In Search Of Shotgun Parsers

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Overview

Context

Defining The Shotgun Parser

Tainted Path Length In Android Applications

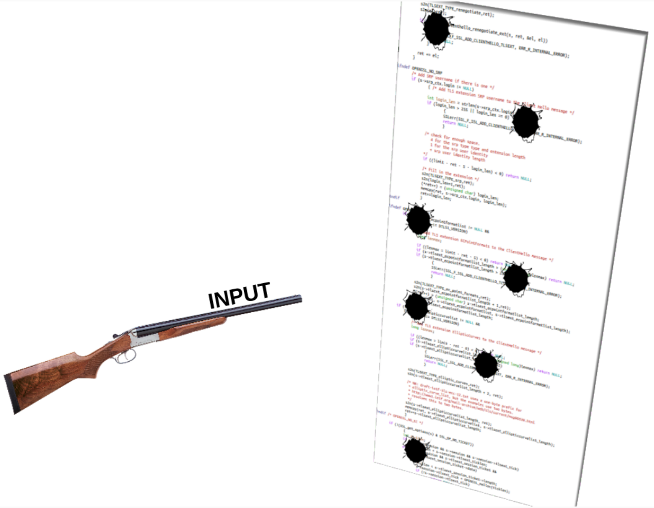
Our Definition In The Wild

Future Work

WHAT ARE WE LOOKING FOR?

Defining The Shotgun Parser

Why Shotgun?



Input **use** and **recognition** intermixed throughout!

What Are We Looking For?

- Before we go searching for shotgun parsers, we need to know what we're looking for!
- How will we know a shotgun parser when we see one?
- We frame our definition in the context of static taint analysis of control flow graphs

Hallmarks of the Shotgun Parser

Large Spread Relative To Size

How far does untrusted data propagate through the code?

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Use Before Full Recognition

Is input data fully validated before being used?

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Large Number of Variables Involved In Each Tainted Path

How much program state is affected by properties 1 and 2?

Property 1: Spread Relative To Size

- Consider an application $\mathcal{A}$, which reads a set of untrusted inputs $\mathcal{N}$

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- Let P_n be the connected subgraph induced by the vertices of G tainted by $n \in \mathcal{N}$, where $d(P_n) \leq d(G)$
- Let $S = \{P_i | 1 \leq i \leq |\mathcal{N}|\}$ be the set of all taint-induced subgraphs on G

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Shotgun parser indicators:

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Shotgun parser indicators:

- $d(P_n)$ comparable to $d(G)$
  - $\rightarrow$ Indicates input n not handled in principled manner
- Large $|S|$
  - $\rightarrow$ Evidence for presence of multiple shotgun parsers in $\mathcal{A}$

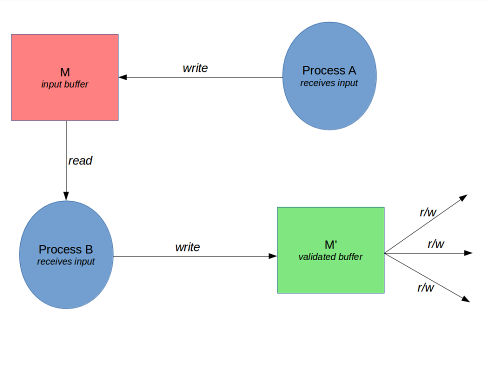
Property 2: Use Before Full Recognition

- We can't quantify whether arbitrary input to an arbitrary piece of code is "fully recognized"

- We *can* start to define a set of standards for handling of specific data types

Property 2: Use Before Full Recognition

For example:



- "For inputs of type *O*, you must do 5 reads of 4 bytes each, then write 20 bytes in a specific order"
- Identify read/write memory events which take place after input is received

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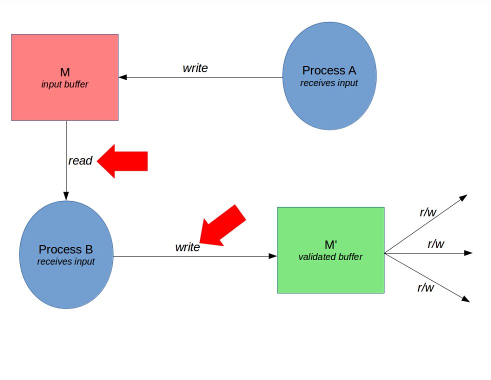

