Fuzz By Number

More Data About Fuzzing Than You Ever Wanted To Know

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Who Am I?

- Former NSA security guy
- Break stuff: iPhone, SecondLife
- Give talks
- Write books
  - “Open Source Fuzzing Tools” (co-author)
  - “Fuzzing for Software Testing and Quality Assurance”
    - Due out in June

Agenda

- Fuzzing, why we care
- How do you test fuzzers?
- My testing
- Results
- Why some bugs are harder to find than others
- Analysis and fun facts

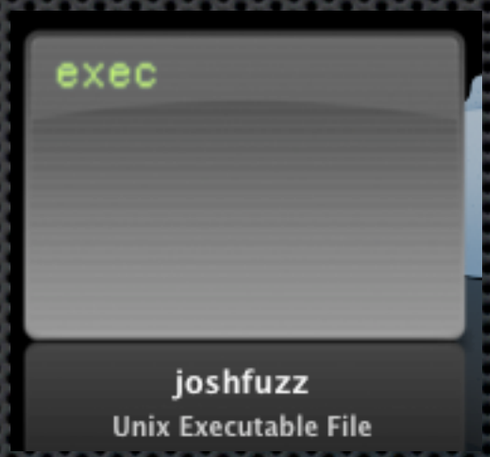
Fuzzing

- Send invalid/semi-valid data into a system
  - If data is too valid, might not cause problems
  - If data is too invalid, might be quickly rejected
- Monitor system for faults
- Not the best tool, but finds lots of bugs
- Better at finding some classes of bugs than others
  - i.e. buffer overflows versus race conditions

Generating Test Cases

- Mutation-based approach
  - Take valid data and add anomalies
  - Only as good as the quality of valid data
  - Easy: requires no knowledge of protocol
- Generation-based approach
  - Generate test cases from protocol specification
  - Hard: need to represent all possibilities of inputs

I Heard Fuzzing Is Useful...



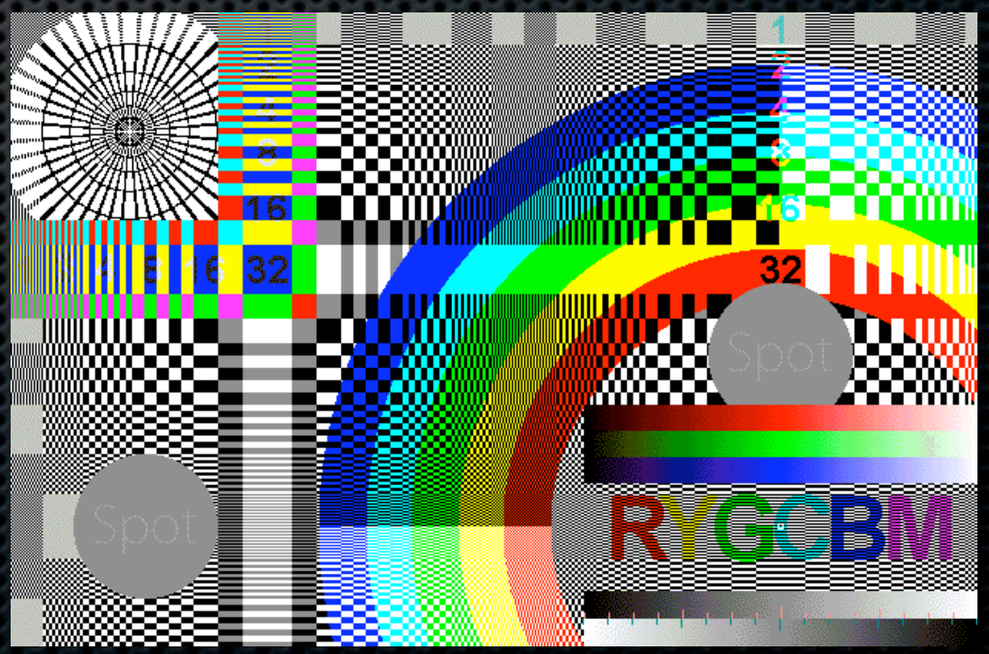
- Which fuzzer do I use?

Fuzzing Lifecycle

- Identifying interfaces
- Input generation <-- This is all we test
- Sending inputs
- Target monitoring
- Exception analysis
- Reporting

How To Test Fuzzers?

- Retrospective testing
- Simulated vulnerability discovery
- Code coverage analysis



Retrospective Testing

- Time period is selected, say 6 months
- All security bugs in the products under study that emerged during the testing period are identified
- 6 month old fuzzers are run against 6 month old products
- We see if the “new” bugs are found

Retrospective Testing (Cont.)

- Positives
  - Measures how well fuzzers *find real bugs in real programs*
- Negatives
  - In good products, not many bugs come out in 6 months
  - Small sample size - hard to draw conclusions
  - Old versions of fuzzers are being tested

Simulated Vulnerability Discovery

- Experienced security researcher adds bugs to a product
- Bugs should be representative of the types of bugs found in this product in the past
- Each bug is verified to be reachable from an external interface
- Another researcher uses fuzzers to try to find these “fake” bugs

Fake Bugs

- Positives
  - Large sample size - add as many bugs as you want
  - The fuzzers still has to actually find the bugs
- Negatives
  - Bugs aren’t “real” - depend on the prejudices of the person adding them

Code Coverage Analysis

- Instrument the target application to measure the amount of code each fuzzer executes
- Absolute numbers are meaningless, but relative numbers can be used
- Lines not executed by a fuzzer indicate the fuzzer will not find bugs in those lines (if they exist)
- Measure “opportunity” of finding bugs

Code Coverage

- Positives
  - Easy to obtain
- Negatives
  - Doesn’t actually measure “bug finding” ability
    - Measures what isn’t tested
  - *Covered does not necessarily mean fuzzed*
    - Think non-security regression tests

Our Testing

- Three network protocols
  - Two servers, one client
- A handful of fuzzers
- Simulated vulnerability discovery and code coverage used

Caveats

- In real life, choice of fuzzer will depend heavily on your particular project
- Funding can be an issue - commercial fuzzers are expensive!
- Fuzzing an obscure or proprietary protocol may limit your choices
- This testing was only 3 protocols and relied heavily on the placement of the fake bugs - buyer beware

Introducing The Fuzzers

- General Purpose Fuzzer (GPF)
- The Art of Fuzzing (Taof)
- ProxyFuzz
- Mu-4000
- Codenomicon
- beSTORM
- Application specific fuzzers: FTPfuzz, PROTOS

GPF

- Open source
- Mutation based (requires packet capture)
- Parses packet capture and adds anomalies
- Can do this automatically or with a custom written “tokAid”
  - Custom tokAids can take many hours to write
- SuperGPF: a mode which modifies packet capture, adds anomalies, and launches many GPF instances
  - Only works for text based protocols

Taof

- Open source, mutation based
- GUI based
- User dissects the captured packets and identifies length fields, etc.
  - Effort comparable to writing a GPF tokAid
- Types of anomalies added are configurable
- Currently cannot handle length fields within length fields
  - Limits effectiveness in many binary protocols

ProxyFuzz

- Open source, mutation based
- Sits in the middle of traffic and randomly injects anomalies into live traffic
- Can set up and run in a matter of seconds
- Completely protocol unaware

Mu-4000

- Commercial fuzzer from Mu Security
- Generation based
  - Understands 55+ protocols
- Easy to use
- Can only fuzz protocols it knows
- Can only fuzz servers
- Sophisticated target monitoring

Codenomicon

- Commercial, generation based fuzzer
- Understands 130+ protocols
- Can only fuzz these protocols
- Fuzz client, server, and file parsing applications
- Limited or no monitoring capabilities

beSTORM

- Commercial, generation based fuzzer
- Understands 50+ protocols
- Can be used to fuzz arbitrary protocols
  - Configured through GUI
- Sophisticated monitoring capabilities

Application Specific Fuzzers

- FTPFuzz
  - GUI driven, open source, generation based
  - Only fuzzes FTP servers
- PROTOS SNMP test suite
  - Generation based
  - Java command line application fires off SNMP packets
  - Found all those ASN.1 bugs a few years ago

What's Missing?

