Revolutionizing the Field of Grey-box Attack Surface Testing with Evolutionary Fuzzing

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Agenda

- Goals and previous works
- (1) Background
  - Software, fuzzing, and evolutionary testing
- (2) Describe EFS in detail
  - GPF && PaiMei && development++ == EFS
- (3) Initial benchmarking results
- (4) Initial results on a real world application
- Conclusion and future works

Goals and Previous Works

- Research is focused on building a better fuzzer
  - EFS is a new breed of fuzzer
    - No definitive proof (yet) that it's better than current approaches
      - Need to compare to Full RFC type, GPF, Autodafe, Sulley, etc
    - As of 6/21/07 there are no (available) other fuzzers that learn the protocol via a grey-box evolutionary approach
      - Embleton, Sparks, and Cunningham's *Sidewinder* research
        - Code has not been released
      - Hoglund claims to have recreated something like Sidewinder, but also didn't release details
      - Autodafe and Sulley are grey-box but require a capture (like GPF), or definition file (like Spike), respectively, and do not evolve

Section 1: Background

- Software Testing
- Fuzz Testing
  - Read Sutton/Greene/Amini
  - And than read DeMott/Takanen
- Evolutionary Testing

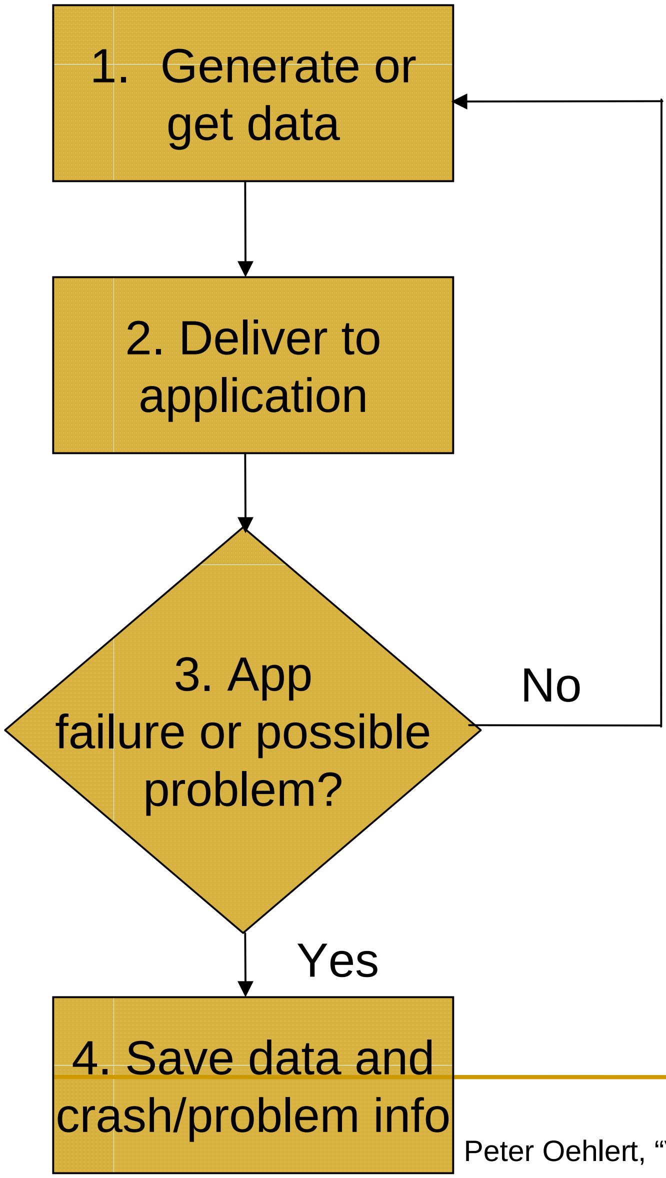
Software Testing

- Software testing can be
  - Difficult, tedious, and labor intensive
    - Cannot “prove” anything other than existence of bugs
  - Poorly integrated into the development process
  - Abused and/or misunderstood
  - Has a stigma as being, “easier” than engineering
- Software testing is expensive and time-consuming
  - About 50% of initial development costs
- However, primary method for gaining confidence in the correctness of software (pre-release)
  - Done right, does increase usability, reliability, and security
    - Example, Microsoft’s new security push: SDL
- In Short, testing is a (NP) hard problem
  - New methods to better test software are important and in constant research

Fuzzing, Testing, QC, and QA

- How does fuzzing fit into the development life cycle?
  - Formal Methods of Development
  - Quality Assurance
    - Quality Control
      - Testing
        - Fuzzing
        - Many other types of testing!
- Fuzzing is one small piece of the bigger puzzle, but one that has be shown useful to ensure better security

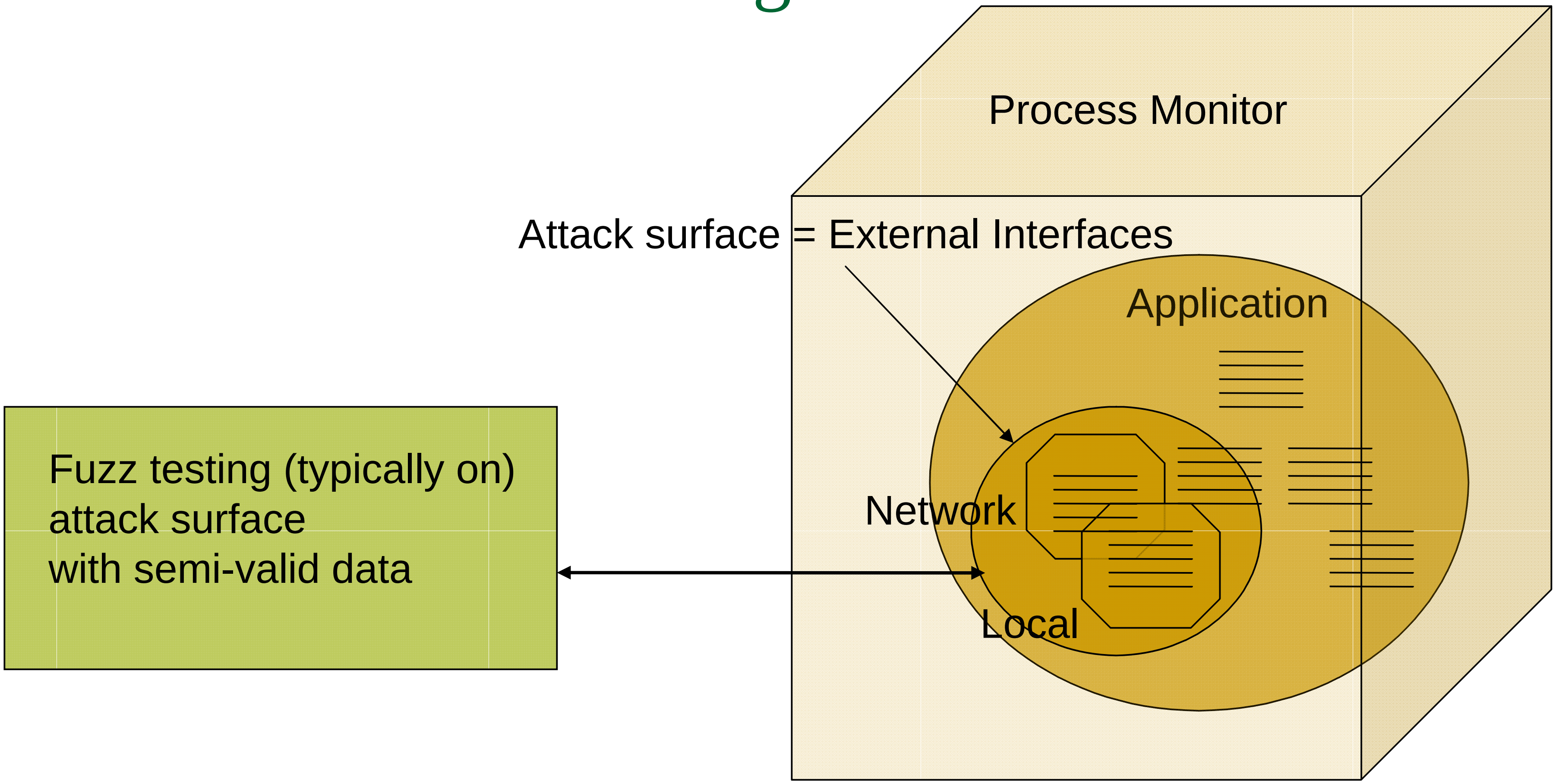
Fuzzing



- Fuzzing is simply another term for interface robustness testing
  - Focuses on:
    - Input validation errors
    - Actual applications - dynamic testing of the finished product
    - Interfaces that have security implications
      - Known as an attack surface
        - Portion of code that is externally exercisable in the finished product
        - Changes of privilege may occur

Peter Oehlert, “Violating Assumptions with Fuzzing”, IEEE Security & Privacy, Pgs 58-62, March/April 2005

Attack Surface Testing



Evolutionary Testing

- Uses evolutionary algorithms (GAs) to discover better test data
  - A GA is a computer science search technique inspired by evolutionary biology
    - Evaluating a granular fitness function is the key
  - ET requires structural (white-box) information (source code)
    - Couldn’t find others doing grey-box ET
- Brief look at ET:
  - Standard approach, typical uses, problems

Current ET Method for Deriving Fitness

- Approach_level + norm(branch distance)
  - Example: a=10, b=20, c=30, d=40
    - Answer: fitness = 2 + norm(10). (Zero == we've found test data.)

```
(s) void example(int a, int b, int c, int d)
 {
(1)        if (a >= b)
        {
(2)            if (b <= c)
            {
(3)                if (c == d)
                {
                    //target
```