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Property 3: Number of Tainted Input Variables

- Consider again a tainted subgraph P_n

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- Consider again a tainted subgraph P_n
- Let P_n now be a weighted graph, where each edge $E(x, y)$ corresponds to the number of variables tainted by n after node x

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Shotgun parser indicators:

- Large number of tainted variables compared to total number of variables
  → Indicates untrusted input affects significant proportion of program state

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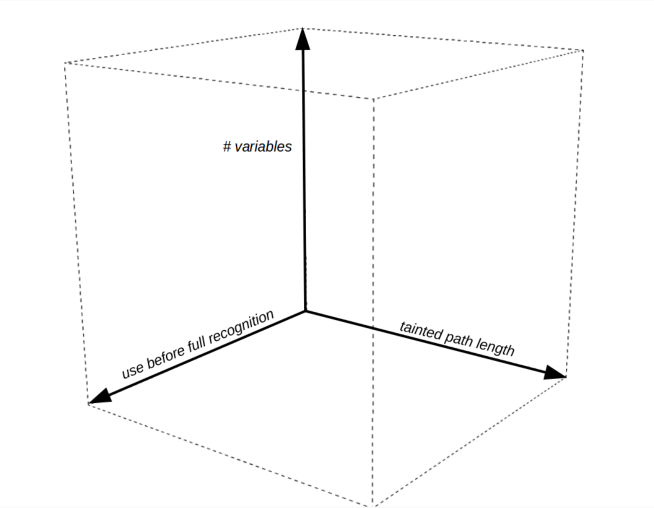
Shotgun parser indicators:

- Large number of tainted variables compared to total number of variables
  - → Indicates untrusted input affects significant proportion of program state
- Areas of P_n where edge weight increases may merit further study
  - → Allows us to triage program statements / methods for further analysis

Definition Summary



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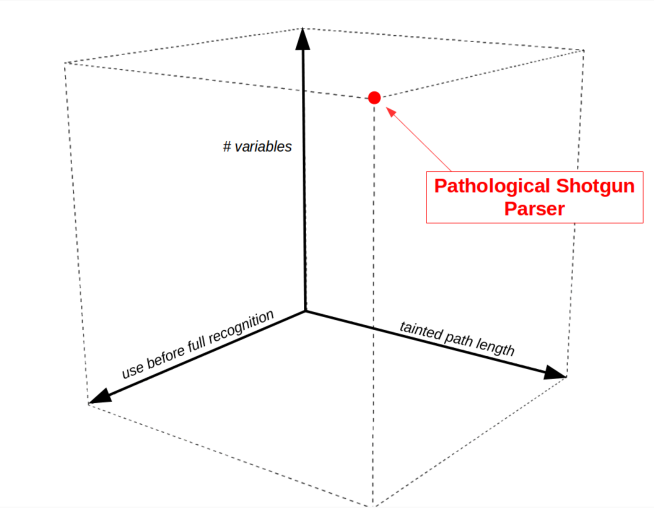


The “worst case” shotgun parser exhibits all three properties in abundance!

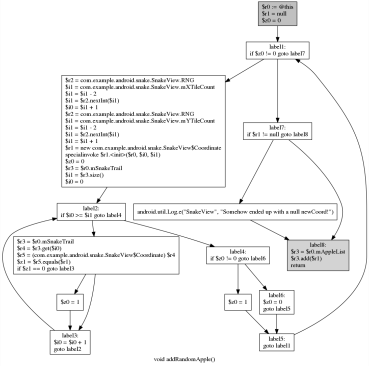
CASE STUDY: ANDROID

First Steps Towards Automated Detection

Our Goals

- Establish foundation for a recognizer
- First look at "state of affairs" in Android applications
- Start examining a different class of errors through the LangSec lens

Our Approach



Jimple CFG for one module of the classic game "Snake"

- Static taint analysis of statement-level control flow graphs
- Compute length of tainted path corresponding to each source
- Analysis uses the Jimple intermediate representation

