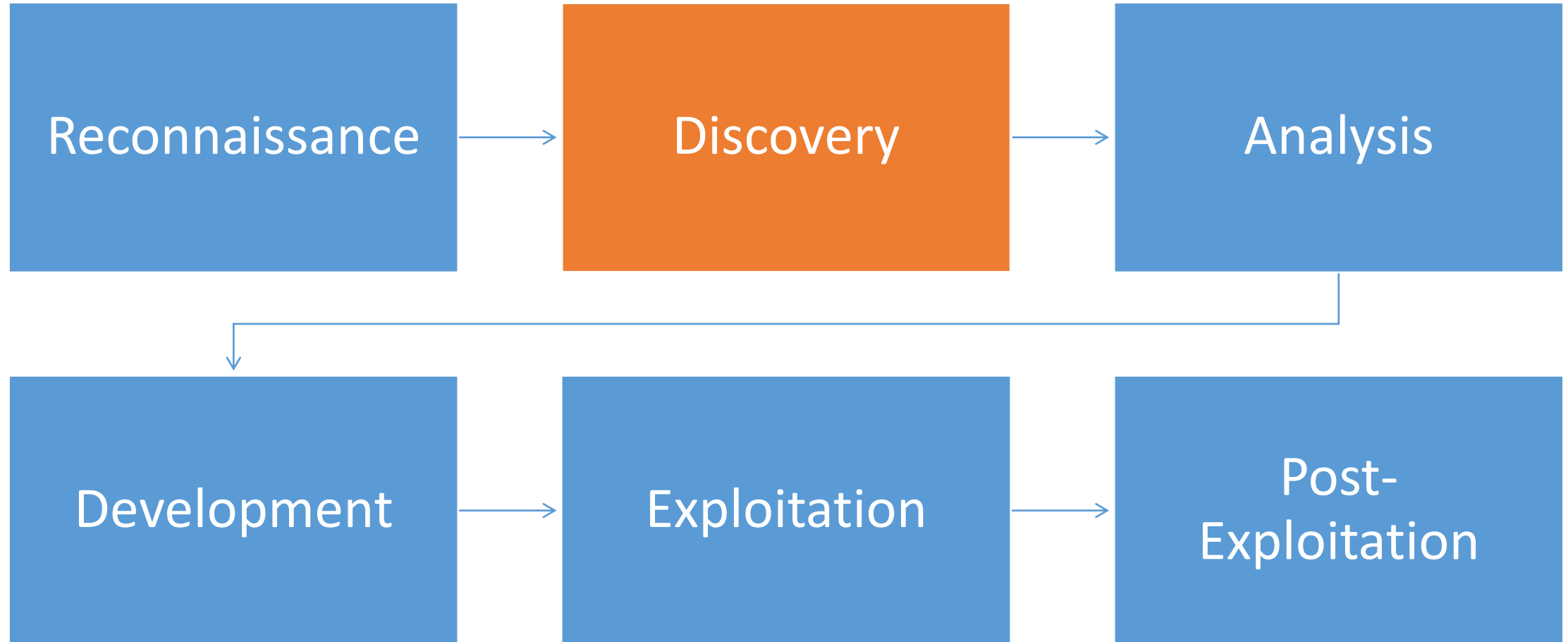


Ambiguity Disclosure

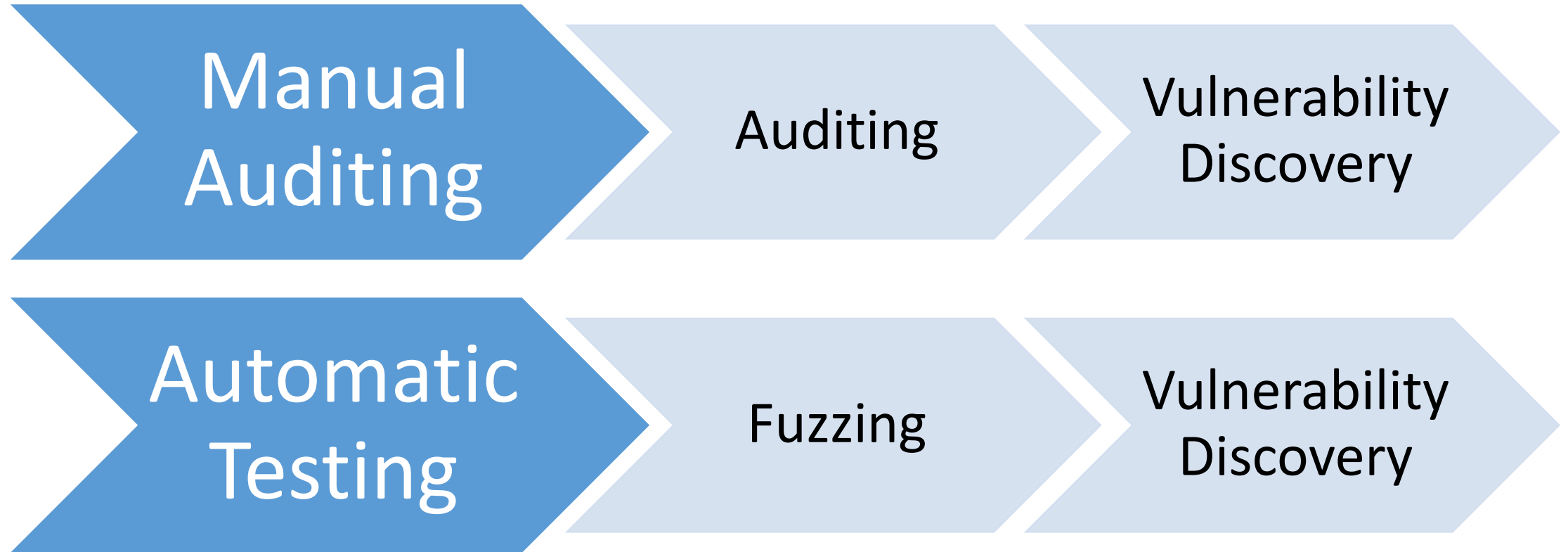
For better and for worse, I will be
deliberately ambiguous at times

Use your **imagination**

Vulnerability Research



Vulnerability Discovery



How can we use program analysis to discover
the highest impact vulnerabilities at the
lowest cost?