Typical ET uses

- Structural software testing
  - Instrument discovered test cases for initial and regression testing
- Wegener et al. of DaimlerChrysler [2001] are working on ET for safety critical systems
- Boden and Martino [1996] concentrate on error treatment routines of operating system calls
- Schultz et al. [1993] test error tolerance mechanisms of an autonomous vehicle

ET Problems

- Flag problem == flat landscape. Resort to random search

```
void flag_example(int a, int b)
{
    int flag = 0;
    if (a == 0)
        flag = 1;
    if (b != 0)
        flag = 0;
    if (flag)
        //target
}
```

- Deceptive problems

```
double function_under_test
   (double x)
{
    if (inverse(x) == 0 )
        //target
}
double inverse (double d)
{
    if (d == 0)
        return 0;
    else
        return 1 / d;
}
```

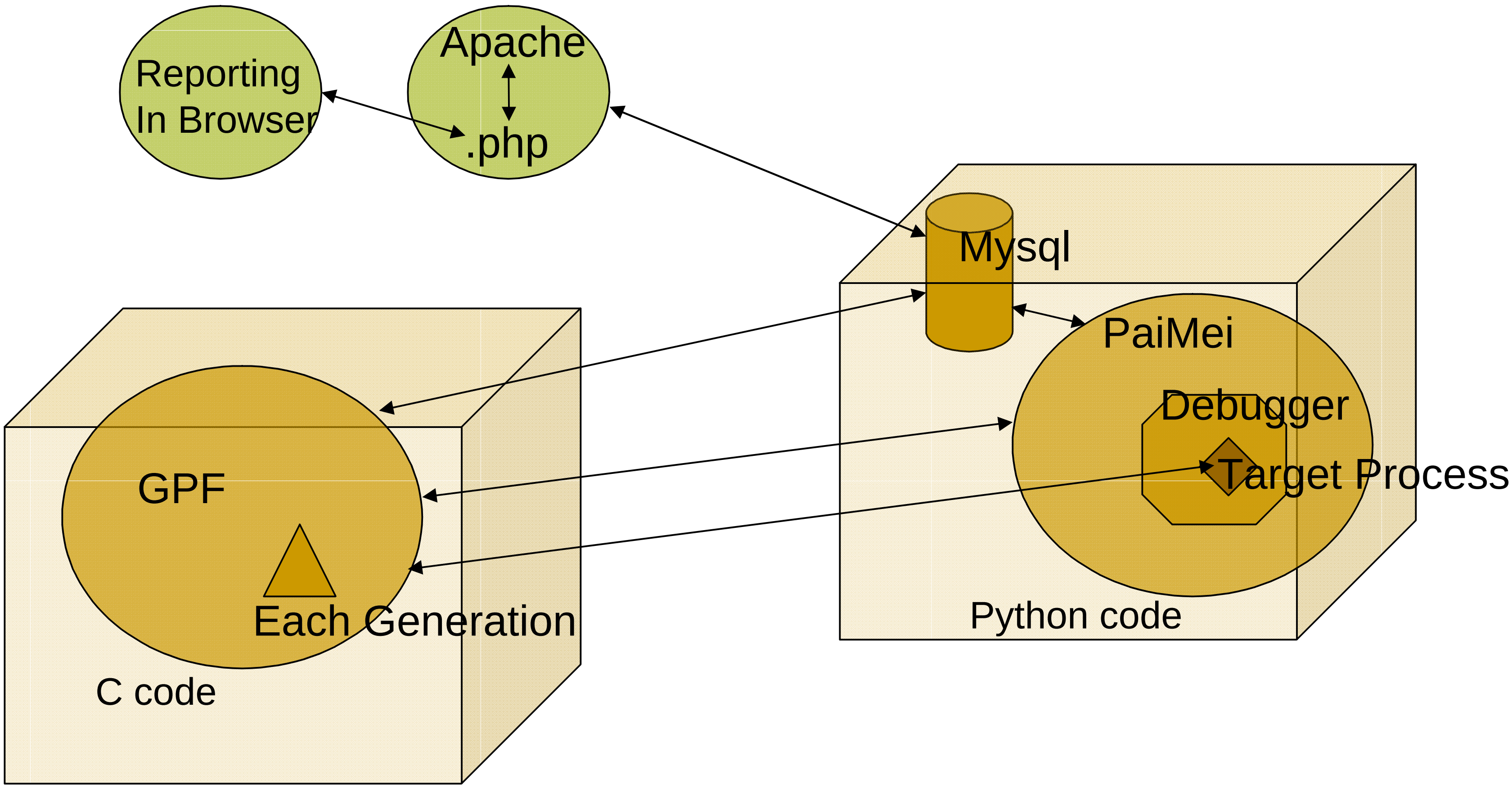
Evolutionary Fuzzing System

- McMinn and Holcombe (U.o.Sheffield) are working on solving ET problems [2]
  - 2006 paper on Extended Chaining Approach
- Our approach is different for two reasons:
  - Grey-box, so no source code needed
  - Application is being monitored while test cases are being discovered. Fuzzing heuristics are used in mutations. This equals real-time testing. Crash files are written while evolution continues. Also includes reporting capability. Seed file helps with some of the traditional ET problems, though still rough fitness landscape.

Section 2: A Novel Approach

- Evolutionary Fuzzing System
  - Evolutionary Testing
    - EFS uses GA's, but does not require source code
  - Fuzzing
    - EFS uses GPF for fuzzing
  - PaiMei
    - EFS uses a modified version of pstalker for code coverage

EFS: A System View



EFS: GPF - Stalker (PaiMei) Protocol

- GPF initialization/setup data → PaiMei
- Ready ← PaiMei
- <GPF carries out communication session with target>
- GPF {OK|ERR} → PaiMei
- <PaiMei stores all of the hit and crash information to the database>

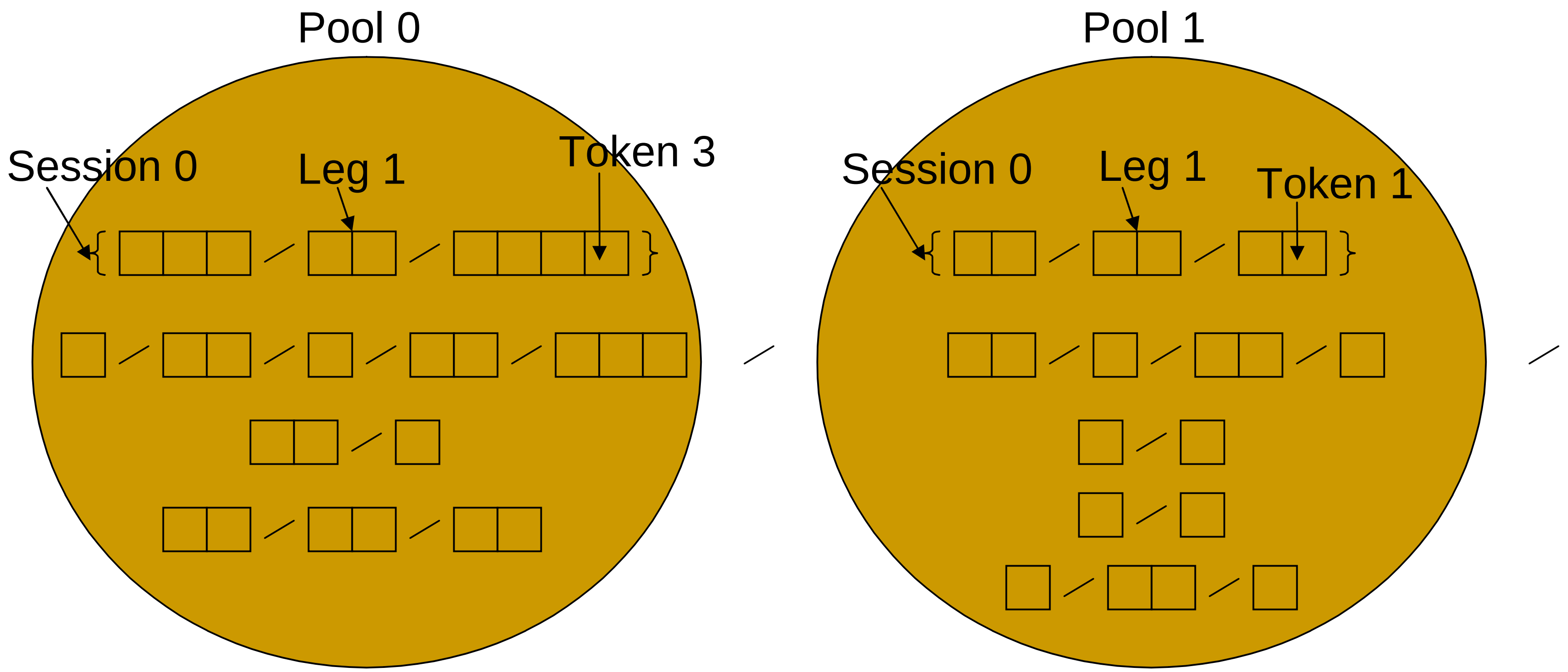
EFS: How the Evolution works

- GA or GP?
  - Variable length GA. Not working to find code snippets as in GP. We’re working with data (GA).
- Code coverage + diversity = fitness function
  - The niching or speciation used for diversity is defined later
  - Corollary 1:
    - Code coverage != security, but < 100% attack surface coverage == even less security
  - Corollary 2:
    - 100% attack surface coverage + diverse test cases that follow and break the protocol with attack/fuzzing heuristics throughout == the best I know how to do