FlowDroid

- Open-source static analysis framework for Android
- Developed by the Secure Software Engineering Group at Paderborn University/ TU Darmstadt

https://blogs.uni-paderborn.de/sse/tools/flowdroid/

We Add:

- Tracking for *all* tainted paths, not only those terminating in a sink
- Unique identifiers for each taint source
- Specific API call source for each taint
- Taint propagation handler functions to measure input path length

Our Implementation

Each time a taint is propagated, our custom handler is invoked:

- Capture incoming flow data object *F* and outgoing set of flow data objects $\mathcal{F}_{\text{out}}$
- If *F* has not been seen before:
  - Init *F*.`length` = 0
  - Store original source context of *F*.
- For each flow fact $f \in \mathcal{F}_{\text{out}}$:
  - *f*.`length` = *F*.`length` + 1
  - Store source context information for *f*

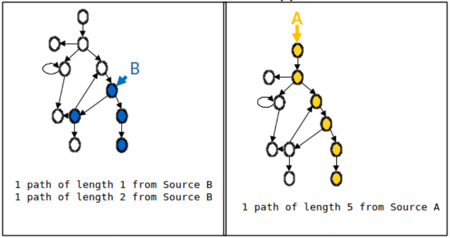
Workflow

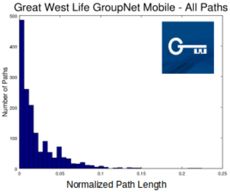
FlowDroid logo credit – Secure Software Engineering Group at the European Center for Security and Privacy by Design

- 56 free apps from 12 different categories

- FlowDroid – Android Data Flow Analysis
- Modified this open-source tool to calculate tainted path lengths

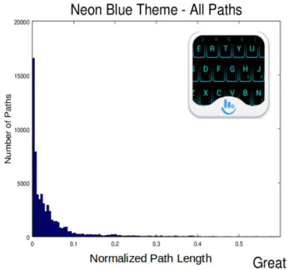
- Measure lengths of all tainted paths for each application

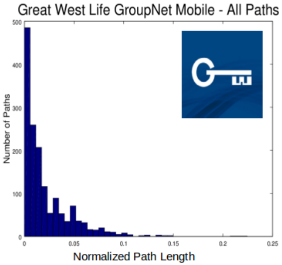




- Histogram of normalized path lengths

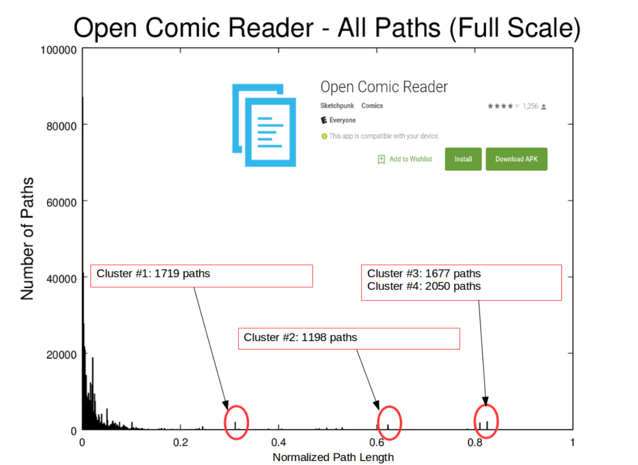
Initial Results





Some Thoughts..

- Our tool is:
  - The foundation of a full SGP recognizer
  - A *prioritization method* for app analysis