Metacharacter Injection Vulnerabilities

- Cross-Site Scripting

```
<h2>Welcome back, <script>alert(1);</script>!</h2>
```

- SQL Injection

```
SELECT * FROM users WHERE user="admin" AND pass="1" OR "1"="1"
```

- Command Injection

```
cp /tmp/e1zXr /var/www/assets/img-`rm -rf --no-preserve-root /`;
```

githubgrep.py (87 lines)

- githubgrep is a very simple script to automate Github code search
- User provides functions, input, and security keywords
- Creates code search queries based on those keywords
- Outputs how many vulnerabilities each search yields with a link
- Code search only allows a certain number of modifiers per query
- Low false-positive rate, taking into account sanitizer keywords

<https://github.com/HockeyInJune/Contemporary-Automatic-Program-Analysis>

githubgrep.py

```
./githubgrep.py -language php  
-functions  
"exec, passthru, shell_exec, system, popen"  
-sources "\$_REQUEST, \$_GET, \$_POST"  
-sanitizers "escapeshellcmd, escapeshellarg"
```

TOTAL NUMBER OF VULNERABILITIES FOUND: 1540130

exec \$_GET NOT escapeshellcmd NO

We've found 94,738 code resu

Last indexed on Aug 3, 2013

```
1 <?php  
2  
3 exec($_GET['command'] . " >
```

Last indexed on Jul 30, 2013

```
1 <?php  
2 echo exec($_GET['cmd']);  
3 ?>
```

Last indexed on Jul 26, 2013

```
1 Start--  
2 <?  
3  
4 @exec( $_GET['cmd'] );  
5  
6 ?>  
7 --End
```

Last indexed on Jun 12

```
1 <?php  
2 if (isset($_GET['command'])
```

githubgrep.py

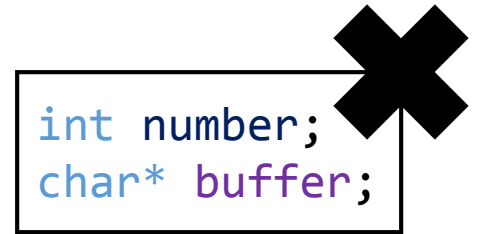
```
./githubgrep.py -language java  
-functions "write,print,println,out"  
-sources  
"getHeader,getHeaders,getQueryString,  
getRequestURI,requestURL,  
getParameter,getParameterValues"  
-sanitizers "encode,sanitize,validate"
```

TOTAL NUMBER OF VULNERABILITIES FOUND:
755536



Type Confusion Vulnerabilities

```
union {  
    int number;  
    char *buffer;  
} u;  
u.number = recv();  
strncpy(u.buffer, input, sizeof(u.buffer));
```



grep (1 line)

```
hij@vm:~/WebKit/Source/WebCore/css/$ grep -A 4 union CSSParser.cpp
```

```
union {  
    double fValue;  
    int iValue;  
    CSSParserString string;  
    CSSParserFunction *function;  
};
```

- Very high false-positive rate, effective only when you know exactly what to look for

<http://blog.leafsr.com/2012/06/27/webkit-css-type-confusion/>

Implicit Type Conversion Vulnerabilities

```
char buffer[128];  
int size = recv();  
  
if (size < 100) {  
    strncpy(buffer, input, size);  
}
```

gcc -Wconversion (1 line)

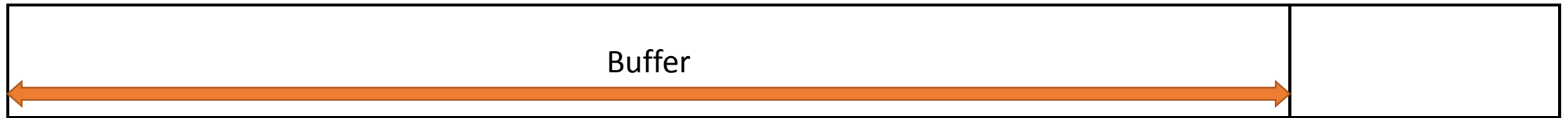
```
hij@vm:~$ gcc -Wconversion implicit.c
```

```
warning: conversion to 'size_t' from 'int' may  
change the sign of the result [-Wsign-conversion]
```

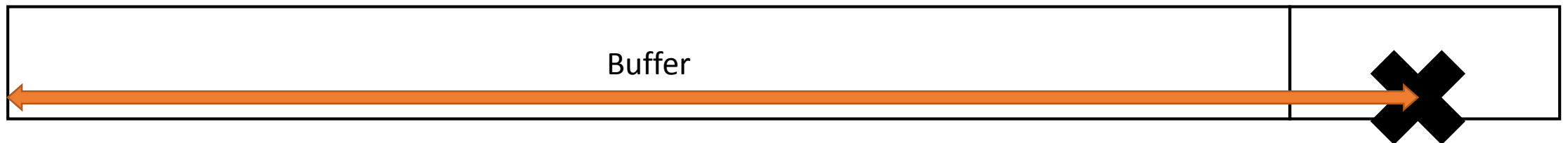
```
    strncpy(buffer, input, size);
```

^

Buffer Overflow Vulnerabilities



```
char buffer[128];  
strcpy(buffer, input);
```



RATS: Rough Auditing Tool for Security

- RATS uses simple static analysis to find potentially vulnerable code
- C, C++, Perl, PHP, Python, and Ruby
- Parses and tokenizes source code
- Checks variables, identifiers, and comments against rules
- High false-positive rate, but every finding is usually worth looking into

<https://code.google.com/p/rough-auditing-tool-for-security/>

RATS: Rough Auditing Tool for Security

```
hij@vm:~/rough-auditing-tool-for-security$ ./rats ../mozjpeg  
Entries in c database: 334
```

```
../mozjpeg/wrjpgcom.c:456: High: strcpy
```

Check to be sure that argument 2 passed to this function call will not copy more data than can be handled, resulting in a buffer overflow.

```
../mozjpeg/wrjpgcom.c:466: High: strcat
```