- What about SPIKE, Sulley, Peach, etc...
- These are fuzzing frameworks, not fuzzers
- Their effectiveness is based solely on the quality of the protocol description they are given
  - We wouldn't be testing the frameworks, but the specification files
- We'd have to write the protocol descriptions - I'm too lazy to do that!

Targets

- FTP Server - ProFTPD
  - Uses common ASCII based protocol
- SNMP Server - Net-SNMP
  - Uses binary based protocol
- DNS client - dig from BIND
  - Uses binary based protocol

The Bugs

- 17 bugs added to each application - Thanks Jake Honoroff!
  - Half were buffer overflows
  - A fourth were format strings
  - A fourth were others types of issues: command injection, double free, wild writes, etc.
- Not detectable with normal client (not THAT obvious)
- Prefaced with logging code
- Not necessarily “exploitable” - but probably

Example: FTP Bug #0

```
MODRET xfer_type(cmd_rec *cmd) {
...
    if (strstr(get_full_cmd(cmd), "%")!=NULL){
        BUGREPORT(0);
       }
    char tempbuf[32];
    snprintf(tempbuf, 32, "%s not understood", get_full_cmd(cmd));
    pr_response_add_err(R_500, tempbuf);
```

- This is a format string bug because pr_response_add_err() expects a format string for the second argument

Results!

FTP

Bug	0	1	3	4	5	9	11	12	13	14	15	16
Random												
GPF Partial	X	X				X						
GPF Full	X	X				X		X	X			
Super GPF	X	X				X	X	X	X			
Taof Partial												
Taof Full	X									X		X
ProxyFuzz Partial												
ProxyFuzz Full	X									X		X
Mu-4000	X	X		X	X						X	
FTPfuzz	X	X		X							X	
Codenomicon	X	X	X	X	X						X	

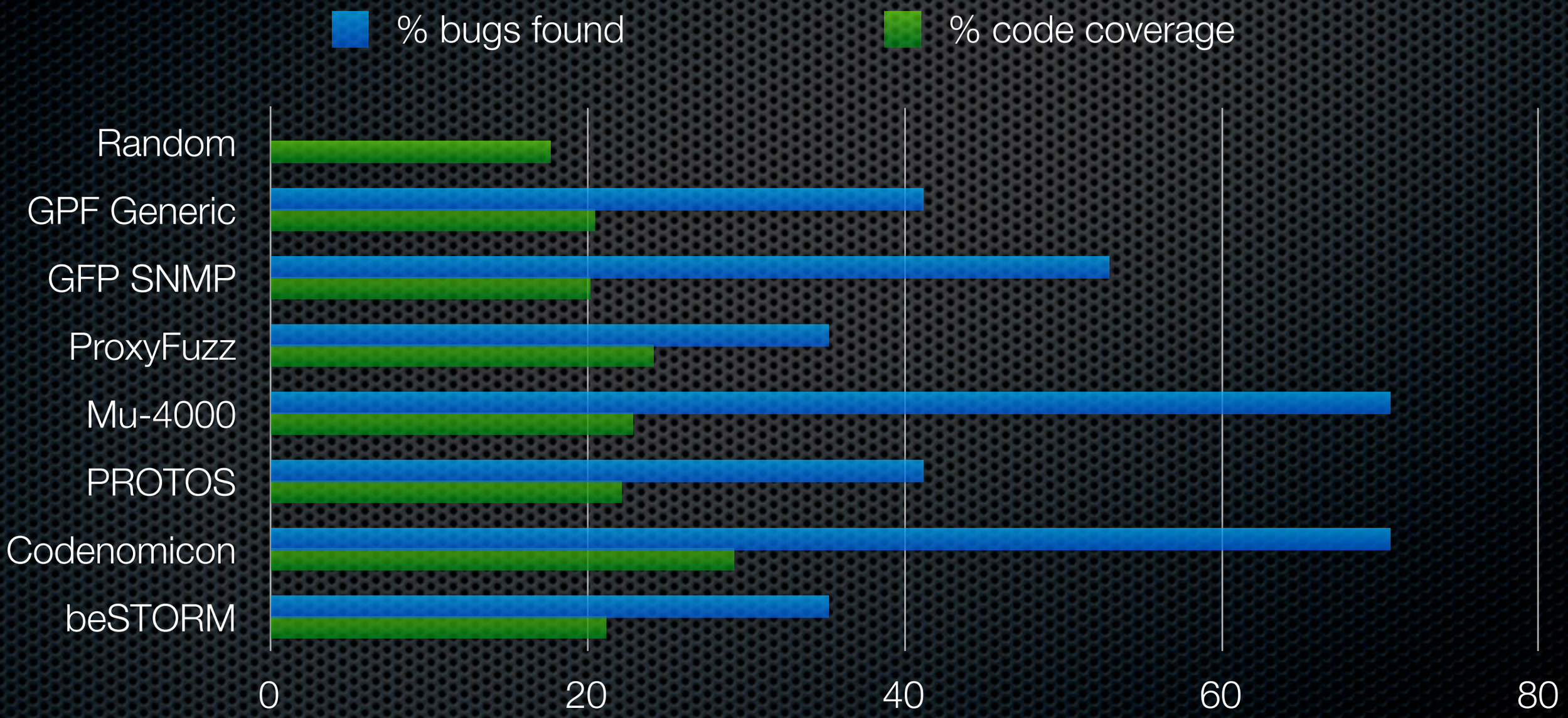
FTP - Summary


% bugs found
% code coverage
Random
GFP Partial
GPF Full
SuperGPF
Taof Partial
Taof Full
PF Partial
PF Full
Mu-4000
Codenomicon
FTPFuzz
0
10
20
30
40
50

SNMP

Bug	0	1	2	3	4	5	6	9	10	11	12	13	14	15	16
Random															
GPF Generic	X	X		X		X		X		X	X				
GPF SNMP	X	X	X	X				X	X	X	X	X			
ProxyFuzz	X	X						X	X	X	X				
Mu-4000	X	X	X	X		X	X	X		X	X	X		X	X
PROTOS	X	X			X						X		X	X	X
Codenomicon	X	X			X	X	X	X		X	X	X	X	X	X
beSTORM	X	X			X						X			X	X