OUR DEFINITION IN THE WILD

Let’s Look At Real Stuff

"ImageTragick" (CVE-2016-3714)

```
  sanitize_command=SanitizeDelegateCommand(command);
  if (asynchronous != MagickFalse)
    (void) ConcatenateMagickString(sanitize_command,"&",MagickPathExtent);
  if (message != (char *) NULL)
    *message='\0';
#if defined(MAGICKCORE_POSIX_SUPPORT)
#if !defined(MAGICKCORE_HAVE_EXECVP)
  status=system(sanitize_command);
#else
  if ((asynchronous != MagickFalse) ||
      (strpbrk(sanitize_command,"&;<>|") != (char *) NULL))
    status=system(sanitize_command);
  else
    {
      pid_t
        child_pid;

      /*
        Call application directly rather than from a shell.
      */
      child_pid=(pid_t) fork();
      if (child_pid == (pid_t) -1)
        status=system(sanitize_command);
      else
        if (child_pid == 0)
          {
            status=execvp(arguments[1],arguments+1);
            _exit(1);
          }
        else
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```
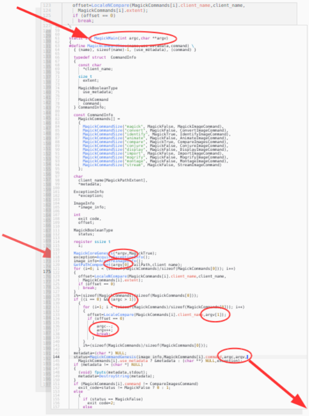

```
static char *SanitizeDelegateCommand(const char *command)
{
  char
    *sanitize_command;

  const char
    *q;

  register char
    *p;

  static char
    whitelist[] =
      "ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz0123456789_- "
      ".@&;<>()|/\\\'\":%=~`";

  sanitize_command=AcquireString(command);
  p=sanitize_command;
  q=sanitize_command+strlen(sanitize_command);
  for (p+=strspn(p,whitelist); p != q; p+=strspn(p,whitelist))
    *p='_';
  return(sanitize_command);
}
```

"ImageTragick" (CVE-2016-3714)

```c
      offset=LocaleNCompare(MagickCommands[i].client_name,client_name,
        MagickCommands[i].extent);
      if (offset == 0)
        break;
    }
    i%=(sizeof(MagickCommands)/sizeof(MagickCommands[0]));
    if ((i == 0) && (argc > 1))
      {
        for (i=1; i < (sizeof(MagickCommands)/sizeof(MagickCommands[0])); i++)
        {
          offset=LocaleCompare(MagickCommands[i].client_name,argv[1]);
          if (offset == 0)
            {
              argc--;
              argv++;
              break;
            }
        }
        i%=(sizeof(MagickCommands)/sizeof(MagickCommands[0]));
      }
    metadata=(char *) NULL;
    status=MagickCommandGenesis(image_info,MagickCommands[i].command,argc,argv,
      MagickCommands[i].use_metadata ? &metadata : (char **) NULL,exception);
    if (metadata != (char *) NULL)
    {
      (void) fputs(metadata,stdout);
      metadata=DestroyString(metadata);
    }
    if (MagickCommands[i].command != CompareImagesCommand)
      exit_code=status != MagickFalse ? 0 : 1;
    else
      {
        if (status == MagickFalse)
          exit_code=2;
        else
        {
          const char
            *option;

          option=GetImageOption(image_info,"compare:dissimilar");
          exit_code=IsStringTrue(option) ? 1 : 0;
        }
      }
    image_info=DestroyImageInfo(image_info);
    exception=DestroyExceptionInfo(exception);
    MagickCoreTerminus();
    return(exit_code);
}

#if !defined(MAGICKCORE_WINDOWS_SUPPORT) || defined(__CYGWIN__) || defined(__MINGW32__)
int main(int argc,char **argv)
{
    return(MagickMain(argc,argv));
}
#else
int wmain(int argc,wchar_t *argv[])
{
    char
      **utf8;

    int
      status;

    register int
      i;