Check to be sure that argument 2 passed to this function call will not copy more data than can be handled, resulting in a buffer overflow.

```
} else if ( keymatch(arg, "comment", 1) ) {  
    comment_arg = argv[++argn];  
    if (comment_arg[0] == '"') {  
        comment_arg = (char *) malloc( (size_t) MAX_COM_LENGTH );  
        strcpy(comment_arg, argv[argn] + 1);  
        for (;;) {  
            comm_l = (unsigned int) strlen(comment_arg);  
            if (comm_l > 0 && comment_arg[comm_l - 1] == '"') {  
                comment_arg[comm_l - 1] = '\\0';  
                break;  
            }  
            strcat(comment_arg, " ");  
            strcat(comment_arg, argv[++argn]);  
        }  
    }  
}
```

Valgrind memcheck

- Valgrind uses dynamic binary instrumentation to detect memory errors
- Rewrites code in memory in order instrument memory operations
- Reports any invalid memory operations
- Low false-positive rate, nearly every report is a bug
- But you need test cases to exercise each vulnerability

<http://valgrind.org/>

Valgrind memcheck

```
valgrind --trace-children=yes ./wrjpgcom -comment "A*70000" testorig.jpg
```

Invalid write of size 1

at 0x4C2BFFC: strcpy (in valgrind/vgpreload_memcheck-amd64-linux.so)
by 0x40123E: main (in mozjpeg/.libs/lt-wrjpgcom)

Address 0x5201e28 is 0 bytes after a block of size 65,000 alloc'd

at 0x4C2B6CD: malloc (in valgrind/vgpreload_memcheck-amd64-linux.so)
by 0x4011E5: main (in mozjpeg/.libs/lt-wrjpgcom)

Valgrind memcheck

```
valgrind --trace-children=yes ./wrjpgcom -comment "A*60000 A*10000 testorig.jpg"
```

Invalid write of size 1

at 0x4C2BCCC: **strcat** (in valgrind/vgpreload_memcheck-amd64-linux.so)
by 0x401324: main (in mozjpeg/.libs/lt-wrjpgcom)

Address 0x5201e28 is 0 bytes after a block of size 65,000 alloc'd

at 0x4C2B6CD: **malloc** (in valgrind/vgpreload_memcheck-amd64-linux.so)
by 0x4011E5: main (in mozjpeg/.libs/lt-wrjpgcom)

Invalid write of size 1

at 0x4C2BCDF: **strcat** (in valgrind/vgpreload_memcheck-amd64-linux.so)
by 0x401324: main (in mozjpeg/.libs/lt-wrjpgcom)

Address 0x52031b1 is not stack'd, malloc'd or (recently) free'd

quicksec (275 lines)

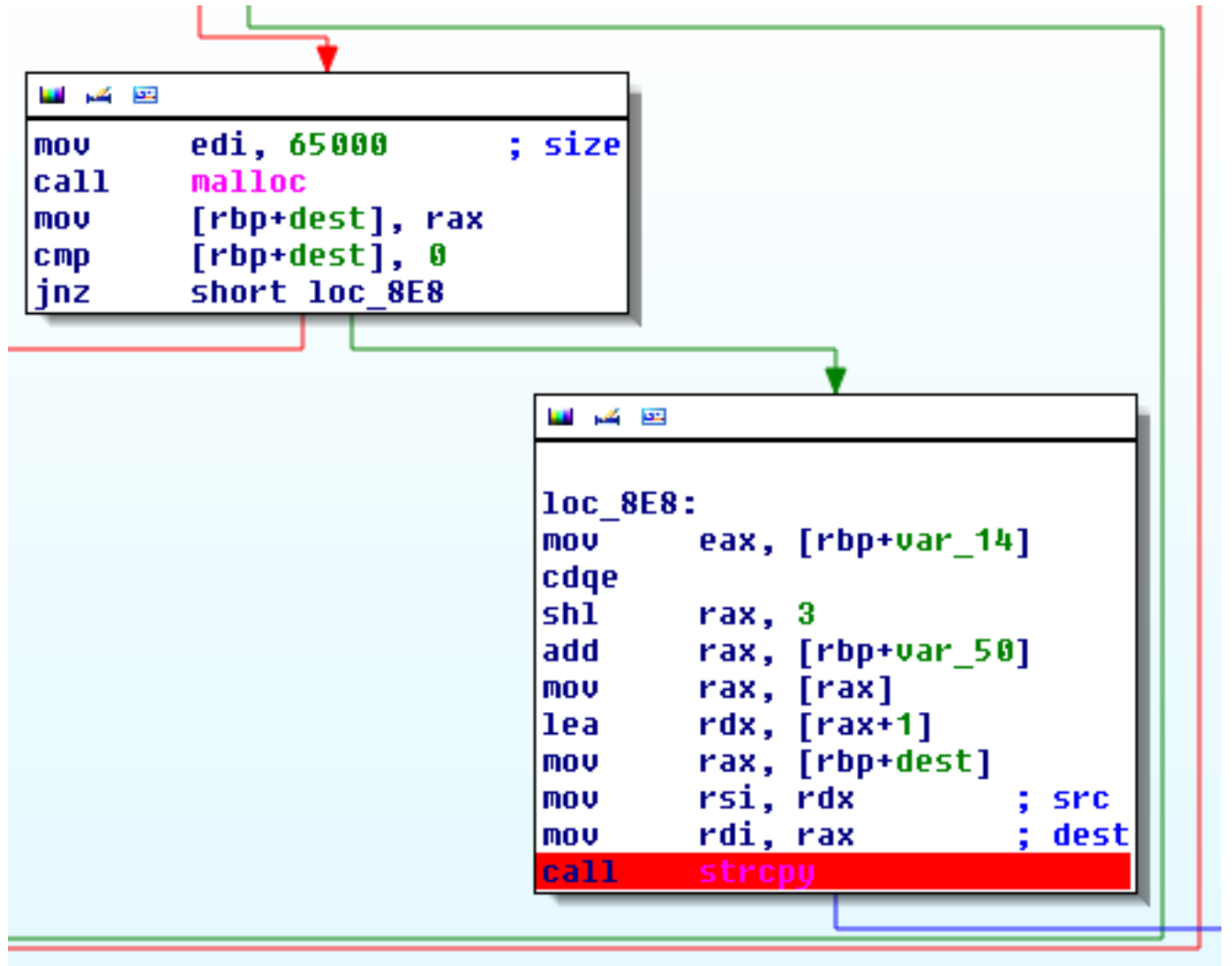
- quicksec is a simple static analysis tool for native code
 - Written by Kevin Chung, a student in my class
- Similar to RATS, it parses and looks for function calls, but in binaries
- It also attempts to determine the vulnerability of its findings
- Low false-positive rate, and every finding is worth looking into