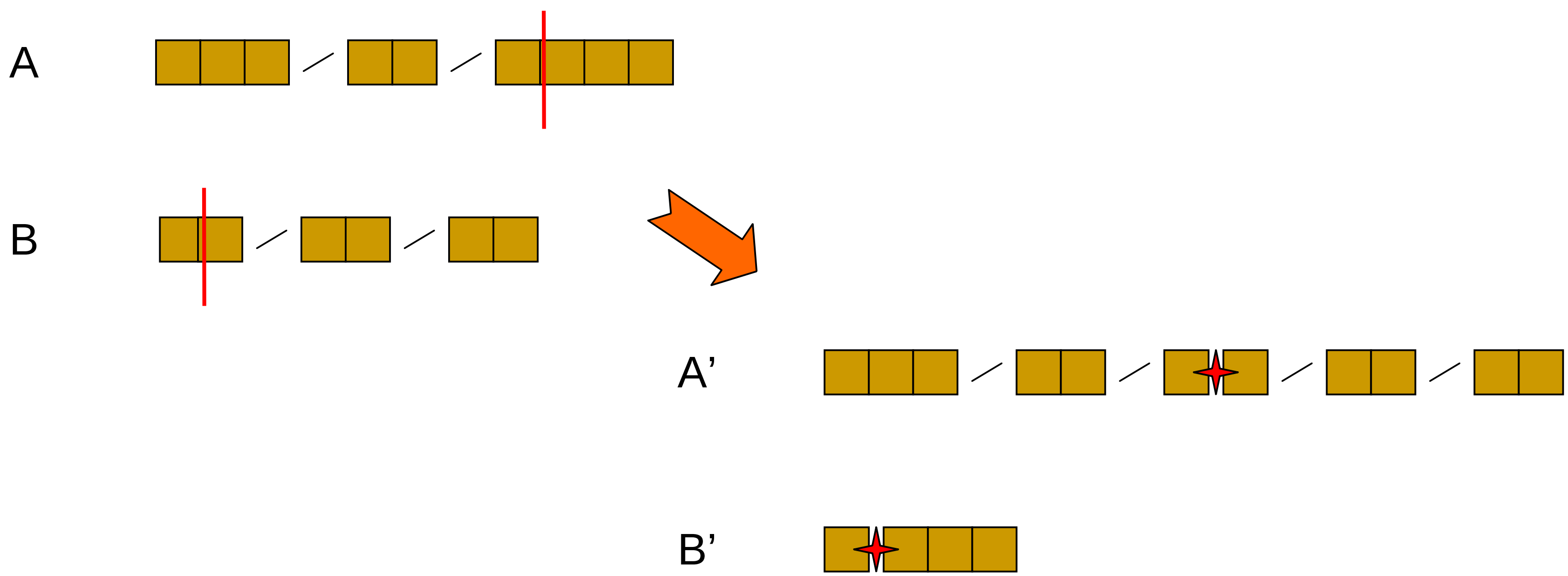
EFS: How the Evolution works (cont.)

- Any portion of the data structures can be reorganized or modified in various ways
  - But not the best pool or the best session/pool
    - Elitism of 1
- All evolutionary code is 100% custom code
  - Session Crossover
  - Session Mutation
  - Pool Crossover
  - Pool Mutation

