

A Maze of Twisty Passages all Alike:  
*A Bottom-Up Exploration of Open Source  
Fuzzing Tools and Frameworks*

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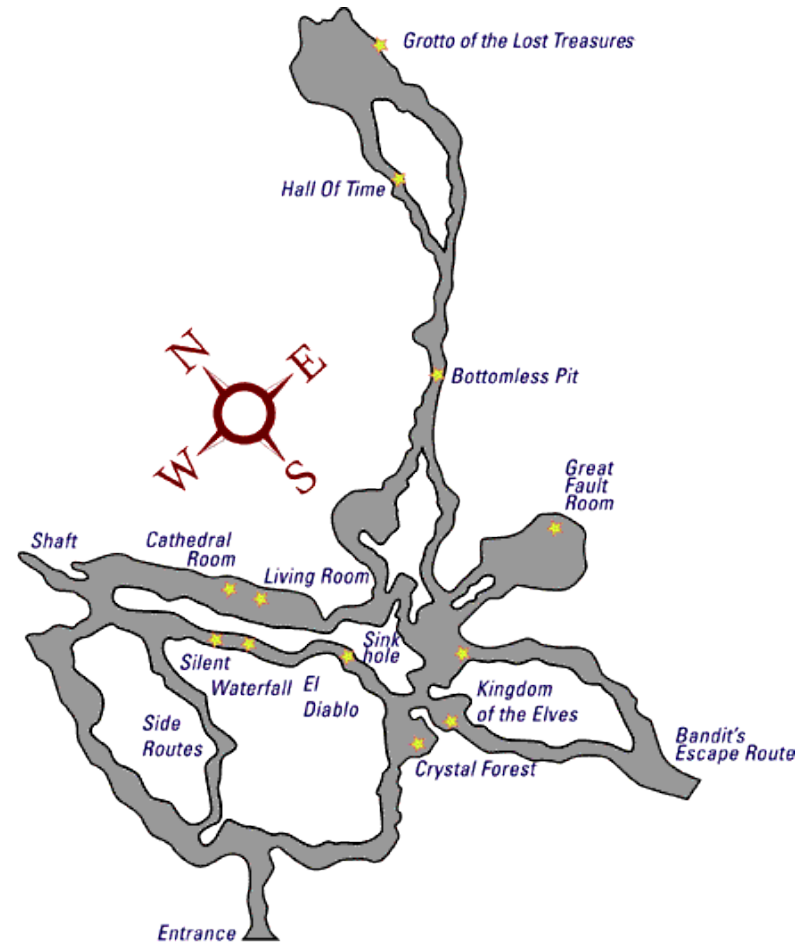
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CERT Vulnerability Discovery Workshop (Feb 2010)

# Agenda

- Introduction
- Beyond smart & dumb fuzzers
- A Case Study in Fuzzer Selection
- Conclusions (and stuff I ran out of time on)



# Where I'm coming from...

- Lots of “big company” security QA/R&D during early-mid 2000s
  - Primarily dealt with binary protocols on embedded devices
  - Wrote a variety of protocol-specific fuzzers and two attempts at block-based multi-protocol fuzzing frameworks (in Python/C#)
  - Used some commercial tools near the end
- Some on-the side (mostly unbillable) vuln research in a small SCADA security consulting firm
  - If Amap and Nessus find bugs, your fuzzers can be pretty crude
  - Still somewhat traumatized by the SCADA disclosure debate
- Enjoyed a sabbatical from vuln research & pen-testing from late 2006 to mid-2009, but slowly getting back into it again
  - Sneak some robustness testing in compliance engagements
  - Focusing Smart Grid (AMI), SCADA redux, etc.
  - Trying to resist the temptation of writing new tools from scratch

# Fuzzing in 2010

- No longer exotic/boutique
  - Responsible for some non-trivial % of vulns discovered
  - Even integrated into commercial signature based vuln scanners
- Over 100 fuzzers on Jeremy Brown's list
  - Range of capabilities and usability/usefulness
  - Dormant to active development
  - Crude Perl hacks to well-defined documented APIs
- Can there be too many choices?