<https://github.com/ColdHeat/quicksec>

quicksec

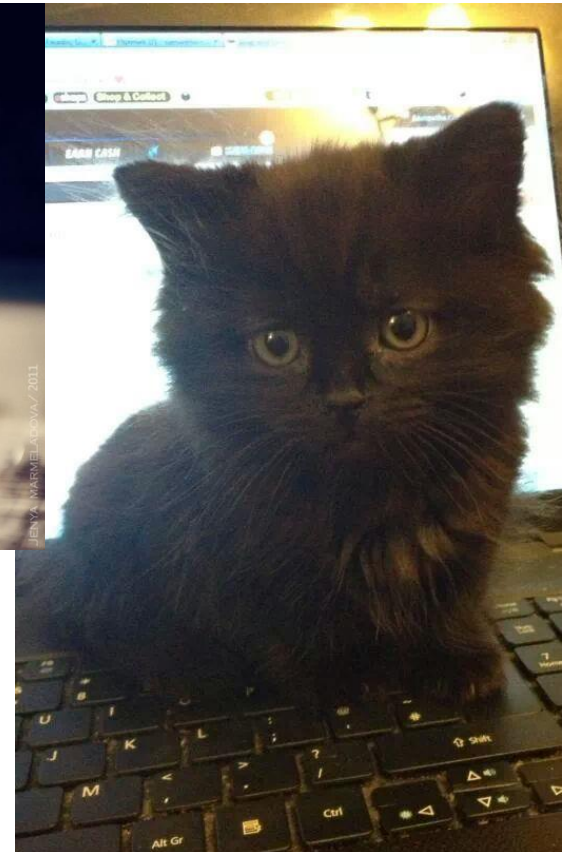
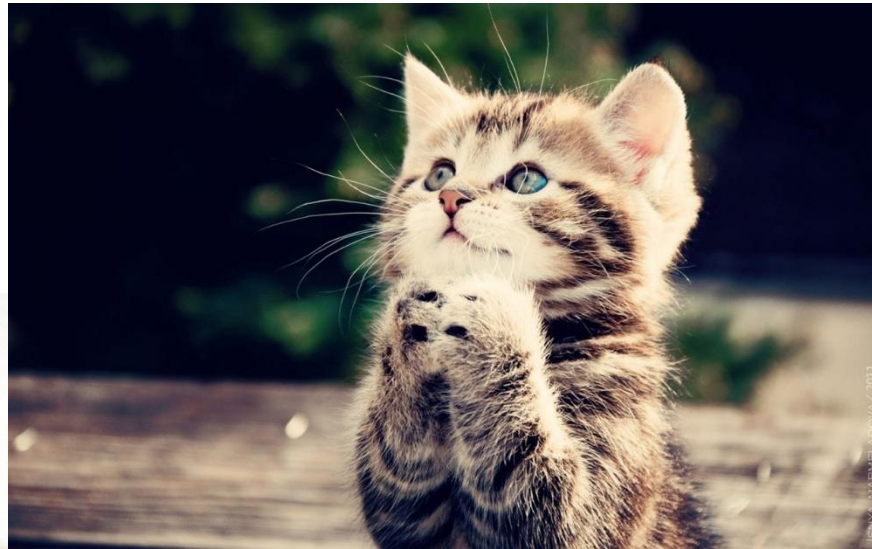
- Output:

```
gets []  
fgets []  
strcpy [2310]  
recv []  
printf []  
read []
```



Kitten Interlude

Brought you by Brad Antoniewicz, Joshua Drake, and ancat!



Use-After-Free Vulnerabilities

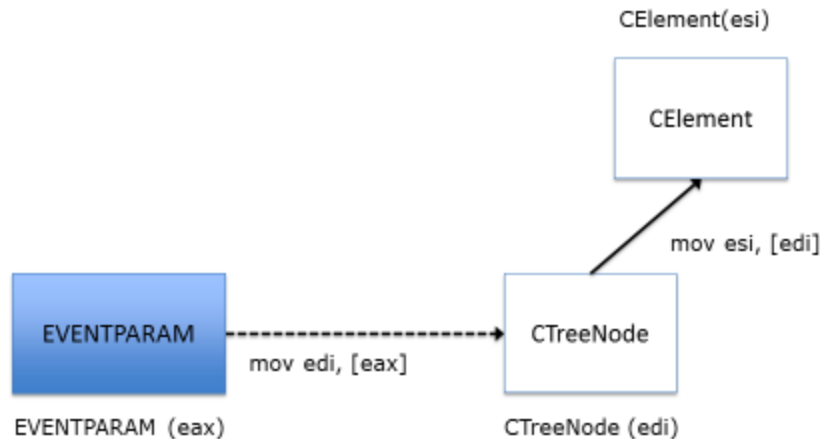


```
free(pointer);  
pointer->function();
```



The Aurora Use-After-Free Vulnerability

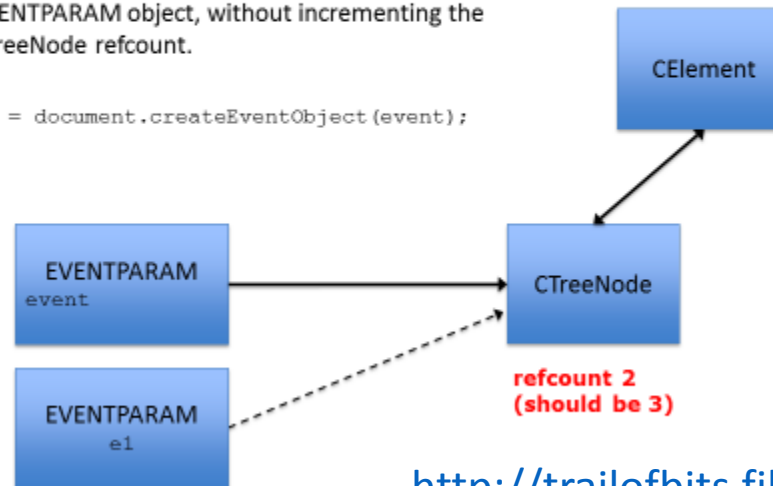
The Aurora Vulnerability



The Aurora Vulnerability

The event handler function creates a copy of the EVENTPARAM object, without incrementing the CTreeNode refcount.

```
e1 = document.createObject(event);
```