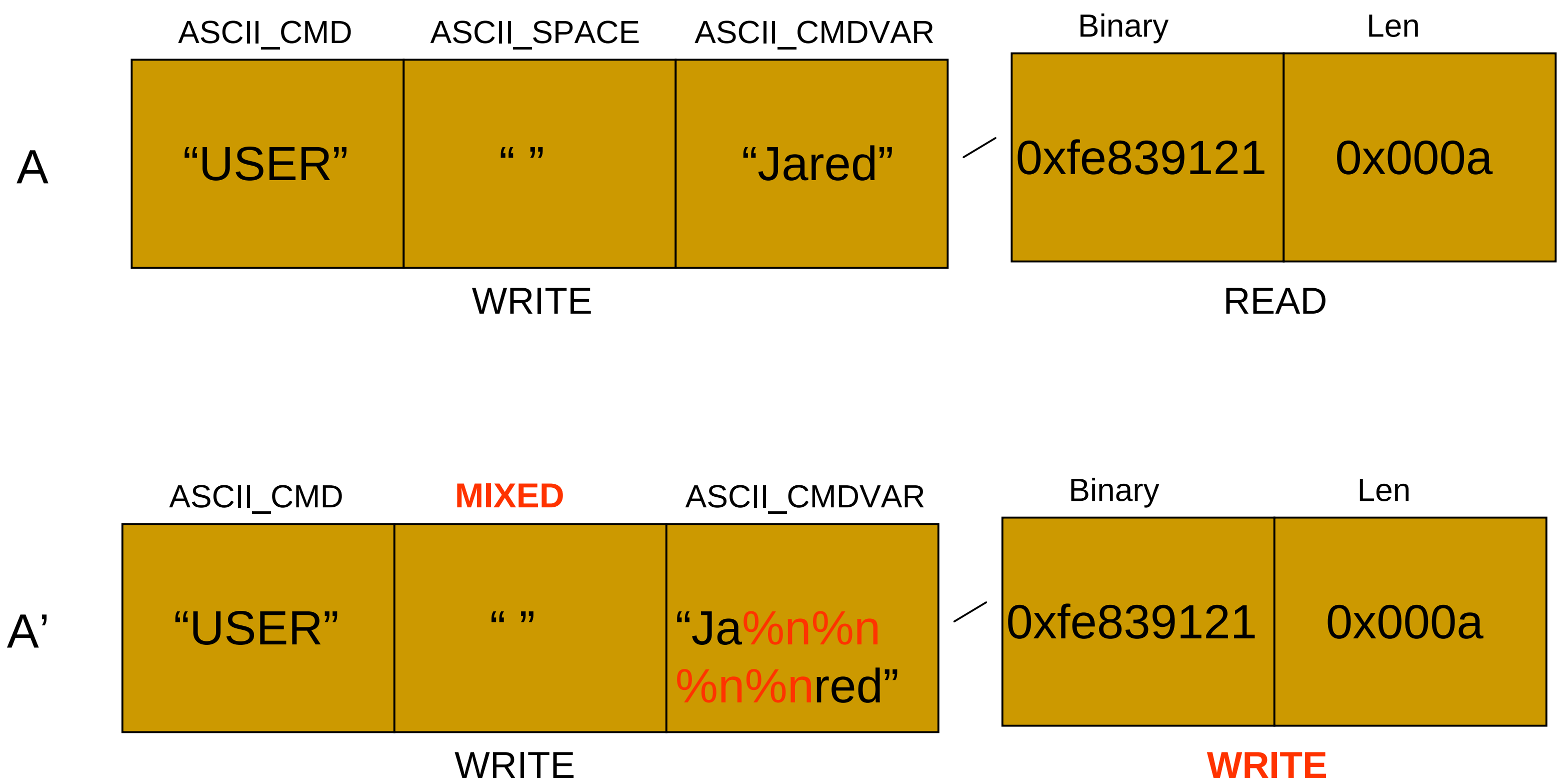
EFS: Data Structures



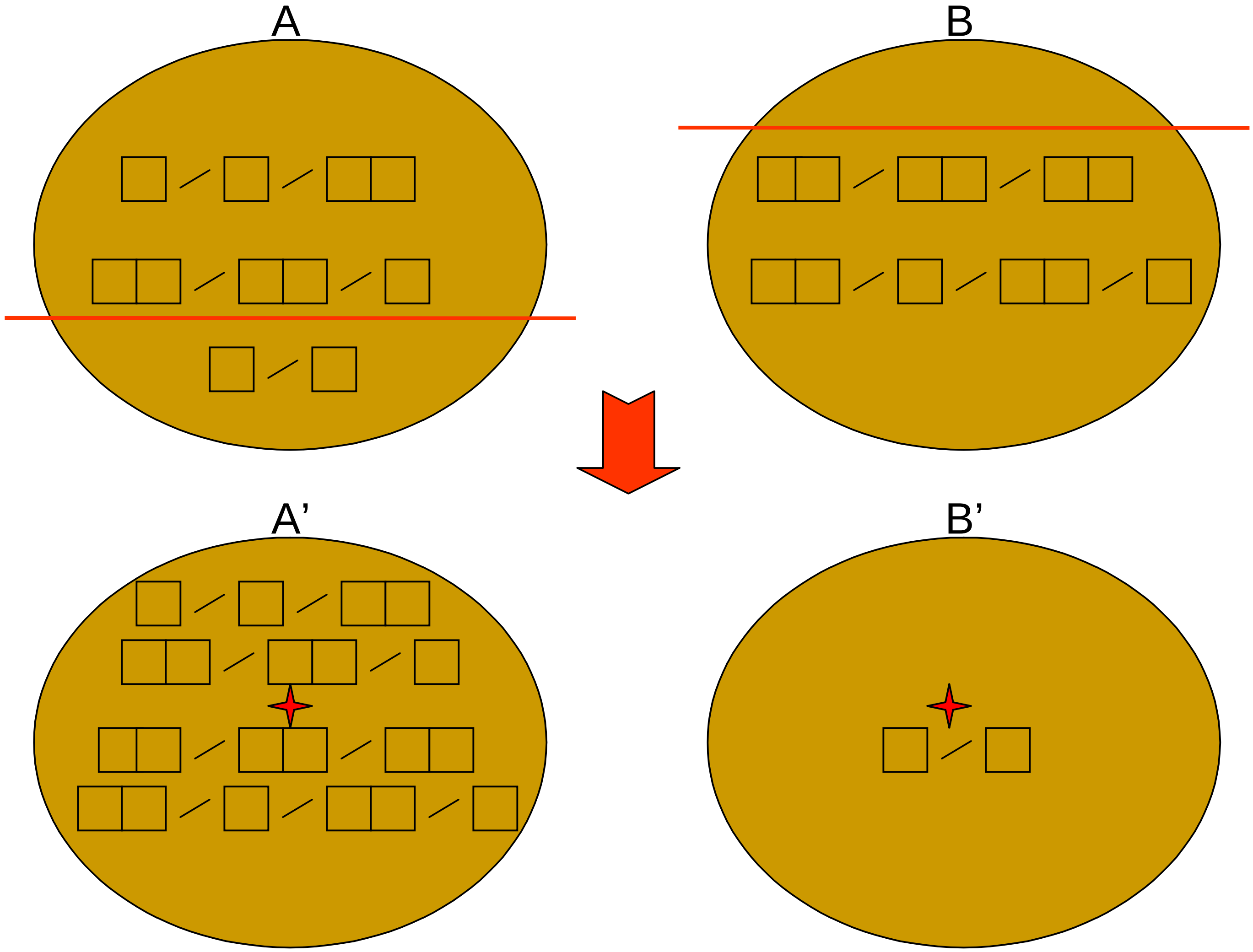
EFS: Session Crossover



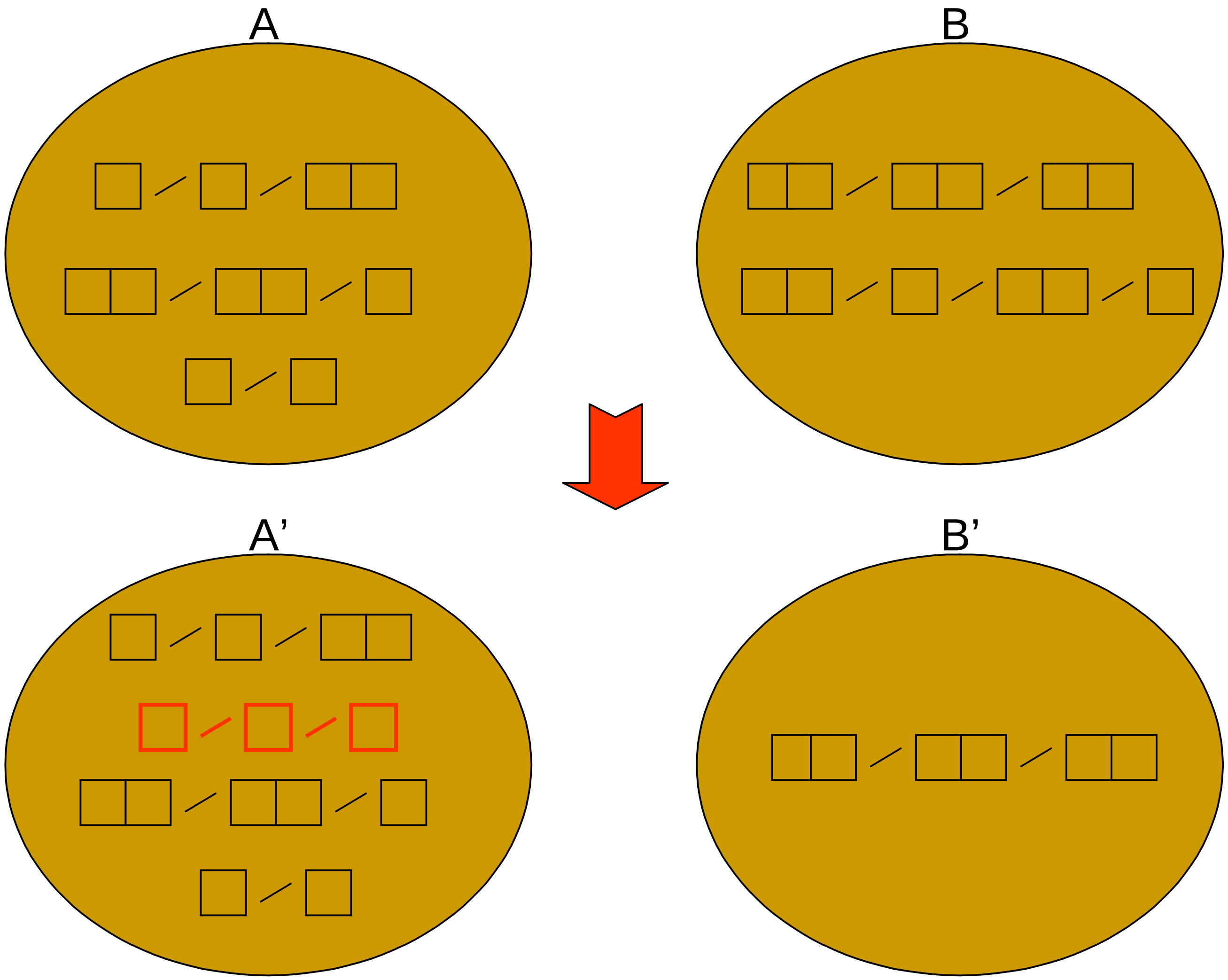
EFS: Session Mutation



EFS: Pool Crossover



EFS: Pool Mutation



Simple Example of Maturing EFS Data

- GENERATION 1
- S1: “USER #$%^&*Aflkdsjflk”
- S2: “ksdfjkj\nPASS %n%n%n%n”
- S3: “\r\njksd Jared9338498\d\d\xfefe”
- ...
- GENERATION 15
- S1: “USER #$%\n PASS %n%n%n%n\r\njksd”
- S2: ”PASS\nQUIT NNNNNNNNNN\r\n”
- S3: “RETR\r\nUSER ;asidf;asifh; kldsjf;kdfj”
- ...

EFS: GPF –E Parameters

- Mysql Host, mysql user, mysql passwd
- ID, generation
- PaiMei host, PaiMei port, stalk type
- Playmode, host, port, sport, proto, delay, wait
- Display level, print choice
- Pools, MaxSessions, MaxLegs, MaxToks, MaxGenerations, SessionMutationRate, PoolCrossoverRate, PoolMutationRate
- UserFunc, SeedFile, Proxy

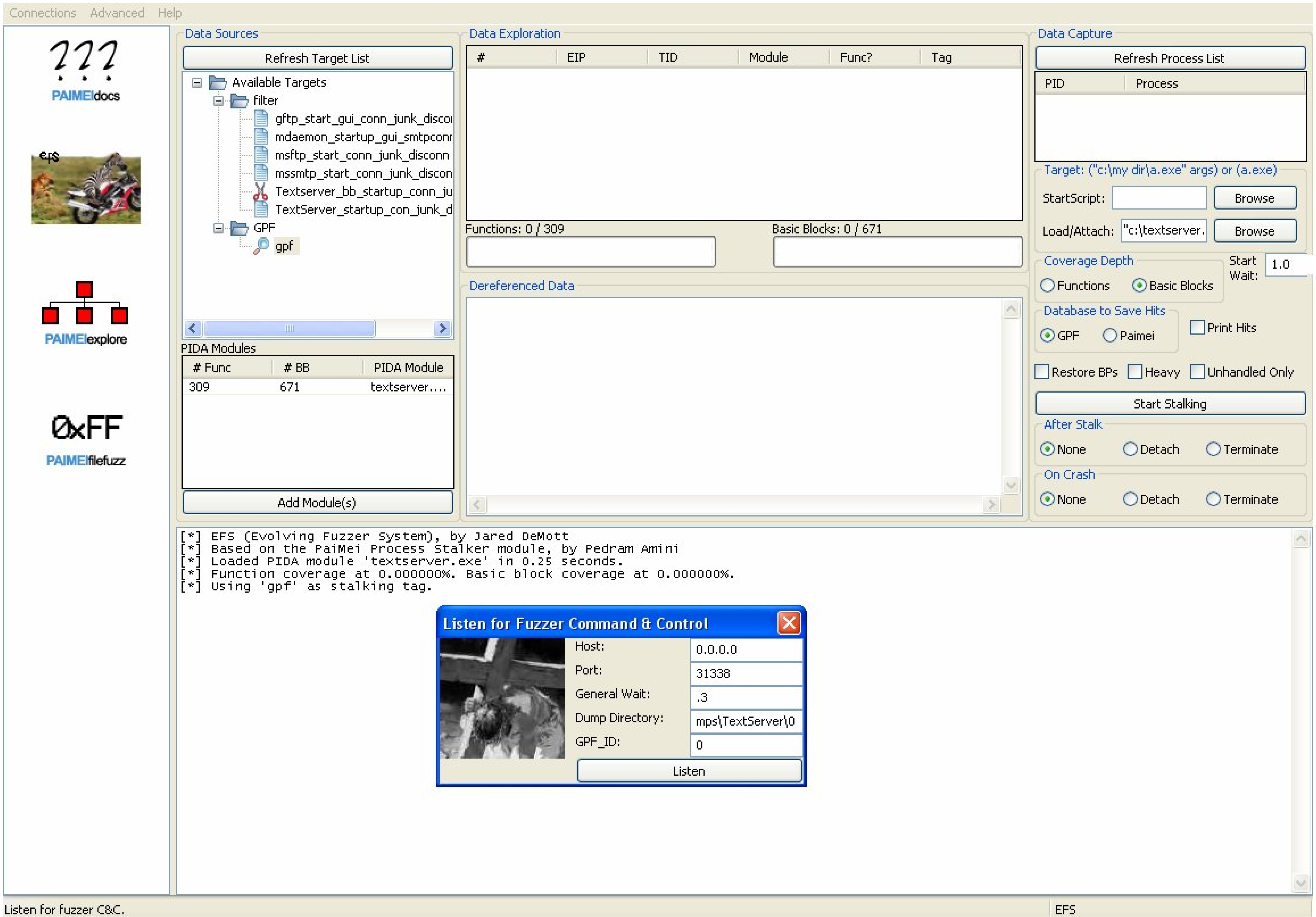
Seed File

- SMTP
  - HELO
  - Mail from: me@you.com
  - Rcpt to: root
  - Data
  - “Hello there”
  - \r\n.\r\n
  - EHLO
  - RSET
  - QUIT
  - HELP
  - AUTH
  - BDAT
  - VRFY
  - EXPN
  - NOOP
  - STARTTLS
  - etc.
- FTP
  - USER anonymous
  - PASS me@you.com
  - CMD
  - PASV
  - RETR
  - STOR
  - PORT
  - APPE
  - FEAT
  - OPTS
  - PWD
  - LIST
  - NLST
  - TYPE
  - SYST
  - DELE
  - etc.