# Objectives & Non-Objectives of this Talk

- Try to untangle the “maze” of FOSS fuzzers by:
  - Isolating the discrete feature-sets most useful for performing efficient software security testing
  - Developing a framework for evaluating and selecting tools for specific users & use cases
  - Identifying common (and useful) design & implementation approaches and highlight some standouts and areas for development
- Avoiding some more interesting problems
  - Coverage metrics
  - Effectiveness and track record of tools
  - Fuzzing bake-off vs. reference implementations
  - Commercial vs. Open Source capabilities

# Who uses Fuzzers and why do we care?

- QA/test engineers
  - “Click on start” and give me a traffic light when done
  - Coverage, repeatability, test case reduction are a major concern
- Pen-testers of various shapes & sizes
  - That probably know how to do a little scripting
  - That should know how protocols work on the wire
  - A single bug might be good enough
- Hard core bug hunters
  - That could implement the protocols they are testing (in .asm)

This diversity of objectives, backgrounds, requirements, programming/scripting languages has led to the “the maze”

# Exploration Approach

- Biases
  - Religious conviction that C (and Perl) should be avoided at all costs and that simple small lightweight tools are always best
  - Selfish interest in binary & proprietary network protocols
  - Which tools would be the most useful for some upcoming projects and that could be used by members of my team (who have less experience with robustness testing)
- Evaluation criteria
  - Tools had to support multiple protocols /applications/file format
  - Compiled relatively easily on a recent version of Ubuntu
  - Open Source only (wasn't anal about license terms)
  - Web client/server tools were sufficiently different to exclude them
- Analysis process
  - Too much time reading through source code and trying to get them to work
  - Not enough time fully testing all the features on real protocols
  - Focus was on identifying discrete attributes (see the .xls for the raw data)
  - Validated scheme based on a larger number of tools and then narrowed down

**BEYOND SMART & DUMB FUZZERS**



# Attributes of Fuzzers/Frameworks

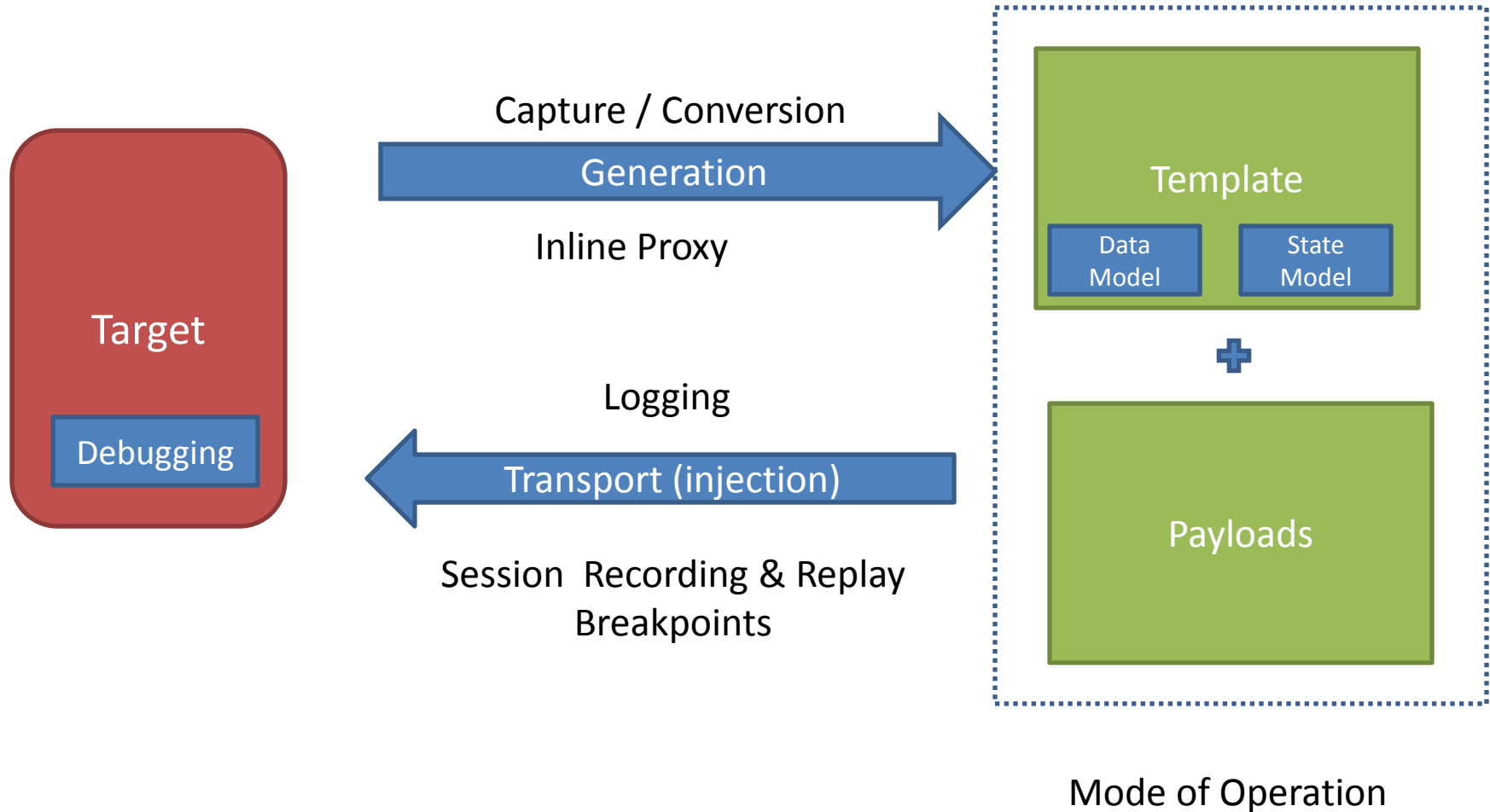
- Target – external interface under test
  - Client, Server, Parser, Kernel, Protocol, etc.
- Mode of Operation
  - API
  - Executable
- Language – Python, C, Ruby, etc.
- Transport – you can inject test cases into the application/protocol (TCP, IP, UDP, SSL, IPv6)
- Template
  - Generation – manual automated, inline, from traces, file source
  - Data Model – representation of messages and protocol state
  - Built-in Functions – crypto, checksum, hashes, encoding, etc.