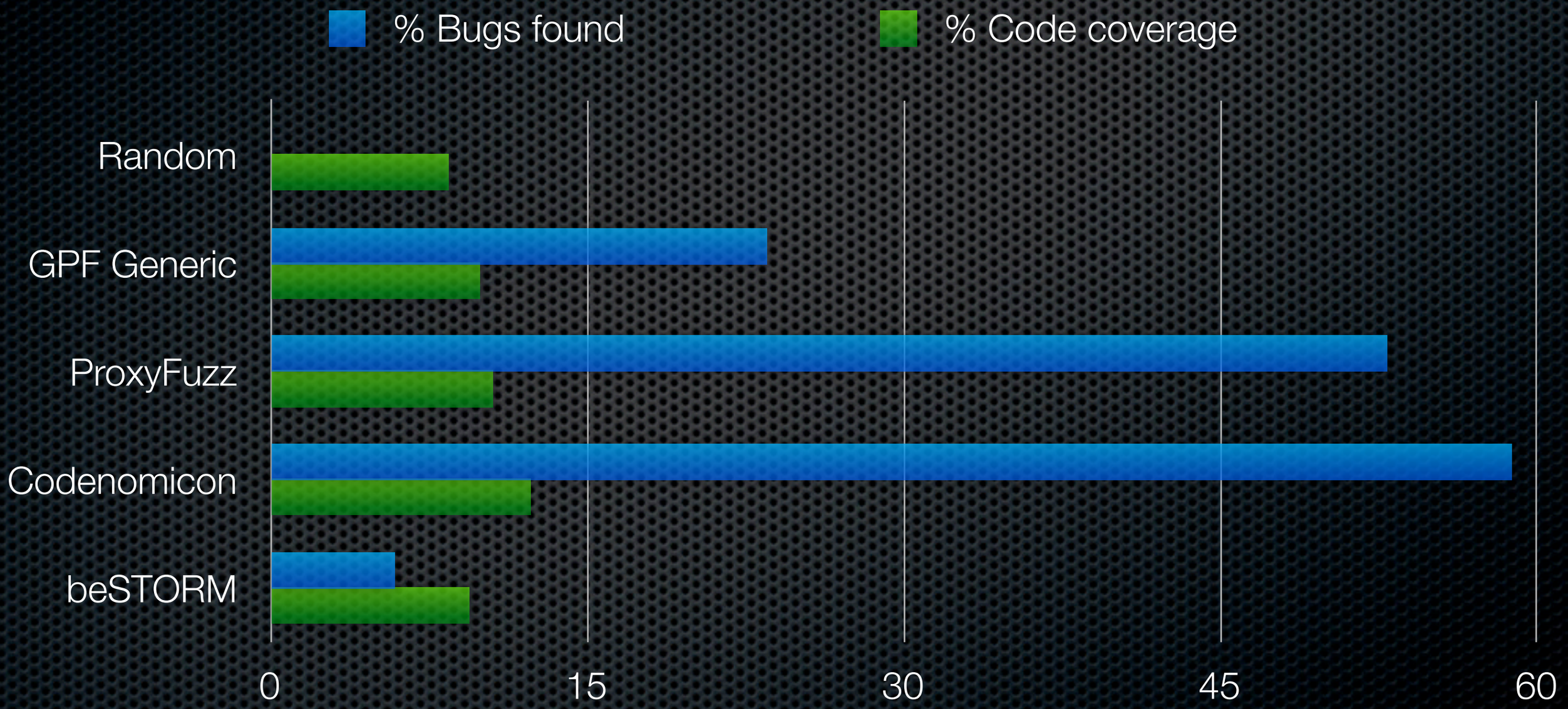
SNMP Summary



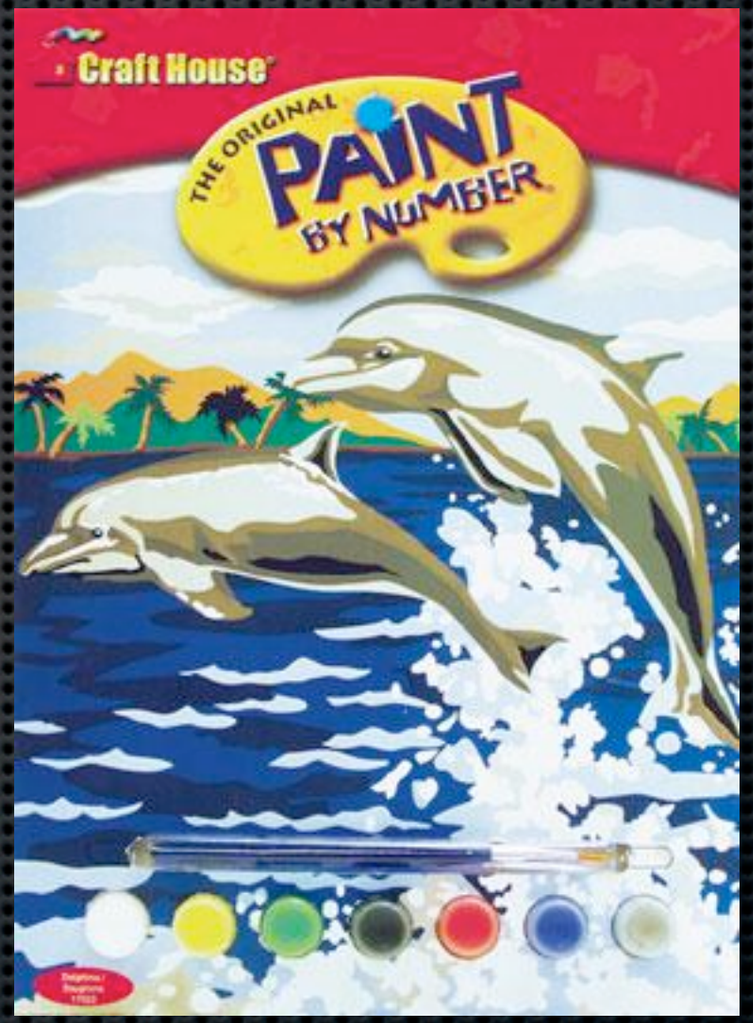
DNS

Bug	0	1	2	3	4	5	7	8	11	12	13	14	15
GPF Random													
GPF Generic							X	X		X		X	
ProxyFuzz	X	X	X		X	X	X	X	X	X			
Codenomicon		X	X	X		X	X	X		X	X	X	X
beSTORM												X	

DNS Summary


% Bugs found
% Code coverage
Random
GPF Generic
ProxyFuzz
Codenomicon
beSTORM
0
15
30
45
60

A Closer Look



FTP Oddities

- Bugs 9, 12, and 13 were found by GPF but no other fuzzers
- Bugs 14 and 16 were found by Taof and ProxyFuzz but no other fuzzers
- Bugs 4, 5, and 15 were found by the generational based fuzzers, but not the mutation based ones

FTP Bug 9

```
MODRET core_size(cmd_rec *cmd) {
…
  if (!path || !dir_check(cmd->tmp_pool, cmd->argv[0], cmd->group, path,
NULL) || pr_fsio_stat(path, &sbuf) == -1) {
    char tempbuf[64];
    if(strstr(cmd->arg, "%")){
       BUGREPORT(9);
    }
    strncpy(tempbuf, cmd->arg, 62);
    strncat(tempbuf, ": ", 64);
    strncat(tempbuf, strerror(errno), 64-strlen(tempbuf));
    pr_response_add_err(R_550, tempbuf);
```

- Generation based fuzzers didn't run SIZE verb - not in RFC
- Likewise, other 2 bugs are in EPSV

FTP Bug 16

```
MODRET core_eprt(cmd_rec *cmd) {
  char delim = '\0', *argstr = pstrdup(cmd->tmp_pool, cmd->argv[1]);
…
  /* Format is <d>proto<d>ip address<d>port<d> (ASCII in network order),
   * where <d> is an arbitrary delimiter character.
   */
  delim = *argstr++;
…
  while (isdigit((unsigned char) *argstr))
    argstr++;
…
  if (*argstr == delim)
    argstr++;
…
  if ((tmp = strchr(argstr, delim)) == NULL) {
    char tempbuf[64];
    if(strstr(cmd->argv[1], "%")!=NULL){
       BUGREPORT(16);
    }
    snprintf(tempbuf, 64, "badly formatted EPRT argument: '%s'", cmd->argv[1]);
    pr_response_add_err(R_501, tempbuf);
    return ERROR(cmd);
  }
```

FTP Bug 16 (Cont.)