EFS: Stalker Start-up Sequence

- Create and PIDA file using IDApro
  - Load the PIDA file in PaiMei
- Configure/start test target
- Stalk by functions or basic blocks
- Filter common break points
  - Start-up, connect, send junk, disconnect, GUI
    - Allows EFS to run faster
- Connect to mysql
  - Listen for incoming GPF connection
- Start GPF in the –E (evolutionary) mode

EFS GUI (the PaiMei portion)



Section 3: Research Evaluation

- Benchmarking EFS
  - Attack surface coverage
  - Text and Binary protocols
  - Functions (funcs) vs. basic blocks (bbs)
  - Pool vs. Diversity (also called niching)
- See benchmarking paper for more details [3]
  - Will be up on vdalabs.com when complete

Benchmarking: An investigation into the properties of EFS

- Develop a tool kit that can be used to test various products
- Currently the toolkit is simply two network programs used to test EFS's ability to discover a protocol
  - Clear text (TextServer)
  - Binary (BinaryServer)
- Intend to insert easy and hard to find bugs, to test 0day hunting ability

TextServer

- Three settings, low (1 path), med (9 paths), high (19 paths)
- Protocol
  - ← "Welcome.\r\n Your IP is 192.168.31.103"
  - "cmd x\r\n" →
  - ← "Cmd x ready. Proceed.\r\n"
  - "y\r\n" →
  - ← "Sub Cmd y ok.\r\n"
  - "calculate\r\n" →
  - ← "= x + y\r\n"

Aside: Measuring the Attack Surface

- One example, TextServer on Medium:
  - Startup and shutdown = 137 BBs or 137/597 = 23% of code.
  - Network code = 15 BBs or 15/597 = 3% of code
  - **Parsing** = 94 BBs or 16% of code. *This is the portion of code likely to contain bugs!*
  - Total Attack surface = network code + parsing. 109bb or 18% of code.
  - Code accounted for: 137+94bb or 39%. (68+22funcs or 31%)

The seed file for TextServer

- “\r\n”
- “calculate”
- “cmd “
- “1”
- “2”
- “3”
- “4”
- “5”
- “6”
- “7”
- “8”
- “9”

Clear Text Results

- EFS had no trouble learning the language of *TextServer.exe*
- Best session was found quickly
- But the entire attack surface was not completely covered
  - Why? Think “error” or “corner cases”
  - Used pools to increase session diversity. Had some success, but still not 100%
  - In a few slides we see that niching was used as well, and did better than pools, but still not 100%

BinaryServer

- Will be similar to TextProtocol, but binary format

Client Request Message Structure→:

Total LEN 4 bytes	Session ID 4 bytes	CMD LEN 2 bytes	CMD Str Var bytes

← Server Response Message Structure:

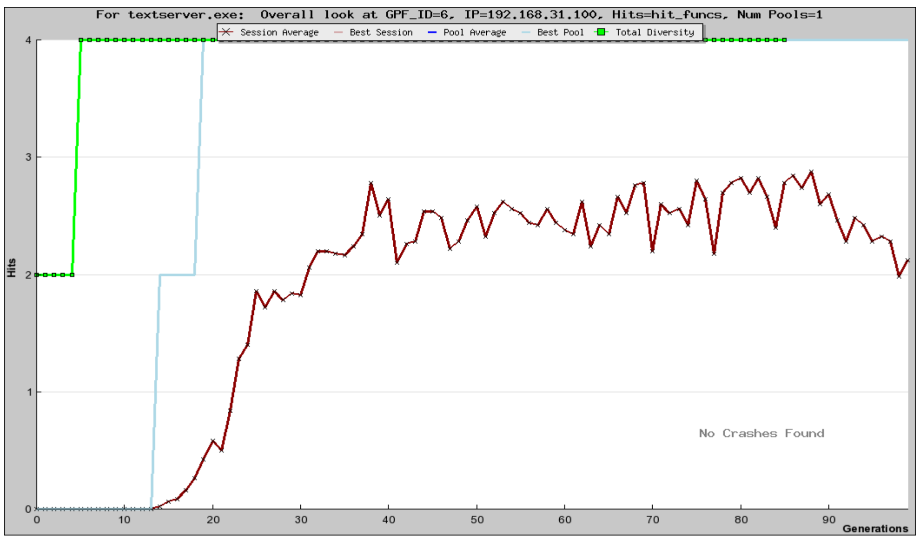
Total LEN 4 bytes	Session ID 4 bytes	RSP LEN 2 bytes	RSP Str Var bytes

Binary Protocol Results

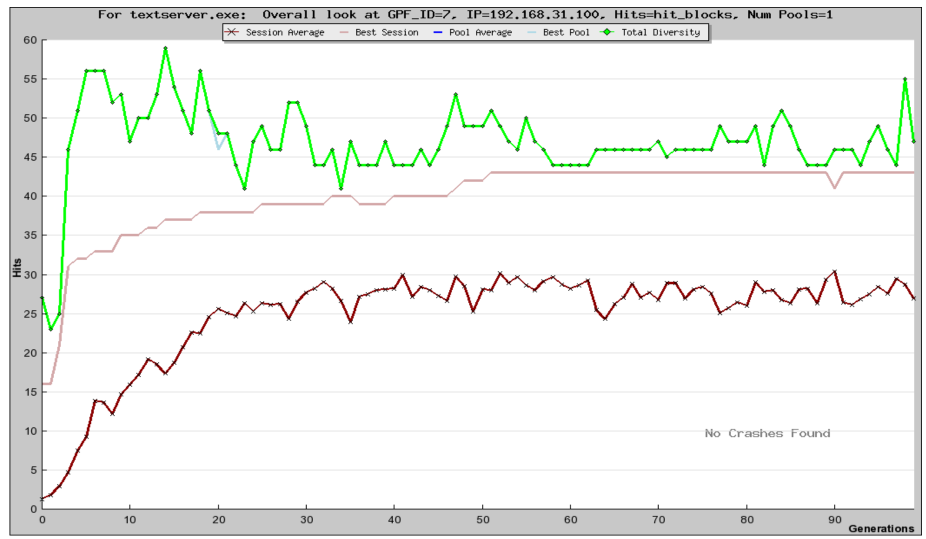
- Lengths shouldn't be too much trouble as EFS/GPF has a tok type for lengths
    - Initial tests support this
  - Hashes are not yet implemented in GPF
  - Binary protocol not yet implemented/tested

Functions vs. Basic Blocks

- For applications with few functions, basic blocks should be used
- For more complex protocols, functions suffice and increase run speed

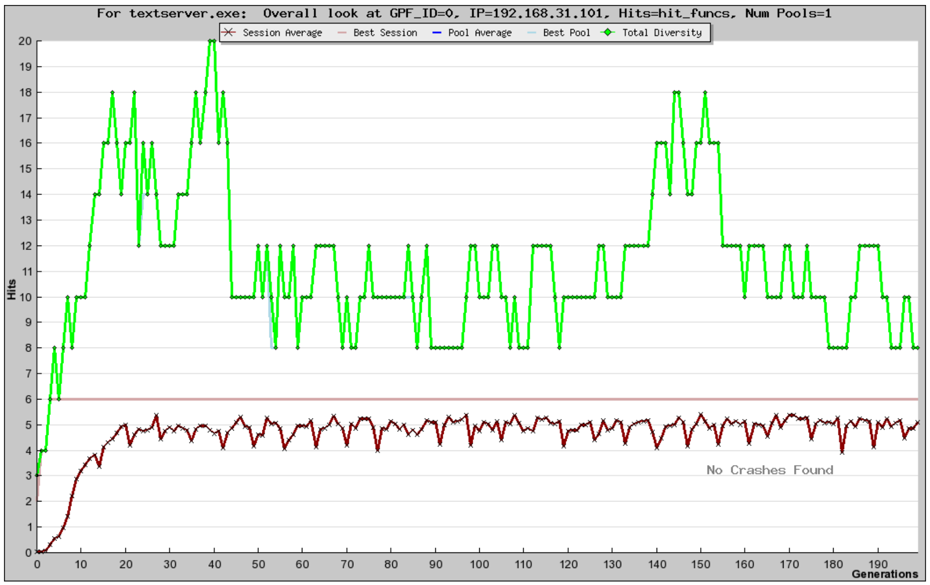


Low, Funcs, 1 Pool:
Best Session: 4/6 or 66%

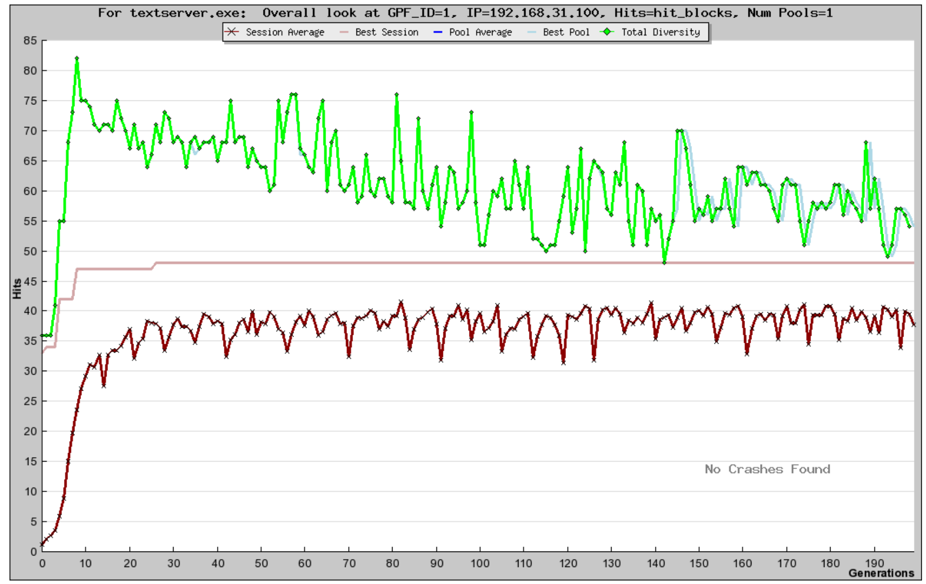


Low, BBs, 1 Pool:
Best Session: 40/37 or 100%+

Funcs vs. BBs (cont.)