# Attributes of Fuzzers & Frameworks (cont.)

- Fault Payloads
  - “canned” vs. programmatic
  - buffer overflow, format string, bit shifting, etc.
- Debugging & Instrumentation
  - Fault detection
  - Control and monitoring of target (both internal
- Session Handling
  - Capture, storage, replay
  - Logging
  - Interactive vs. Unattended
  - Pause, stop restart, breakpoints
- Documentation & Examples

See the spreadsheet for the details...

# Attributes & Workflow (all features)



# Operating Modes

- Approaches
  - API-based
    - Write code in a scripting language
    - Extend existing processors
    - **Examples:** sulley, ruckus, peach, fuzzled
  - Executable
    - Execute fuzzing engine against a more/less complex configuration file with more/less complex command-line options
    - **Examples:** peach, GPF, autodafe
- Primary consideration: time to test/develop
  - Go with executable if you have limited time
  - If you have to partially implement the protocol anyway you should probably go with API
  - Some configurations files (templates) are more convoluted than coding

# More on Templates

- Template development is the most tedious (and sometimes difficult) process of modeling the valid/invalid data
- Auto generation of an “unknown” protocol remains a “holy grail” problem
  - This is was the point of the protocol informatics (PI) project

# Example Template Files

```
block_begin("packet_3");
block_end("packet_3");
send("packet_3"); /* tcp */

block_begin("packet_4");
  block_begin("packet_4.6.54.mbtcp");
    // name      : modbus_tcp.trans_id
    // showname: transaction identifier: 0
    // show       : 0
    // size: 0x2 (2)
    hex(
    00 00
    );
    // name      : modbus_tcp.prot_id
    // showname: protocol identifier: 0
    // show       : 0
    // size: 0x2 (2)
    hex(
    00 00
    );
    // name      : modbus_tcp.len
    // showname: length: 6
    // show       : 6
    // size: 0x2 (2)
    hex(
    00 06
    );
    // name      : modbus_tcp.unit_id
    // showname: unit identifier: 1
    // show       : 1
    // size: 0x1 (1)
    hex(
    01
```

Autodafe (Modbus/TCP)

The screenshot shows the GPF (MongoDB) interface. The main window displays a hex dump of a packet. The right sidebar shows the source code for the packet. Below the hex dump, there are several input fields for converting the data to different formats.