EVENTPARAM Copy Constructor

What is wrong with this copy constructor?

```
.text:74E4C892 ; public: __thiscall EVENTPARAM::EVENTPARAM(st
.text:74E4C892
.text:74E4C892 arg_0      = dword ptr  8
.text:74E4C892 arg_4      = dword ptr  0Ch
.text:74E4C892
.text:74E4C892          mov     edi, edi
.text:74E4C894          push    ebp
.text:74E4C895          mov     ebp, esp
.text:74E4C897          push    ebx
.text:74E4C898          mov     ebx, [ebp+arg_0]
.text:74E4C89B          push    esi
.text:74E4C89C          mov     esi, [ebp+arg_4]
.text:74E4C89F          push    edi
...
.text:74E4C8D5          push    3Eh
.text:74E4C8D7          pop     ecx
.text:74E4C8D8          mov     edi, ebx
.text:74E4C8DA          rep movsd
```

aurorauaf.py (62 lines)

- aurorauaf checks a binary for compiler-generated copy constructors
- Uses IDAPython to find copy constructors and demangle their names
- Visual C++ uses `rep movsd` for shallow-copy copy constructors
- Low false-positive rate, but high false-negative rate
- Copy constructors are very often inlined by Visual C++ compiler

<https://github.com/HockeyInJune/Contemporary-Automatic-Program-Analysis>

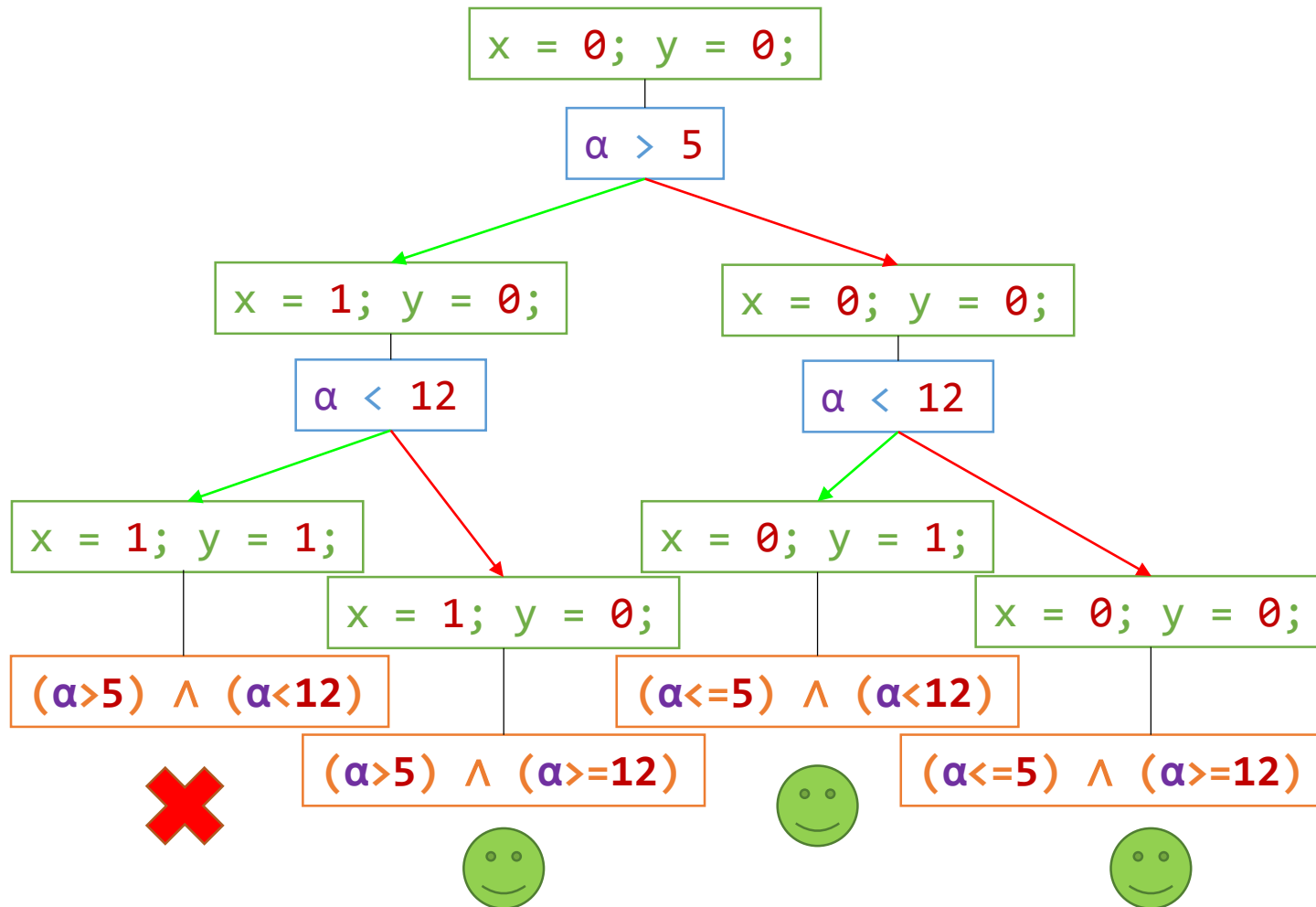
aurorauaf.py

- Output:

`EVENTPARAM::EVENTPARAM(EVENTPARAM const *)` looks
compiler generated! Check it out at [0x74e4c892](#)

`CEditEvent::CEditEvent(CEditEvent const *)` looks
compiler generated! Check it out at [0x750bbfc2](#)

Symbolic Execution



```
int a = α; //symbolic
int x = 0, y = 0;
if ( a > 5 ) {
    x = 1;
}
if ( a < 12 ) {
    y = 1;
}
assert( x + y != 2 );
```

Constraint Solving

- z3, theorem prover, Lisp s-expression interpreter

$(\alpha > 5) \wedge (\alpha < 12)$ ❌

```
(declare-const a Int)      sat
(assert (> a 5))            (model
(assert (< a 12))          (define-fun a () Int
(check-sat)                6)
(get-model)                )
```