- Need to not have enough delimiters
- The data after the second one needs to have a format string specifier
- Generation based fuzzers did not issue EPRT

- GPF was not random *enough*

```
   :     */
 2 :    if (*argstr == delim)
 2 :      argstr++;
   :
   :    else {
 0 :      pr_response_add_err(R_501, "Illegal EPRT command");
 0 :      return ERROR(cmd);
   :    }
   :
 2 :    if ((tmp = strchr(argstr, delim)) == NULL) {
 0 :      pr_log_debug(DEBUG3, "badly formatted EPRT argument: '%s'", cmd->argv[1]);
   :          char tempbuf[64];
 0 :          if(strstr(cmd->argv[1], "%")!=NULL){
 0 :                  BUGREPORT(16);
   :          }
 0 :          snprintf(tempbuf, 64, "badly formatted EPRT argument: '%s'", cmd->argv[1]);
```

FTP Bug 4

```
char *dir_canonical_path(pool *p, const char *path) {
  char buf[PR_TUNABLE_PATH_MAX + 1]  = {'\0'};
  char work[256 + 1] = {'\0'};

  if (*path == '~') {
    if(strlen(path) > 256 + 1){
      BUGREPORT(4);
  }
  if (pr_fs_interpolate(path, work, strlen(path)) != 1) {
    if (pr_fs_dircat(work, sizeof(work), pr_fs_getcwd(), path) < 0)
      return NULL;
  }
```

- Need a long path path that starts with a ‘~’.

FTP Bug 4 (Cont.)

- Generation based fuzzers got this one
- Mutation based did not - never began a path with a '~'

```
    :
 70 : char *dir_canonical_path(pool *p, const char *path) {
 70 :   char buf[PR_TUNABLE_PATH_MAX + 1]  = {'\0'};
 70 :   char work[256 + 1] = {'\0'};
    :
 70 :   if (*path == '~') {
  0 :     if(strlen(path) > 256 + 1){
  0 :         BUGREPORT(4);
    :     }
  0 :     if (pr_fs_interpolate(path, work, strlen(path)) != 1) {
  0 :       if (pr_fs_dircat(work, sizeof(work), pr_fs_getcwd(), path) < 0)
  0 :         return NULL;
    :     }
    :
    :   } else {
 70 :     if (pr_fs_dircat(work, sizeof(work), pr_fs_getcwd(), path) < 0)
  0 :       return NULL;
    :   }
    :
```

SNMP Bug #4

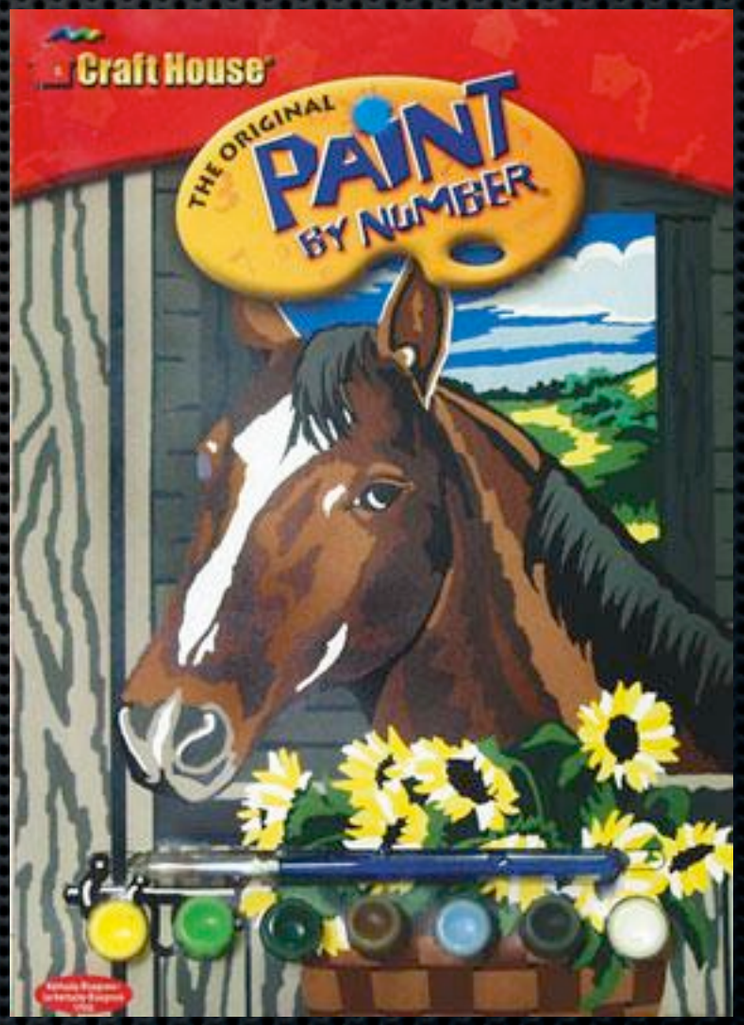
```
int snmp_pdu_parse(netsnmp_pdu *pdu, u_char * data, size_t * length)
{
…
    data = asn_parse_sequence(data, length, &type, (ASN_SEQUENCE | ASN_CONSTRUCTOR),
"varbinds");
    if (data == NULL)
        return -1;
...
    while ((int) *length > 0) {
…
        switch ((short) vp->type) {
…
        case ASN_OCTET_STR:
        case ASN_IPADDRESS:
        case ASN_OPAQUE:
        case ASN_NSAP:
            if (vp->val_len < sizeof(vp->buf)) {
                vp->val.string = (u_char *) vp->buf;
            } else {
                vp->val.string = (u_char *) malloc(200);
              if (vp->val_len > 200)
              {
                  BUGREPORT(4);
              }
           }
…
            asn_parse_string(var_val, &len, &vp->type, vp->val.string,
                             &vp->val_len);
        break;
```

SNMP Bug #4 (Cont.)