Conversion Type	Value
Signed 8 bit:	83
Unsigned 8 bit:	83
Signed 16 bit:	28499
Unsigned 16 bit:	28499
Signed 32 bit:	1920298835
Unsigned 32 bit:	1920298835
32 bit float:	4.861338e+30
64 bit float:	7.429827e+15
Hexadecimal:	53
Octal:	123
Binary:	01010011
Stream Length:	8

☒ Show little endian decoding ☐ Show unsigned and float as hexadecimal

Offset: 0

GPF (MongoDB)

# A Peach Template

```
<!-- Create a simple data template containing a single string -->
<DataModel name="HttpRequest">

  <!-- The HTTP request line: GET http://foo.com HTTP/1.0 -->
  <Block name="RequestLine">

    <!-- Defaults can be optionally specified via the
         value attribute -->
    <String name="Method"/>
    <String value=" " type="char"/>
    <String name="RequestUri"/>
    <String value=" "/>
    <String name="HttpVersion"/>
    <String value="\r\n"/>
  </Block>

  <!-- This block uses the Header block as a base
       and overrides one field -->
  <Block name="HeaderHost" ref="Header">
    <String name="Header" value="Host" isStatic="true"/>
  </Block>

  <!-- This block uses the Header block as a base
       and overrides two fields -->
  <Block name="HeaderContentLength" ref="Header">
    <String name="Header" value="Content-Length" isStatic="true"/>
    <String name="Value">
      <!-- Indicate a relation between this field
           and the "Body" field. -->
      <Relation type="size" of="Body"/>
    </String>
  </Block>

  <String value="\r\n"/>

  <Blob name="Body" minOccurs="0" maxOccurs="1"/>
</DataModel>
```

```
<StateModel name="State2" initialState="Initial">
  <State name="Initial">
    <Action type="output">
      <DataModel ref="HttpRequest" />
      <Data ref="HttpOptions" />
    </Action>
  </State>
</StateModel>

<!-- Create a simple test to run -->
<Test name="HttpGetRequestTest" description="HTTP Request GET Test">
  <StateModel ref="State1"/>

  <!-- Target a local web server on port 80 -->
  <Publisher class="tcp.Tcp">
    <Param name="host" value="127.0.0.1" />
    <Param name="port" value="80" />
  </Publisher>
</Test>

<Test name="HttpOptionsRequestTest" description="HTTP Request OPTIONS Test">
  <StateModel ref="State2"/>

  <!-- Target a local web server on port 80 -->
  <Publisher class="tcp.Tcp">
    <Param name="host" value="127.0.0.1" />
    <Param name="port" value="80" />
  </Publisher>
</Test>

<!-- Configure a single run -->
<Run name="DefaultRun" description="HTTP Request Run">

  <!-- The set of tests to run -->
  <Test ref="HttpGetRequestTest" />
  <Test ref="HttpOptionsRequestTest" />

</Run>
```

Single XML file contains message format, states, and injection commands

# Auto Template Generation

- Approaches
  - PDML\*
    - Autodafe - pdml2ad generates block based description based on
    - Peach – allows creation of Peach pit
  - Pcap
    - GPF – creates text file (.gpf) that is replayed (with multiple malformation options)
  - Inline
    - Taof
- Caveats
  - Best to just use a single stream
  - PDML requires a Wireshark dissector

\* Not Open Source but pcapr.net does this and JSON file that you can run with `mudos` to inject the packets against a target



# Payload Generation

- Approaches
  - Primitive randomization
    - Tcpjunk, isic, GPF pure mode
  - “CGI-Scanner”-style dictionary of known bad requests (format strings, strings and numeric input to test boundary conditions
    - 4f,autodafe, SPIKE
  - Various mutation APIs
    - Peaches, Ruckus, Antiparser