LLVM KLEE

- KLEE is an automatic test case generator built on top of LLVM
- Uses symbolic execution to explore potential states of a program
- Constraint solving to generate test cases to increase code coverage
- Excellent at increasing code coverage and generating test cases
- Requires source code or LLVM bitcode

<http://klee.github.io/klee/>

LLVM KLEE

```
#include <klee/klee.h>
int main(int argc, char** argv) {
    int a; //symbolic
    klee_make_symbolic(&a, sizeof(a), "a");
    int x = 0, y = 0;
    if ( a > 5 ) { x = 1; }
    if ( a < 12 ) { y = 1; }
    if ( ( x + y ) == 2 ) { return -1; }
    else { return 0; }
}
```

LLVM KLEE

```
u@ec2:~/klee/examples/demo$ klee demo.o
```

```
KLEE: output directory is "klee/examples/demo/klee-out-0"
```

```
KLEE: done: total instructions = 62
```

```
KLEE: done: completed paths = 3
```

```
KLEE: done: generated tests = 3
```

```
u@ec2:~/klee/examples/demo$ ktest-tool test000001.ktest
```

```
object      0: name: 'a'
```

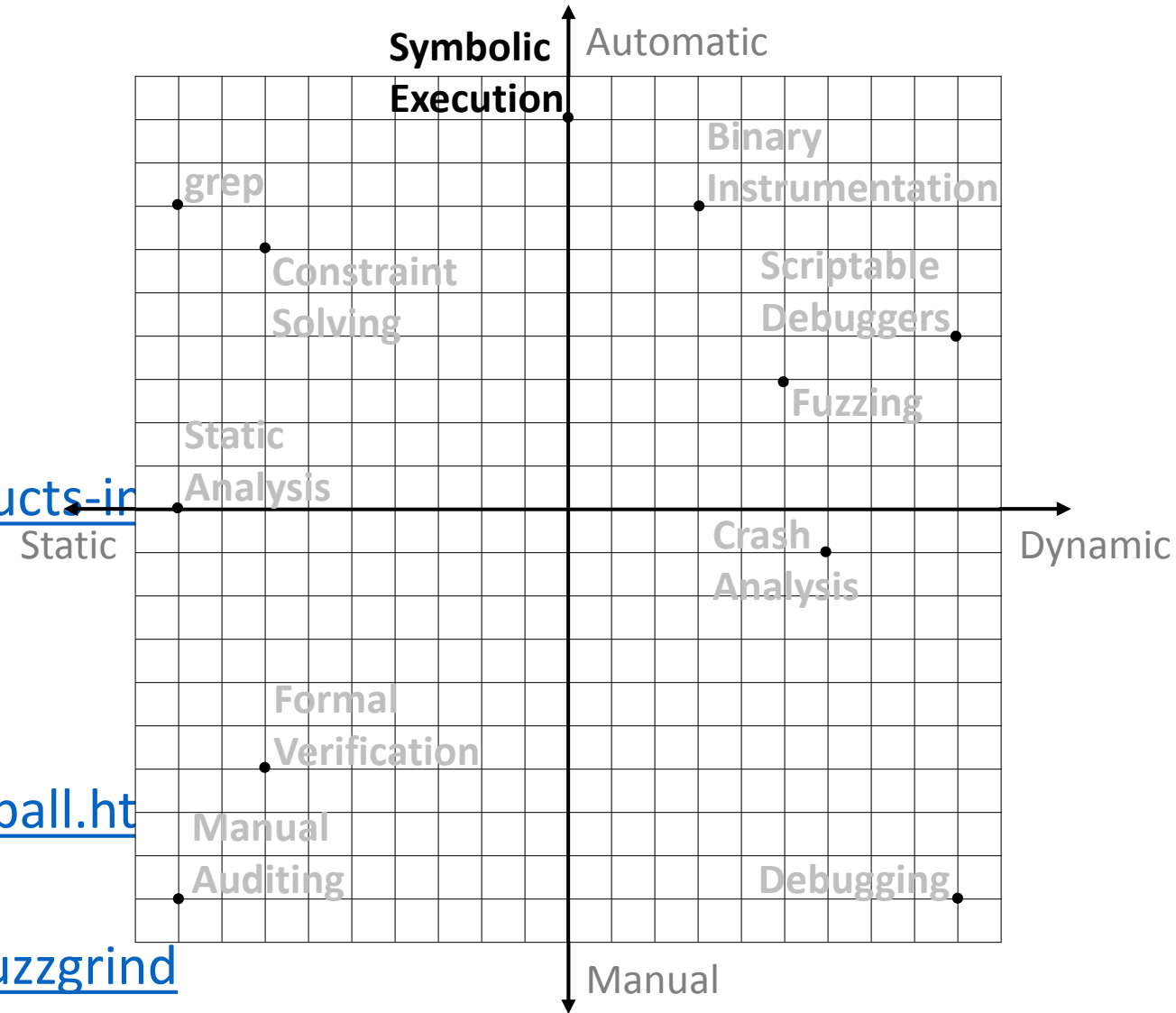
```
object      0: size: 4
```

```
object      0: data: 0
```