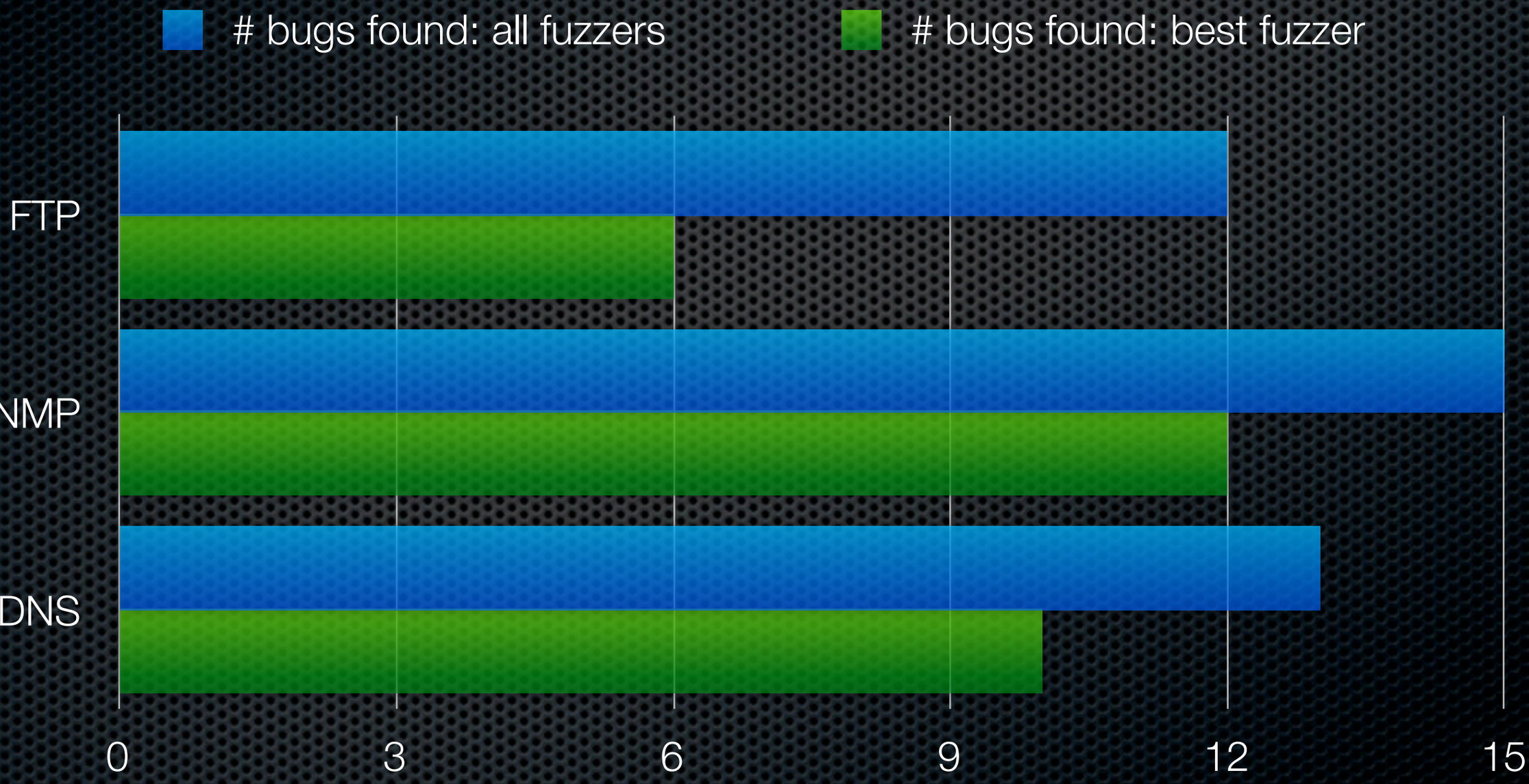
- Bug is reached with a particular type of packet and a large length and corresponding long string
- GPF executes the function but doesn't even make it to the switch statement (i.e. its too random)
- ProxyFuzz and Mu-4000 sent the right kind of packet, but not with a long enough string

```
        :            case ASN_OPAQUE:
        :            case ASN_NSAP:
     3292 :                if (vp->val_len < sizeof(vp->buf)) {
     3292 :                    vp->val.string = (u_char *) vp->buf;
        :                } else {
        0 :                    vp->val.string = (u_char *) malloc(vp->val_len);
        :                }
     3292 :                if (vp->val.string == NULL) {
        0 :                    return -1;
        :                }
     3292 :                asn_parse_string(var_val, &len, &vp->type, vp->val.string,
        :                                 &vp->val_len);
     3292 :                break;
```