# Tools by Development Status (Last Release)

## **Recent Development**

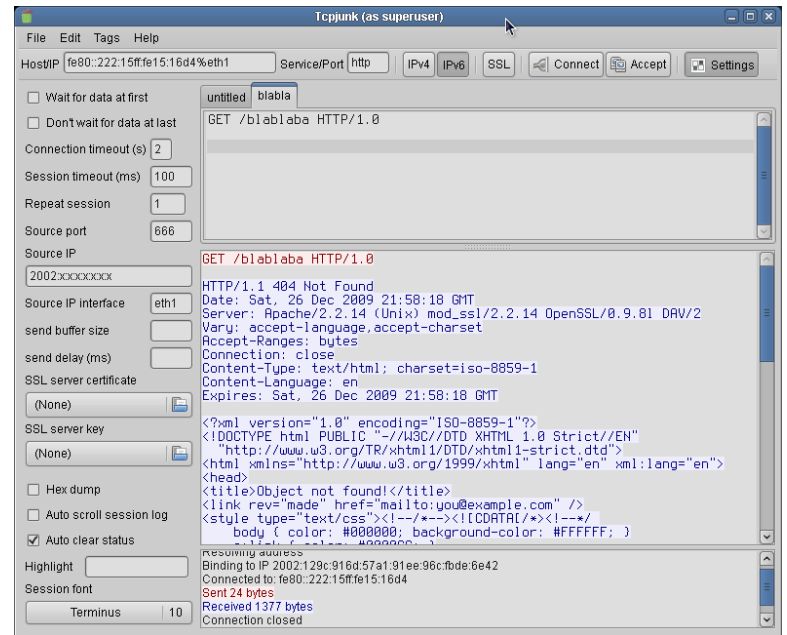
- Tcpjunk (1/2010)
- Peach (1/2010)
- Sulley (2/2009)
- Ruckus (4/2009)

## **Apparently Dormant**

- Fuzzled (10/2007)
- Autodafe (8/2006)
- Scratch (9/2004)
- SPIKE (4/2004)
- SMUDGE (9/2004)
- GPF (Jared?)

# Dealbreakers: Active Projects

- Peach
  - Robust set of features but a huge learning curve and insane dependencies (a 20MB installer?)
  - Not Linux/OSX friendly
  - PDML conversion disappeared/is hidden in 2.3.x
  - Maybe I can reuse some of the APIs
- Tcpjunk
  - No example templates
  - No way to automatically create them
  - ASCII protocol bias



# Recommended Improvements for the “Keepers”

- GPF
  - Write some wrappers for command-line arguments
- Taof
  - Better representation of binary protocols and marking of “fuzz points”
- Sulley
  - Automatic generation block descriptions

# **A CASE STUDY IN TOOL SELECTION**

# Fuzzing MongoDB in 20 minutes (hypothetically)



- What is MongoDB?
  - Document oriented #nosql database (in the same family as CouchDB)
  - Written in C++ (with broad driver support in various scripting languages)
  - Uses SpiderMonkey (or Google V8) for its .js engine – queries are in JavaScript (and JSON)
  - Has a proprietary JSON like serialization protocol called BSON

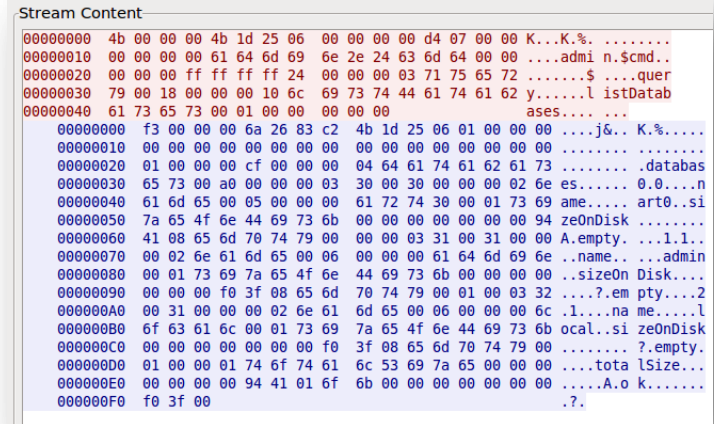
CAVEAT: <http://github.com/mongodb/mongo-c-driver/> does show evidence of embedded fuzzing in bson.c

# Selecting your fuzzer: info gathering

- Do you have a protocol specification?
- Is your protocol supported by Wireshark?
- What are the data types and representation format? Protocol states?
- Is authentication & encryption required?
- If authentication is required, can you replay?