LLVM KLEE Demo

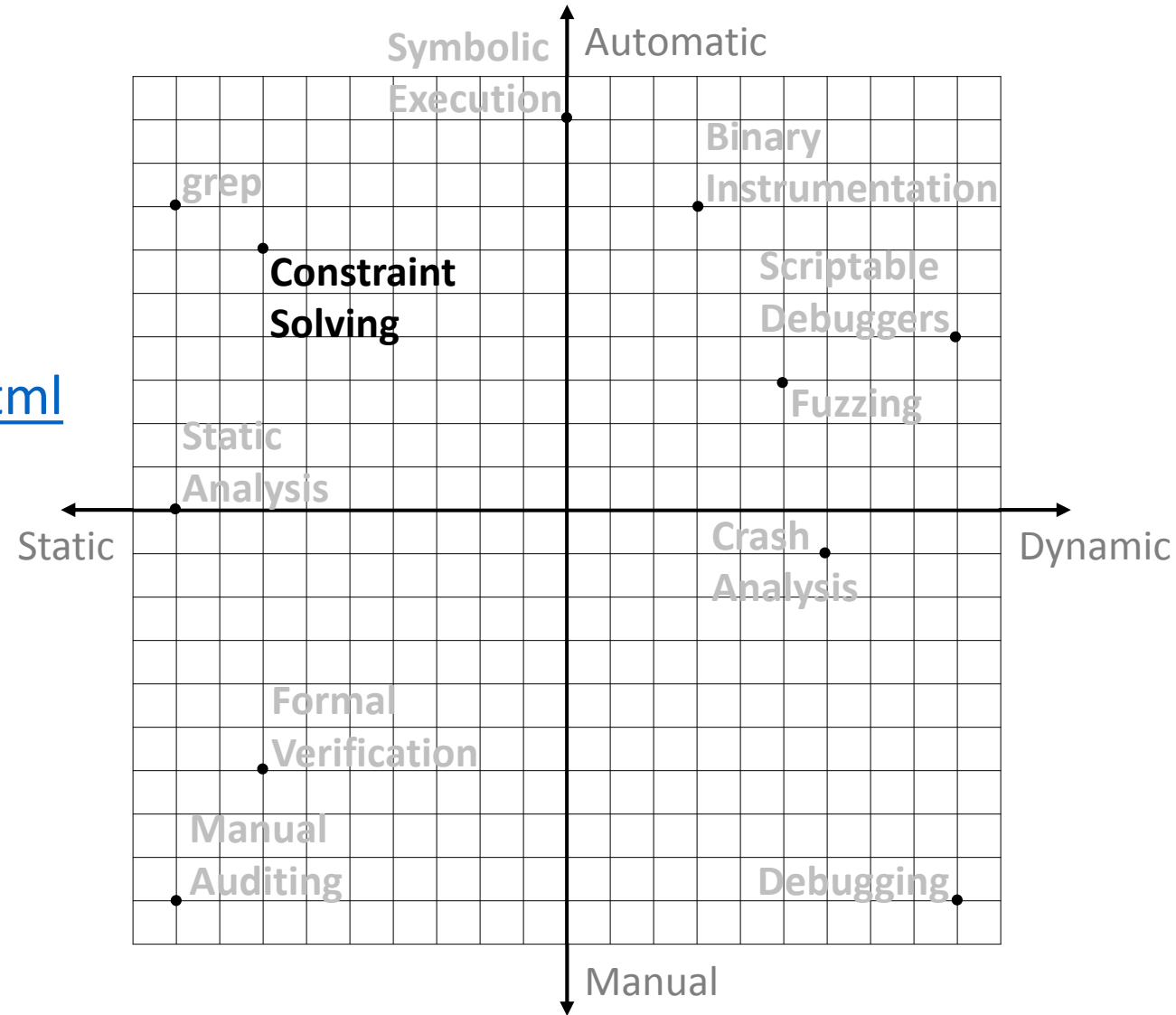
Symbolic Execution Engines

- S2E
 - <http://s2e.epfl.ch/>
- Clang Static Analyzer
 - <http://clang-analyzer.llvm.org/>
- Immunity Debugger
 - <http://www.immunityinc.com/products-immunity-debugger/>
- KLEE
 - <http://klee.github.io/klee/>
- FuzzBALL
 - <http://bitblaze.cs.berkeley.edu/fuzzball.html>
- Fuzzgrind
 - <http://esec-lab.sogeti.com/pages/Fuzzgrind>