    utf8=NTArgvToUTF8(argc,argv);
    status=MagickMain(argc,utf8);
    for (i=0; i < argc; i++)
      utf8[i]=DestroyString(utf8[i]);
    utf8=(char **) RelinquishMagickMemory(utf8);
    return(status);
}
#endif
```

"ImageTragick" (CVE-2016-3714)



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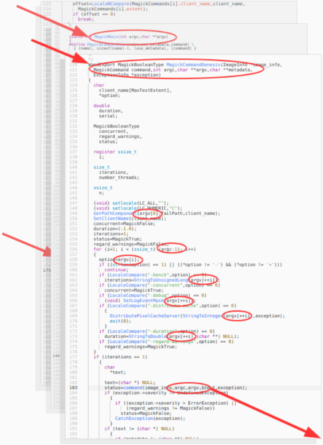

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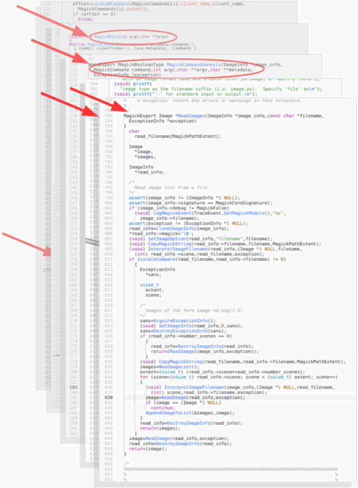

"ImageTragick" (CVE-2016-3714)

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Observations:

- (Relatively) long path
  - 7 direct function calls between input and (attempted) validation, but input is also passed elsewhere
- *Raw input* is passed between (and used in) 5 different functions before being read into a native data structure
- Input use and validation is intermixed
- Unsuitable validation mechanism

"Heartbleed" (CVE-2014-0160)

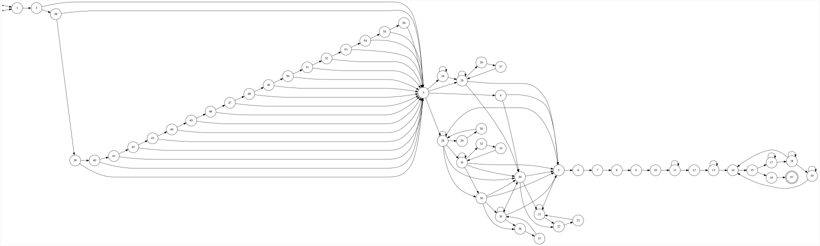
```
tls1_process_heartbeat(SSL *s)
        {
        unsigned char *p = &s->s3->rrec.data[0], *pl;
        unsigned short hbtype;
        unsigned int payload;
        unsigned int padding = 16; /* Use minimum padding */