Med, Funcs, 1 Pool:
Best Session: 6/6 or 100%
Diversity Peak: 20/22 or 90%



Med, BBs, 1 Pool:
Best Session: 47/37 or 100%+
Diversity Peak: 83/94 or 88%

Testing the effects of Pools

- Pools work to achieve better session diversity
  - Also achieved better crash diversity in gftp
- Didn't achieve 100% coverage of attack surface
- Case study at the end will show the positive affects of pools
- Comparing and adding to niching

Niching (or Speciation) to Foster Diversity

- Recently implemented so grab the new stuff off vdalabs.com
- Provides a fitness boost for sessions and pools that are diverse when compared to the best
  - ***Fitness = Hits + ((UNIQUE/BEST) * (BEST-1))***
    - ***Hits: code coverage, funcs or bbs***
    - ***UNIQUE: number of hits not found in the best session***
    - ***BEST: Session or Pool with the best CC fitness***

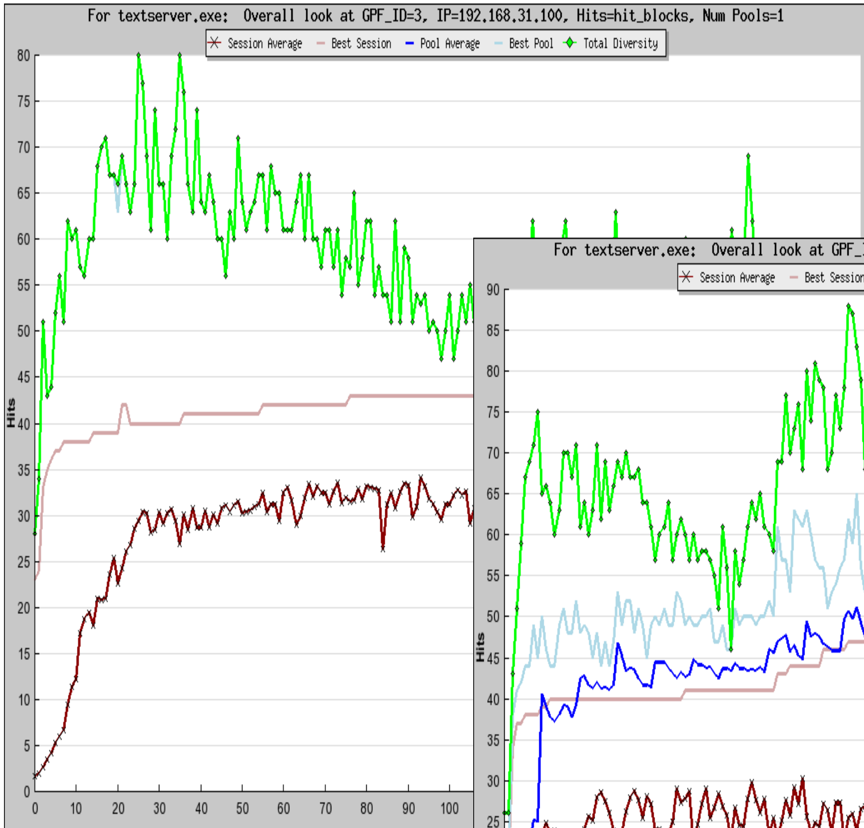
Diversity in Action

- S1: 10 hits - (a, b, c, d, e, f, g, h, i, j)
- S2: 7 hits - (a, b, d, e, f, g, h)
- S3: 5 hits - (v, w, x, y, z)

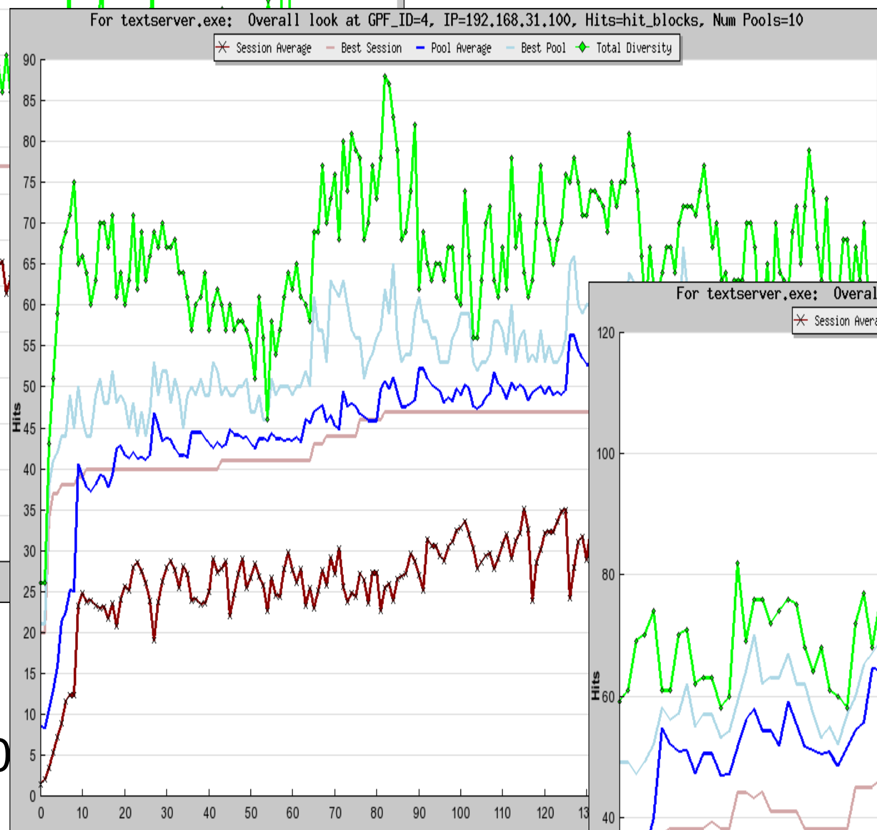
- Final fitnesses:
- S1: 10 +((0/10) * 9) = 10
- S2: 7 + ((0/10) * 9) = 7
- S3: 5 + ((5/10) * 9) = 9.5