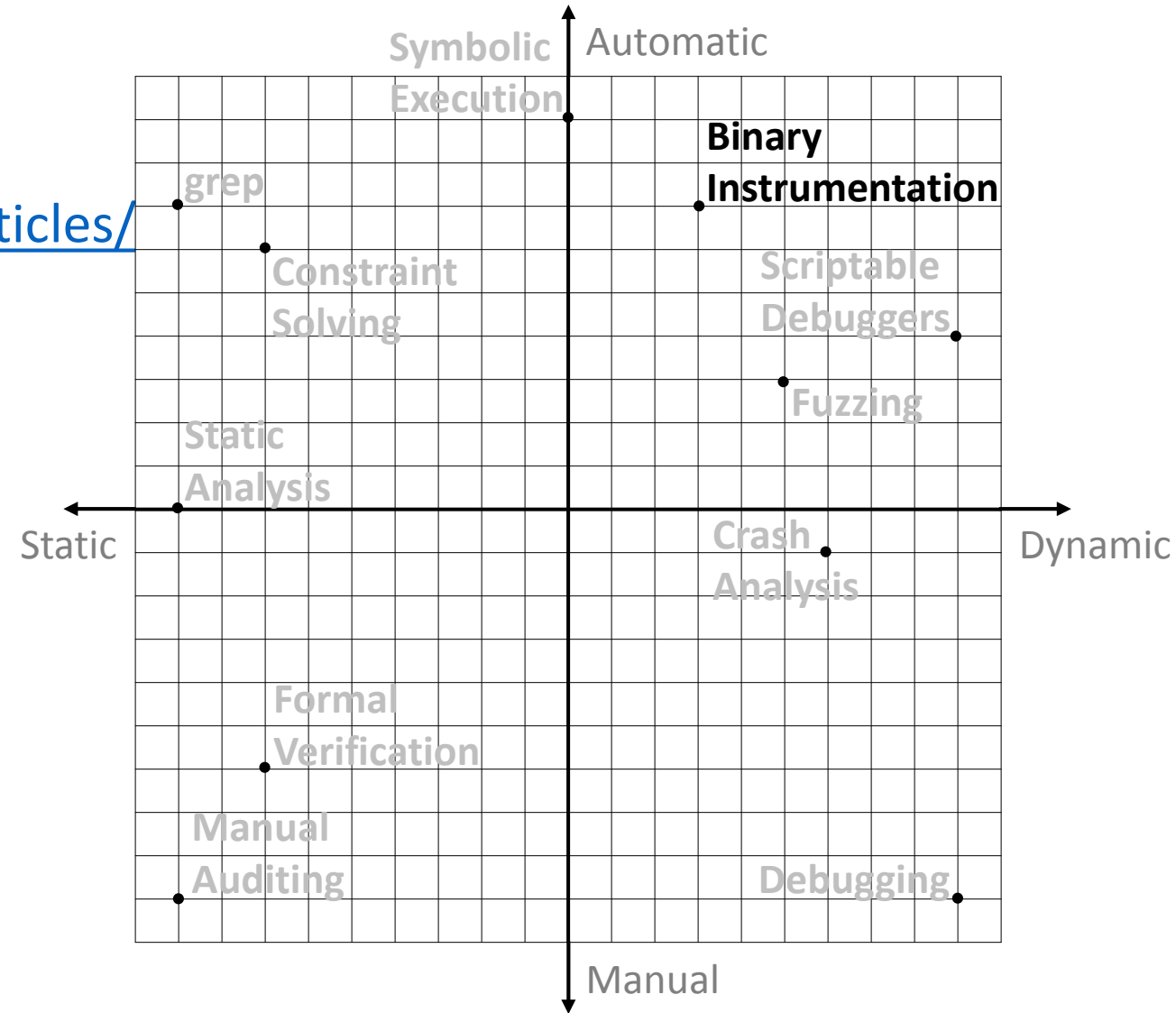
Constraint Solvers

- z3
 - <http://z3.codeplex.com/>
- Kleaver
 - <http://klee.github.io/klee/KQuery.html>
- STP
 - <http://stp.github.io/stp/>
- CVC4
 - <http://cvc4.cs.nyu.edu/web/>
- Yices 2
 - <http://yices.csl.sri.com/>



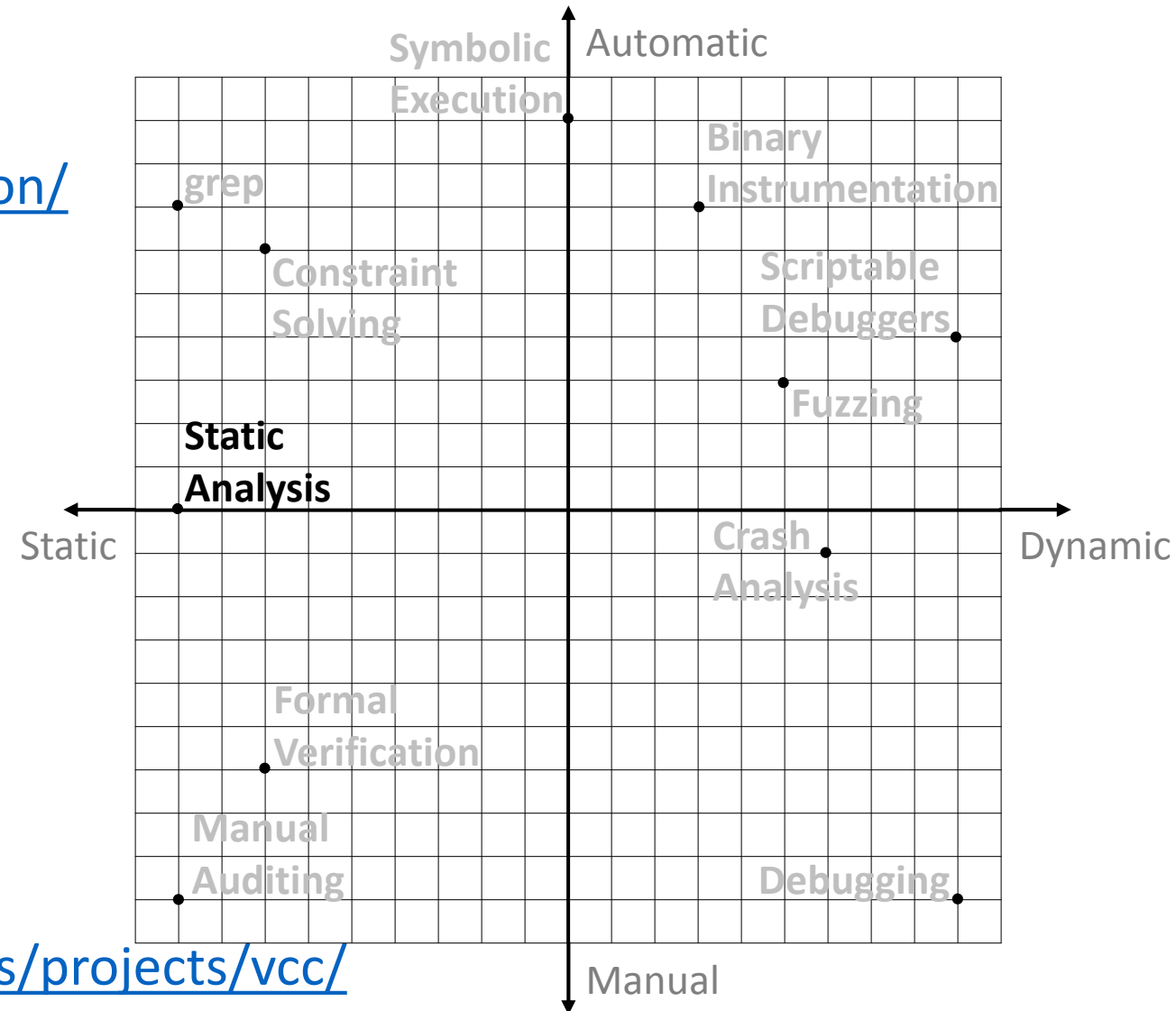
Binary Instrumentation Engines

- PIN
 - <https://software.intel.com/en-us/articles/>
- DynamoRIO
 - <http://dynamorio.org/>
- Valgrind
 - <http://valgrind.org/>



Static Analysis Platforms

- IDA Python
 - <https://code.google.com/p/idapython/>
- BAP: Binary Analysis Platform
 - <http://bap.ece.cmu.edu/>
- Insight
 - <http://insight.labri.fr/trac>
- Jakstab
 - <http://www.jakstab.org/>
- Stack
 - <http://css.csail.mit.edu/stack/>
- VCC: A Verifier for Concurrent C
 - <http://research.microsoft.com/en-us/projects/vcc/>



Conclusions

Program analysis is a set of powerful, low-cost techniques

If you do vulnerability discovery, invest in program analysis

Thanks

Andrew Ruef

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Ben Nell

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John Villamil

Julien Vanegue

#bap on Freenode

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Chris Rohlf

Dan Guido

Dino Dai Zovi

Erik Cabetas

Geri Del Priore

John Terrill

Jordan Wiens

Look at all the bugs we discovered!
Do you have any questions about them?