# Info Gathering

- Protocol specification (partial)
  - <http://www.mongodb.org/display/DOCS/Mongo+Wire+Protocol>
- Not supported by Wireshark
  - PDML doesn't help me here
  - So I need to use GPF or Taof
- No authentication by default
- Mixed Binary + ASCII protocol
- Passes lots of JavaScript/JSON
  - Fusil might be a possibility here
- Build on existing client implementations?



Stream Content

```
00000000 4b 00 00 00 4b 1d 25 06 00 00 00 00 d4 07 00 00 K...K.%.....
00000010 00 00 00 00 61 64 6d 69 6e 2e 24 63 6d 64 00 00 ....admi n.$cmd...
00000020 00 00 00 ff ff ff ff 24 00 00 00 03 71 75 65 72 .....$ .....quer
00000030 79 00 18 00 00 00 10 6c 69 73 74 44 61 74 61 62 y.....l istDatab
00000040 61 73 65 73 00 01 00 00 00 00 00 00 00 00 00 00 ases.....

00000000 f3 00 00 00 6a 26 83 c2 4b 1d 25 06 01 00 00 00 ....j&.. K.%....
00000010 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
00000020 01 00 00 00 cf 00 00 00 04 64 61 74 61 62 61 73 ..... databas
00000030 65 73 00 a0 00 00 00 03 30 00 30 00 00 00 02 6e es..... 0.0....n
00000040 61 6d 65 00 05 00 00 00 61 72 74 30 00 01 73 69 ame..... art0...si
00000050 7a 65 4f 6e 44 69 73 6b 00 00 00 00 00 00 94 zeOnDisk .....
00000060 41 08 65 6d 70 74 79 00 00 00 03 31 00 31 00 00 A.empty. ....1.1..
00000070 00 02 6e 61 6d 65 00 06 00 00 00 61 64 6d 69 6e ..name.. ..admin
00000080 00 01 73 69 7a 65 4f 6e 44 69 73 6b 00 00 00 00 ..sizeOn Disk....
00000090 00 00 00 f0 3f 08 65 6d 70 74 79 00 01 00 03 32 ....?.em pty....2
000000A0 00 31 00 00 00 02 6e 61 6d 65 00 06 00 00 00 6c .1....na me.....l
000000B0 6f 63 61 6c 00 01 73 69 7a 65 4f 6e 44 69 73 6b ocal..si zeOnDisk
000000C0 00 00 00 00 00 00 f0 3f 08 65 6d 70 74 79 00 ..... ?.empty.
000000D0 01 00 00 01 74 6f 74 61 6c 53 69 7a 65 00 00 00 ....tota lSize...
000000E0 00 00 00 94 41 01 6f 6b 00 00 00 00 00 00 00 00 .....A.o k.....
000000F0 f0 3f 00 ..?..
```



# 20 Minute Results

- Taof
  - Used proxy mode to connect mongo client to server
  - Logged initial connection
- GPF
  - Server rejected all payloads generated by “simple fuzzing” - bad recv() mostly due to length
  - Converted login sequence and used replay mode
    - Many caught assertions in BSON processing and assertion failures
    - Created “interesting” databases and eventually a malloc failure

# CONCLUSIONS

# Non-Surprising Conclusions

- There is no single fuzzer (or framework) to “rule them all”
  - All of the tools have tradeoffs & feature/documentation gaps
- Seemingly dead projects (and even those written in C) can still be useful
- Pay me now or may be later
  - You will have to write “code” no matter what
  - Ambivalent about learning/using block-based fuzzing DSLs
  - Generation & mutation is not the only thing you do with the protocols

# So going forward...

- For quick best-effort fuzzing, go with GPF
  - or Taof for fuzzing newbies
- Develop protocol specific fuzzers in Python but re-use APIs where possible
  - Sulley, Antiparser, and possibly even Peaches

# A Subjective Fuzzer “Magic Quadrant”