General
Conclusions

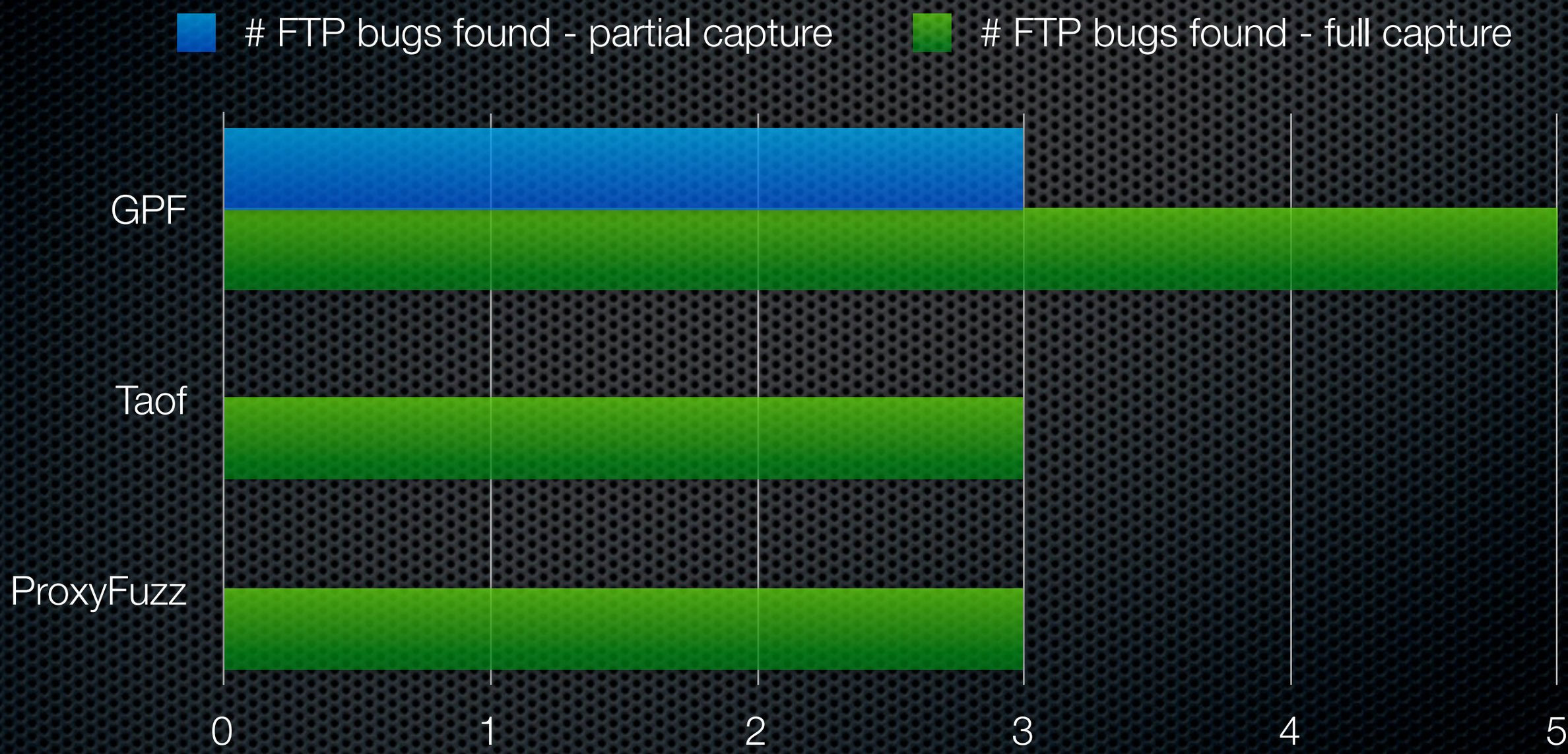


The More Fuzzers The Better

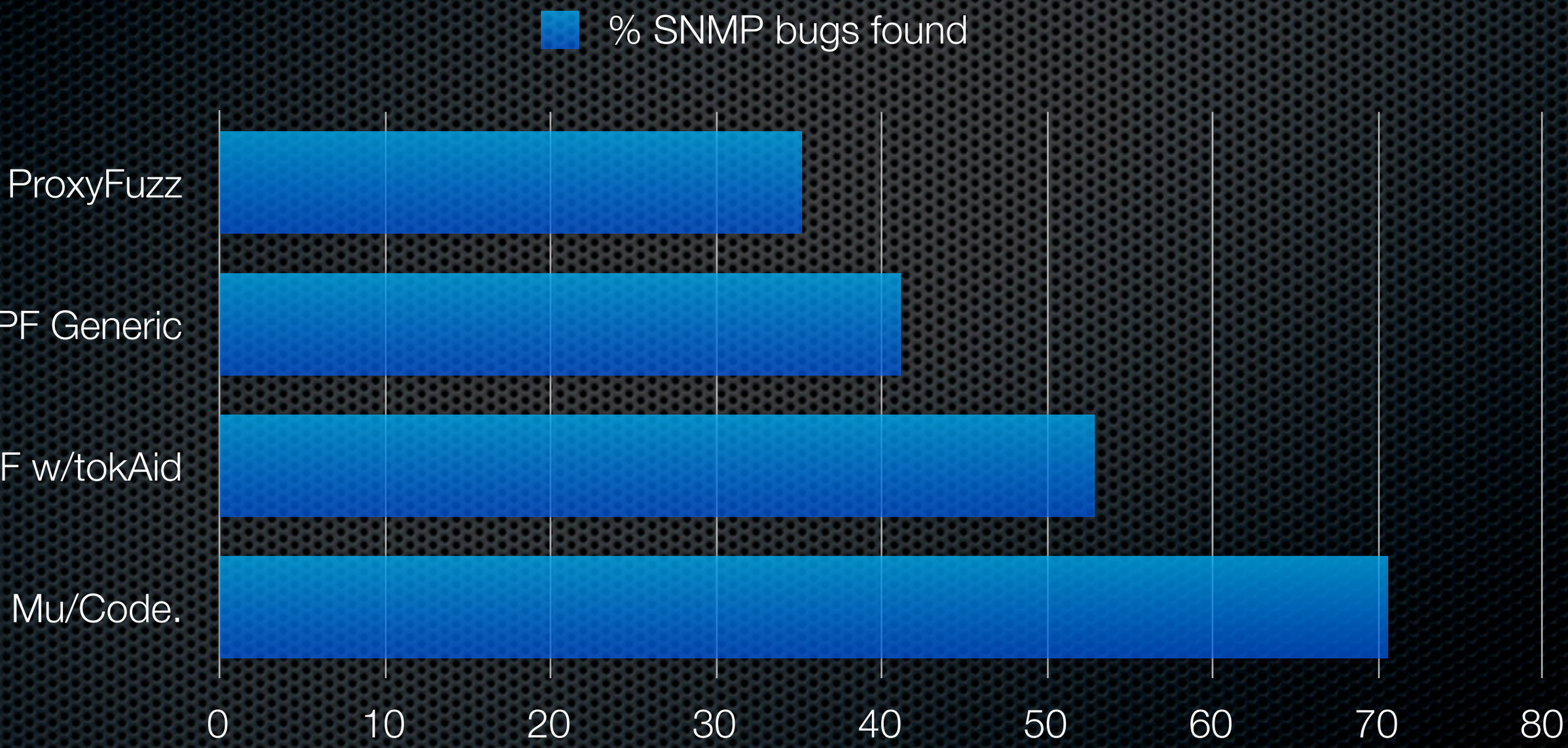


Generation Based Approach Most Effective

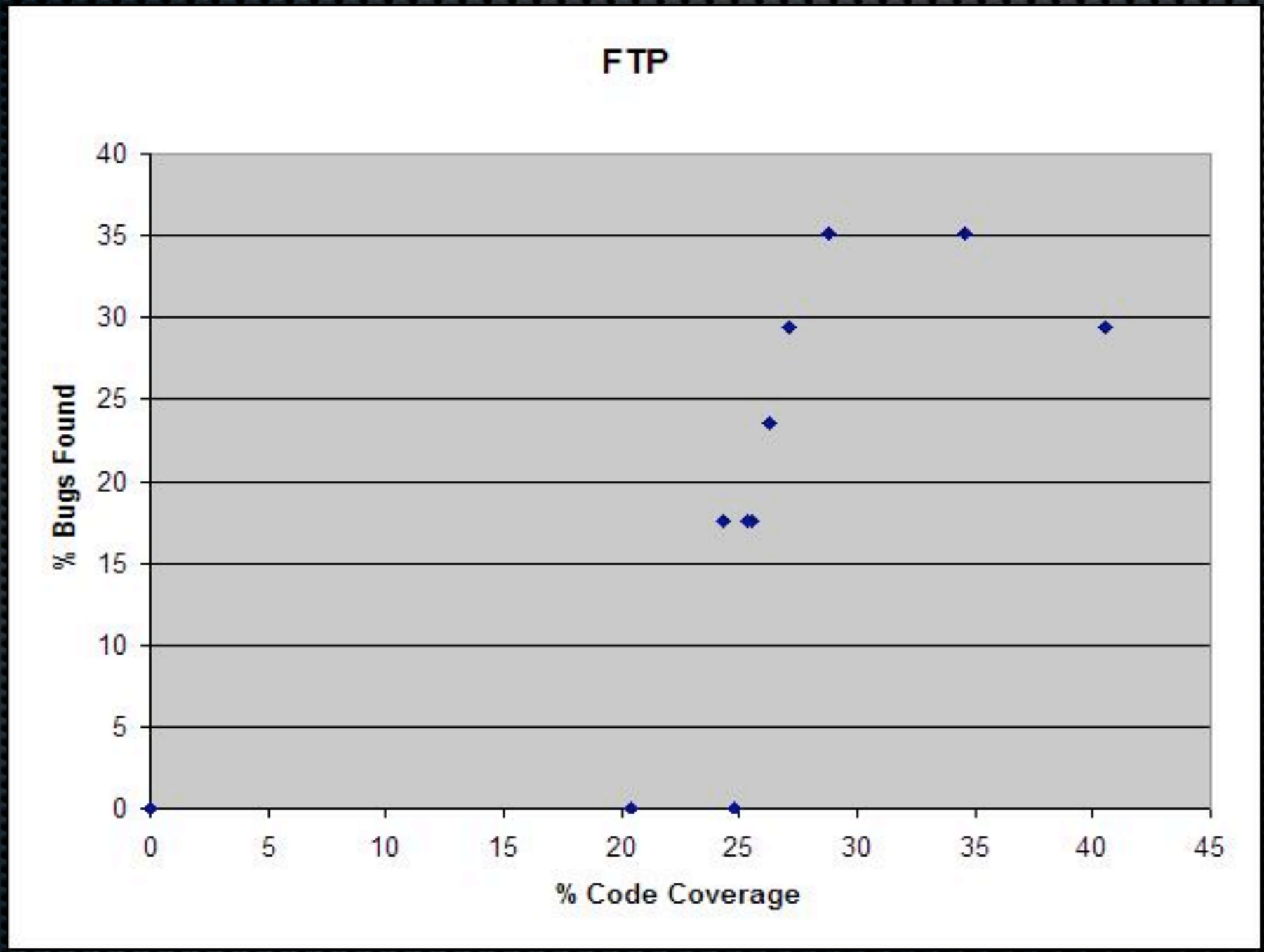