- Same for pools

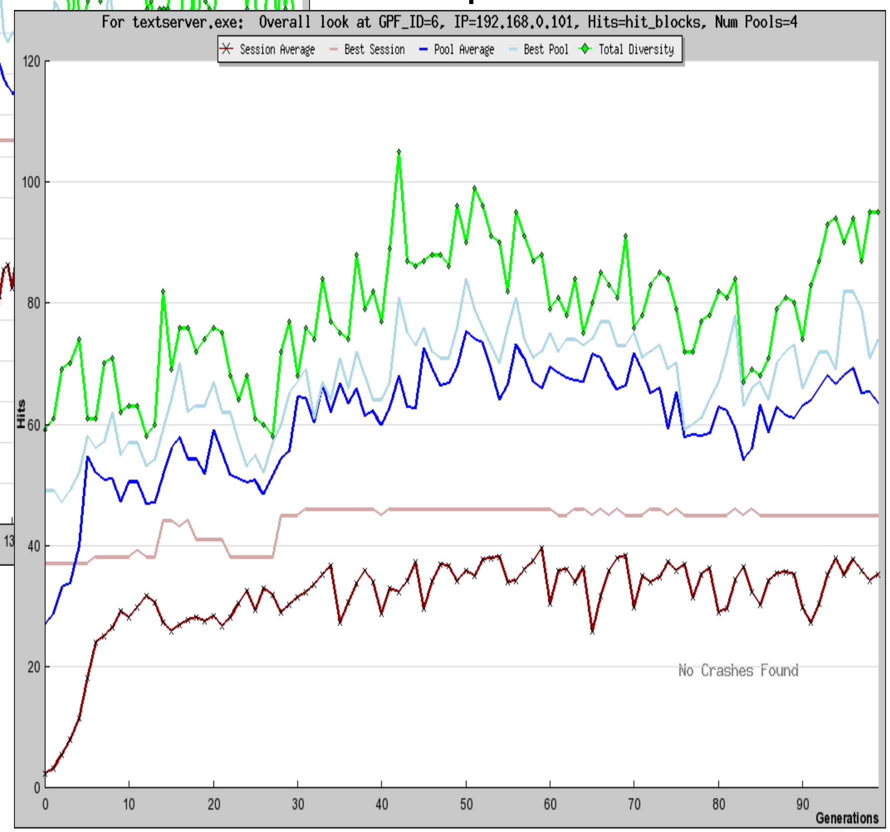
Pools and Diversity



High, BBs, 1 Pool
Best Session: 43
Diversity Peak: 80
Downward trend



High, BBs, Multi-Pool
Best Session: 47
Diversity Peak: 87
Up and down trend



High, BBs, Multi-Pool
DIVERSITY ON
AVG: 46
Total Peak: 107
Up and down trend

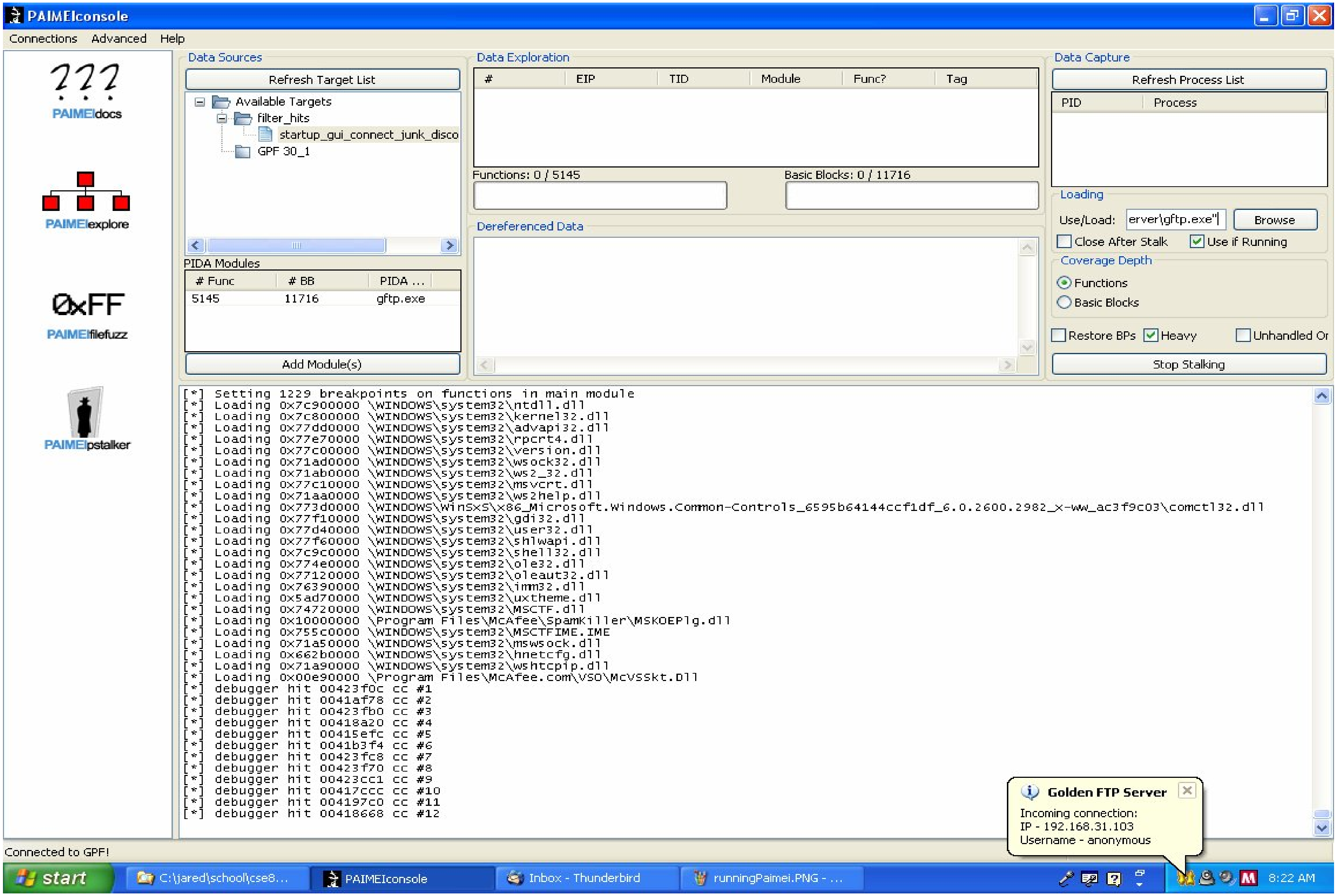
Section 4: Results

- Initial Results
  - Golden FTP
  - IIS FTP/SMTP

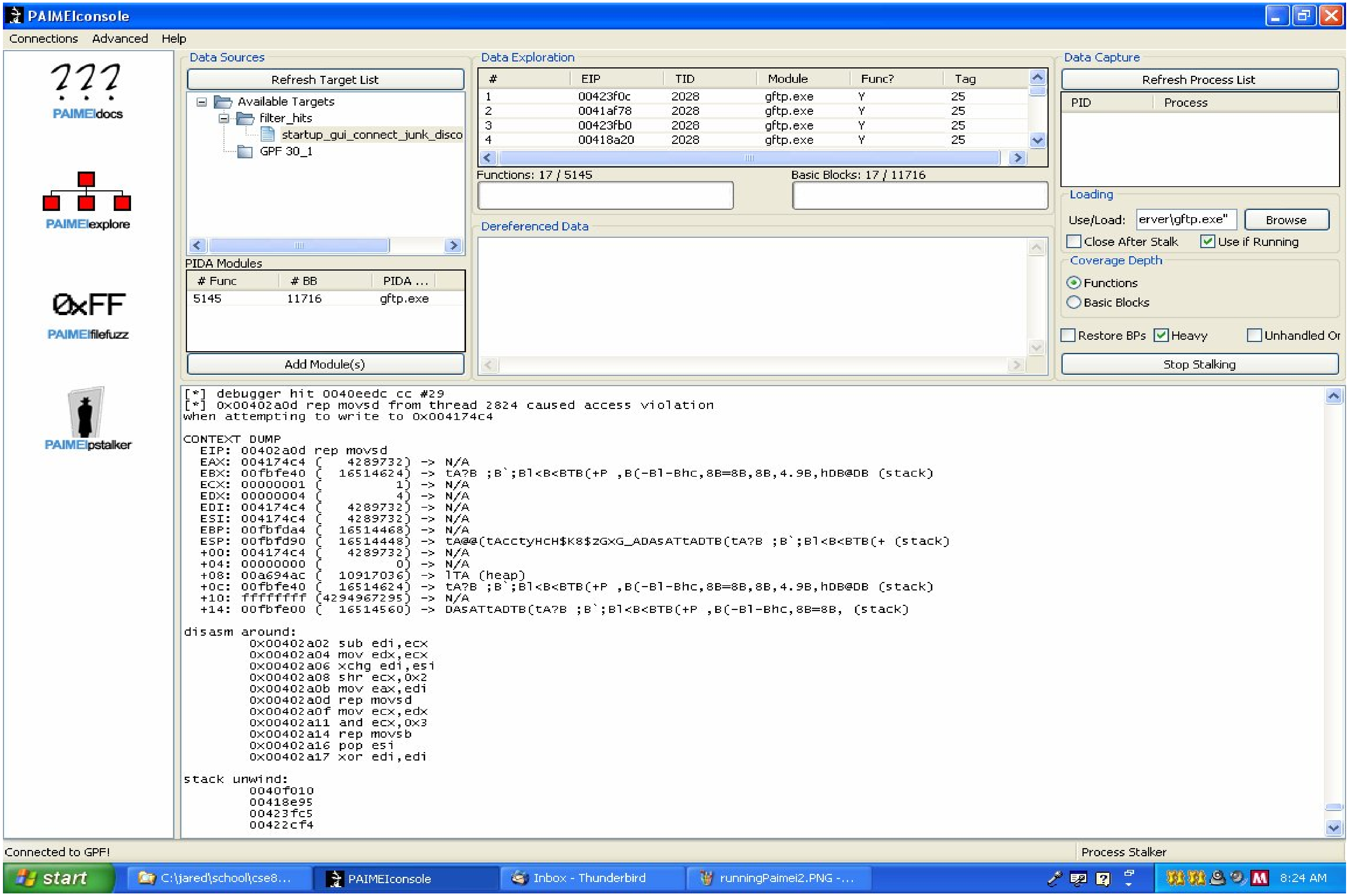
Testing on Real World Code

- Golden FTP
  - Found lots of bugs
- IIS FTP and SMTP
  - Found no bugs, but did seem to show some instability in FTP
    - Would lock or die once and a while
- Plan to test many more
  - Haven't tried any with diversity on yet