        /* 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);
                bp += payload;
                /* Random padding */
                RAND_pseudo_bytes(bp, padding);
```

"Heartbleed" (CVE-2014-0160)

Observations:

- Input passed via several function calls before processing, but not used along the way
- Low degree of input use / validation intermixing, however...
- Almost *total* lack of validation of heartbeat payload!

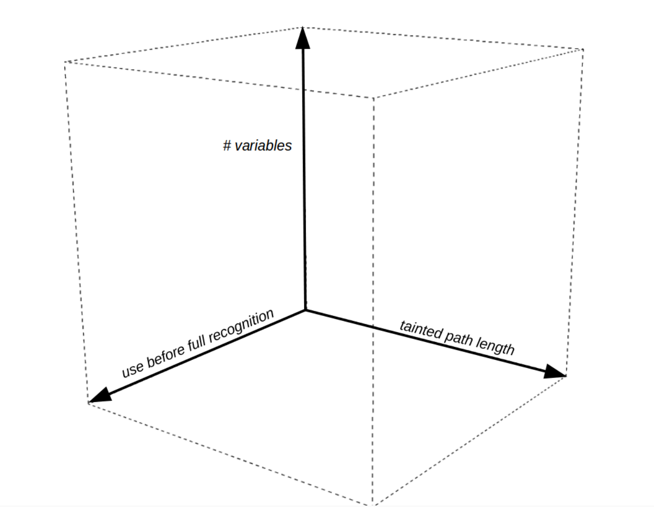
Mongrel Web Server - HTTP 1.1 Parser



Parsing Done Right!

- Define a finite state machine for HTTP parsing (uses the Ragel compiler)
- Finite state machine $\equiv$ regular grammar
- Input language is correctly, formally defined
- Input data is correctly, formally recognized

In The Context Of Our Definition...



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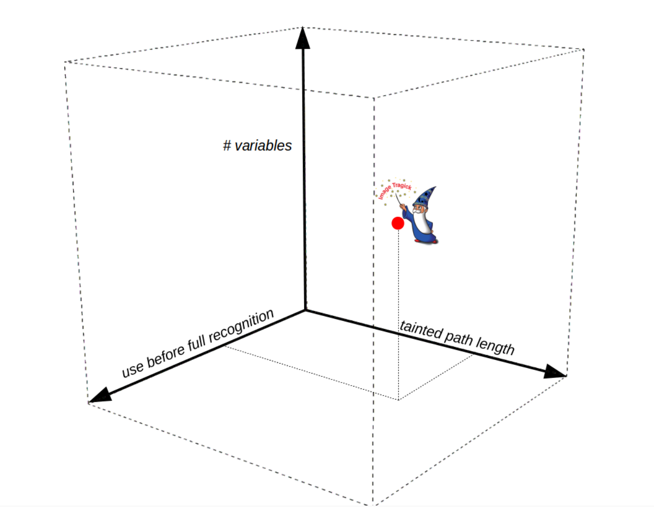

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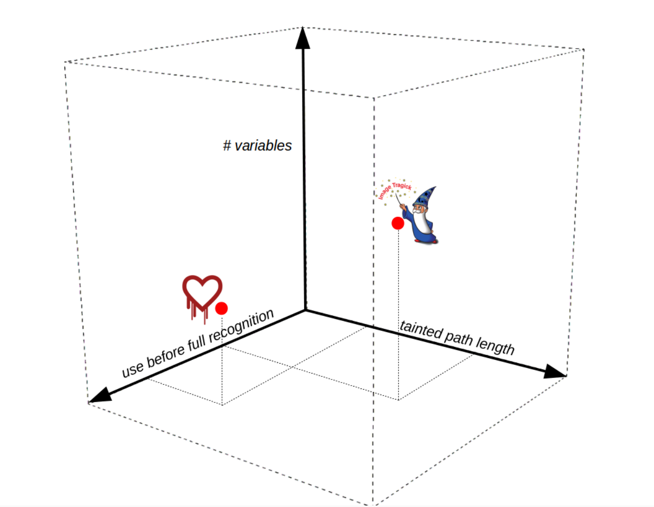

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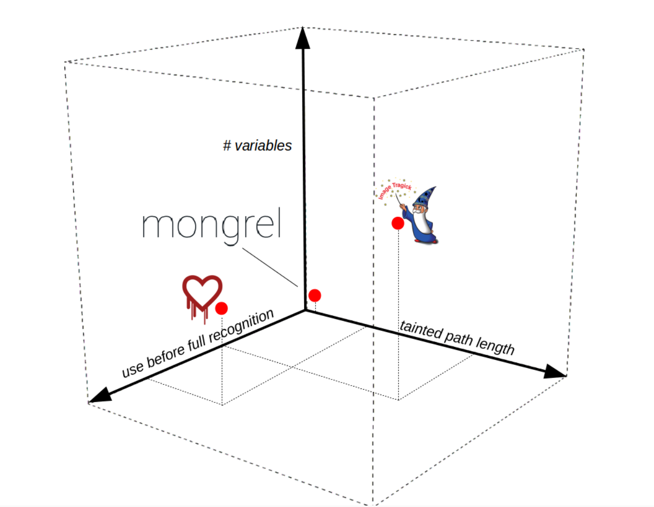

FUTURE WORK

Where Do We Go From Here…

Many Roads Lead From Here

- "Climb the hill of Android"
- Develop automated analysis frameworks based on our definition for other software ecosystems
- Develop well-defined input/output patterns for common types (characterize "recognition")
- Rigorously characterize existing vulnerabilities
- . . .

Acknowledgements

We gratefully acknowledge Steven Arzt from the Secure Software Engineering Group at TU Darmstadt *for his ongoing assistance with technical questions about FlowDroid via the Soot mailing list*

Other Thoughts...

- Not all vulnerabilities are shotgun parsers...and not all shotgun parsers are necessarily vulnerable

- However:
    - If input data is scattered throughout the code - not just an issue of attack surface, but being error-prone
    - Path length also speaks to how long it takes you to *do* the parsing - why aren't you validating as soon as data enters your software?

Practical Issues

- Platform specific complications
  - → FlowDroid dummy main method - necessary due to Android Lifecycle
- Abstraction level
  - → Jimple is an intermediate representation
- Static analysis of real applications is memory intensive!
  - → And we had time constraints...