Initial Test Cases Important



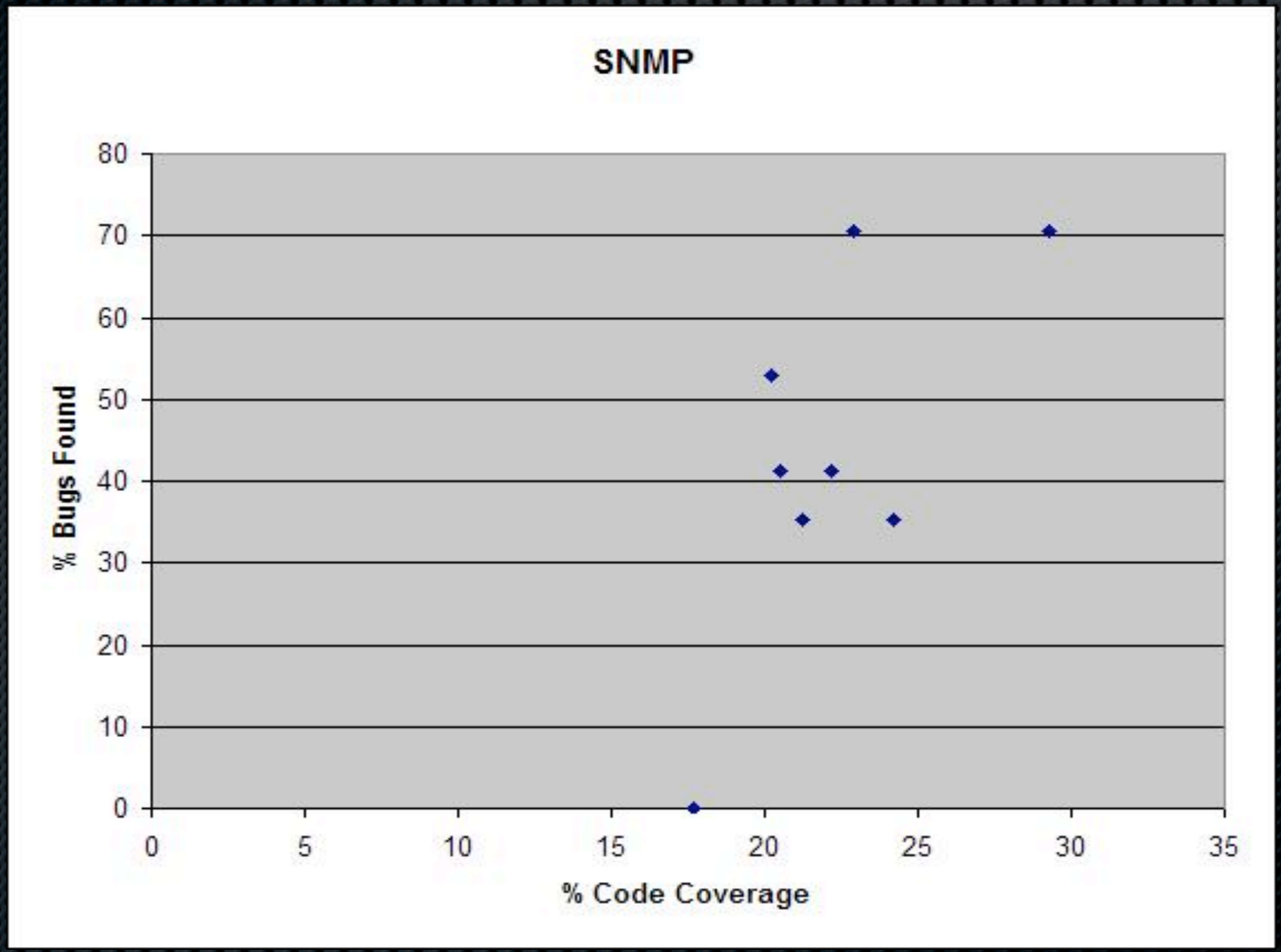
Protocol Knowledge Is Good



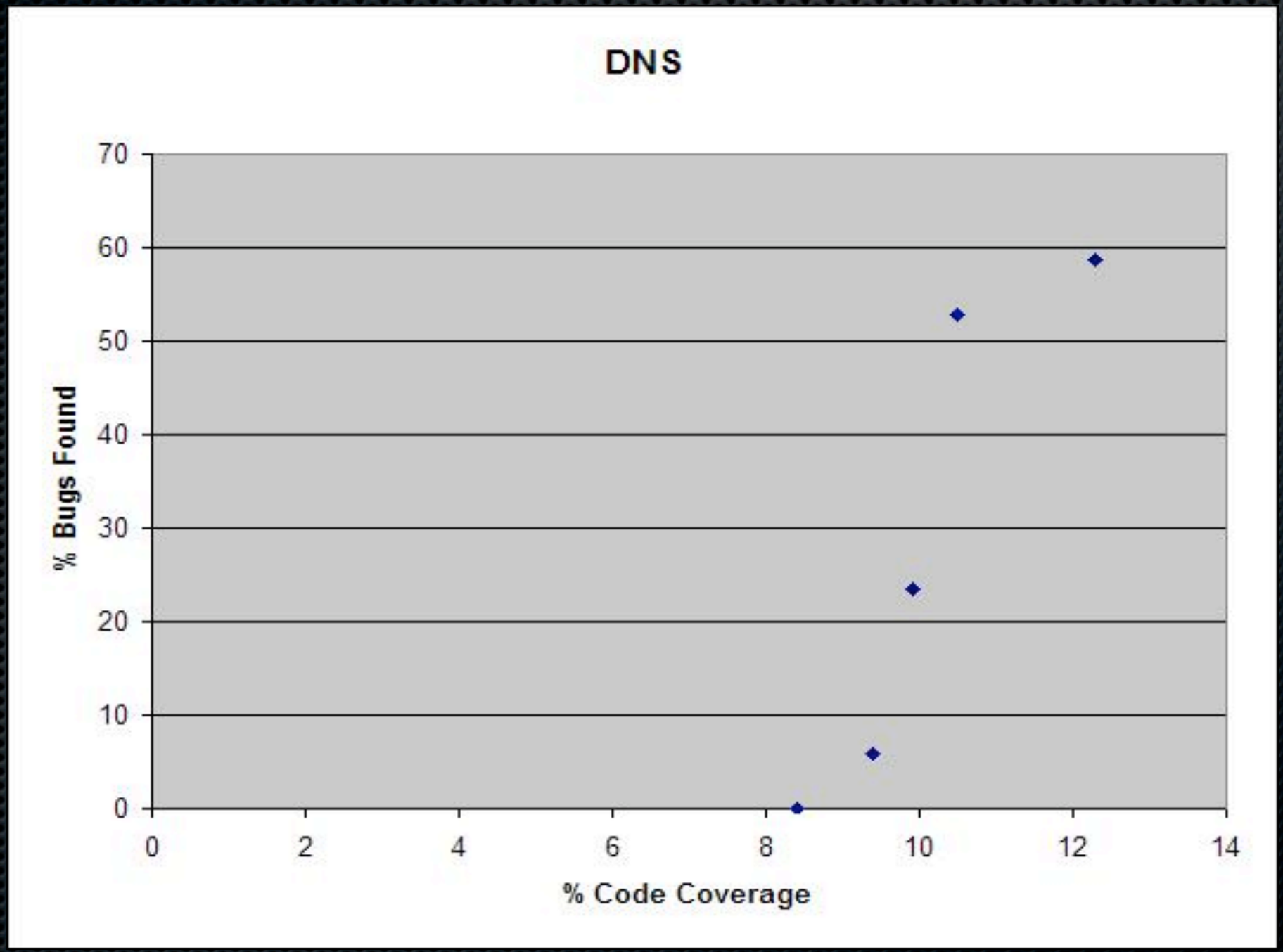
Does Code Coverage Predict Bug Finding?



More Code Coverage...



More Code Coverage...



Statistics Says “Yes”

Dep Var: BUGS N: 11 Multiple R: 0.716 Squared multiple R: 0.512

Adjusted squared multiple R: **0.458** Standard error of estimate: 9.468

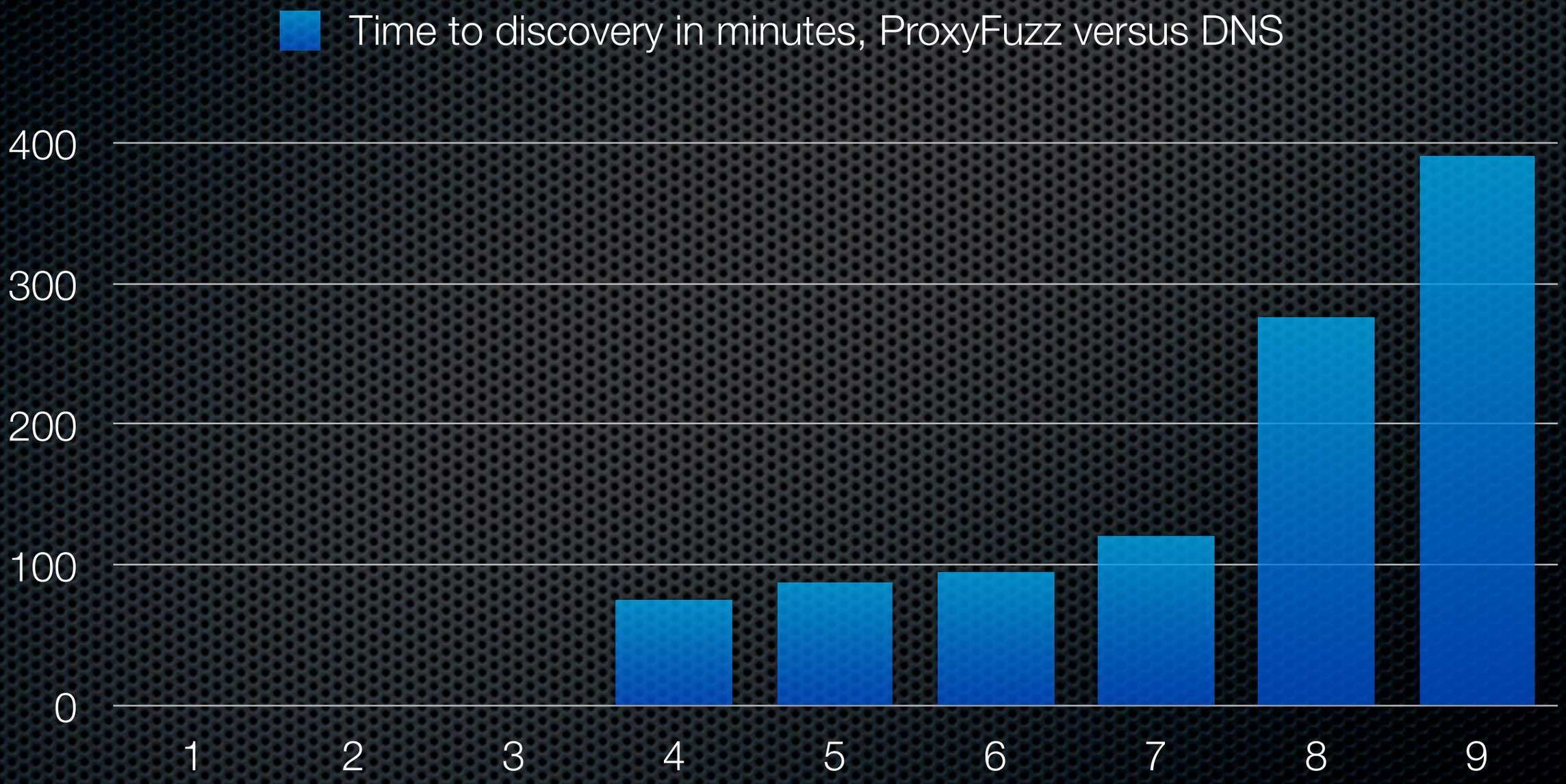
Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	-5.552	8.080	0.000	.	-0.687	0.509
CC	**0.921**	0.300	0.716	1.000	3.074	0.013

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	847.043	1	847.043	9.449	**0.013**
Residual	806.813	9	89.646		

- A 1% increase in code coverage increases the percentage of bugs found by .92%

How Long To Run Fuzzers?



A Real Bug

- All this fuzzing with different fuzzers against a real program might have actually found a real bug
- It is possible that some were found but were lost in the "noise"
- One Net-SNMP bug was found (DOS)
  - Only found by Codenomicon
  - Reported and fixed

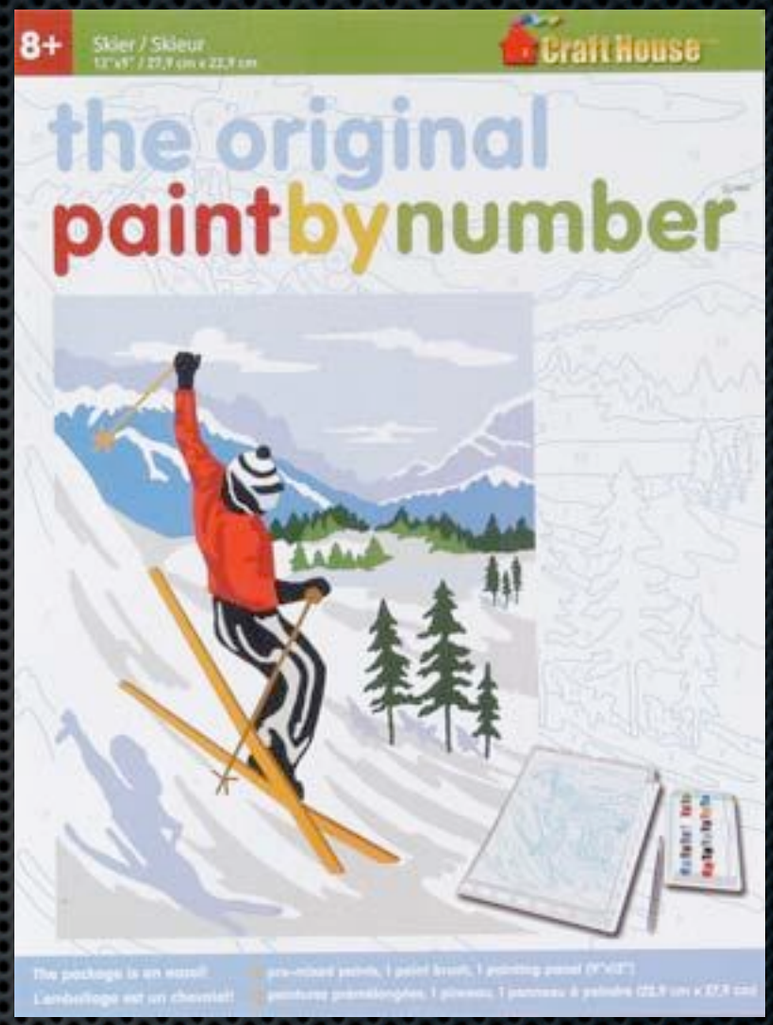
Conclusions

- Verified a lot of what intuition tells us
- Incorporate as much protocol specific knowledge as possible
- Commercial fuzzers are good (if you can afford them)
- Multiple fuzzers are better than one
- Run fuzzers for a very long time (longer than you'd think)
- Code coverage in fuzzers is useful as a measurement

Special Thanks To:

- Commercial fuzzer vendors who let me use their product - very cool!
- Open source fuzzer developers who helped me find/fix bugs in their fuzzers

Questions?



- Buggy programs will be made available
- Contact me at: cmiller@securityevaluators.com