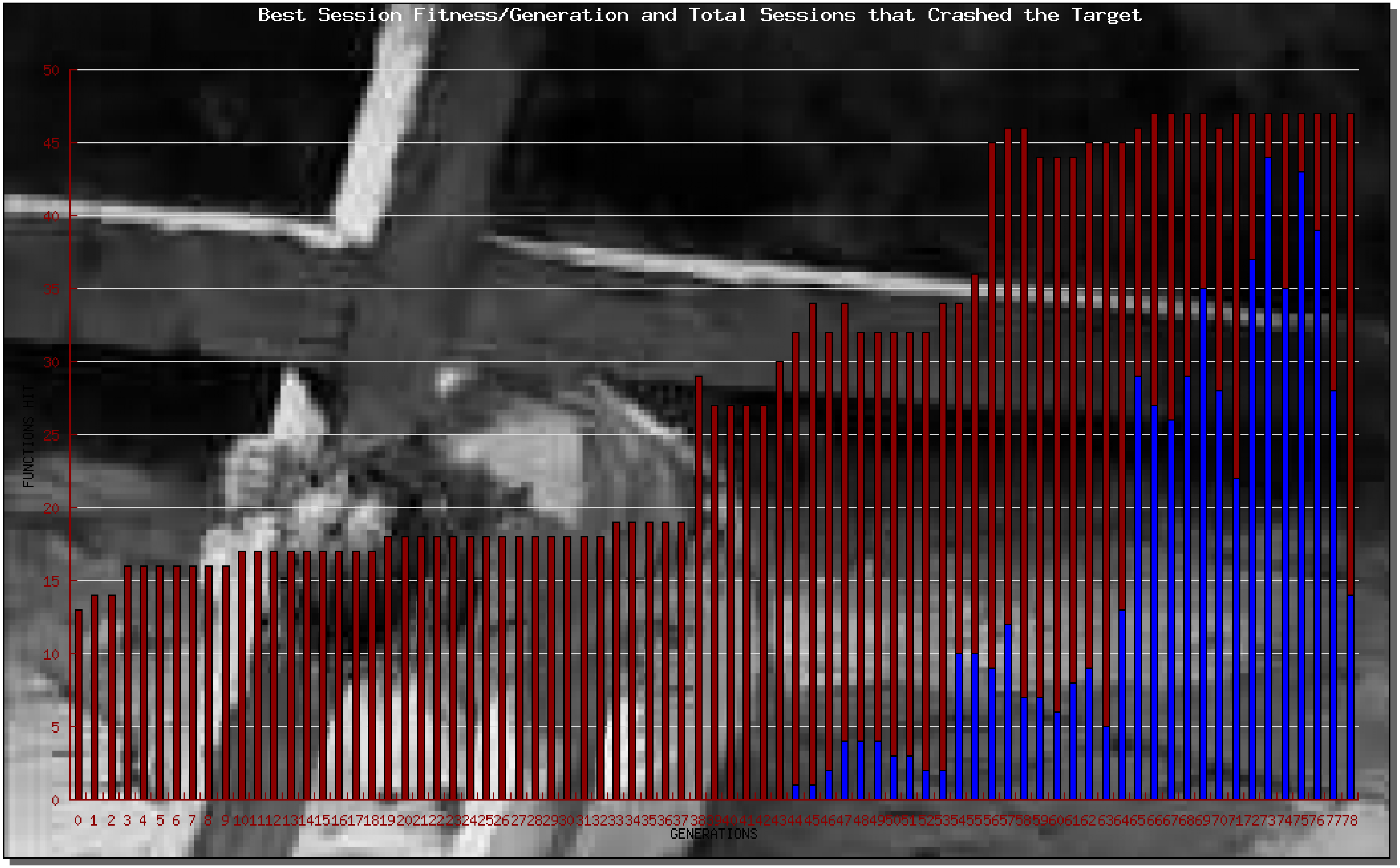
EFS: Found user & password (outdated picture)



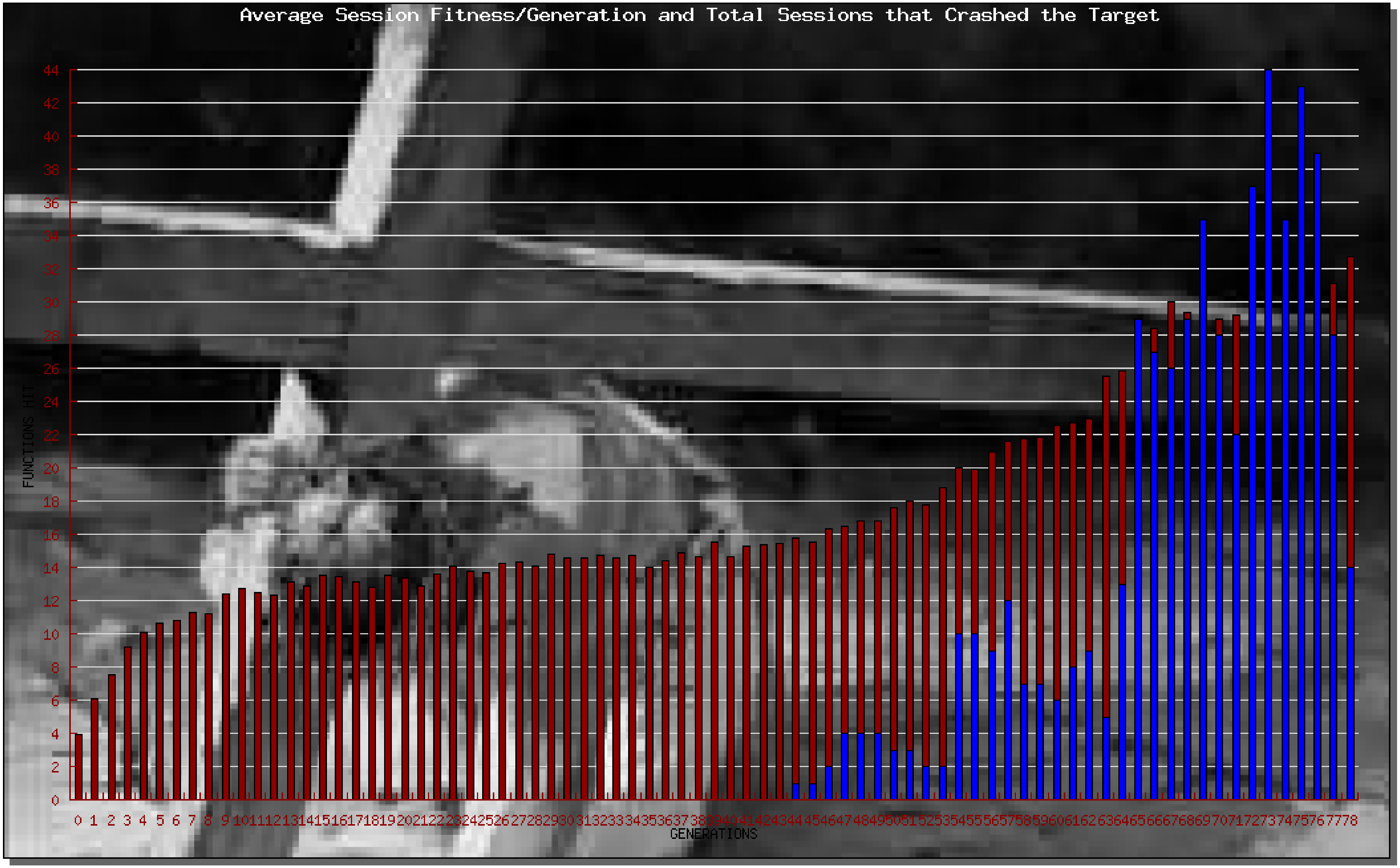
EFS: Crash Example (outdated picture)



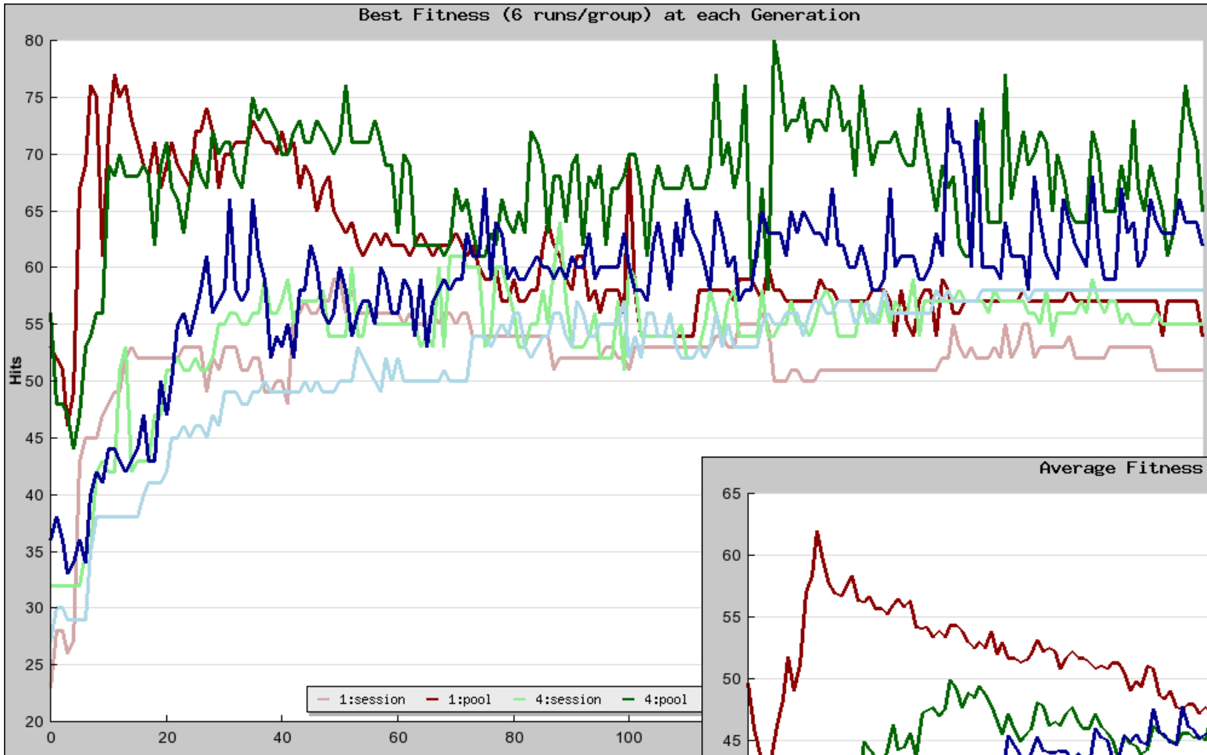
EFS: gftp.exe Results (max) (outdated picture)



EFS: gftp.exe Results (avg) (outdated picture)

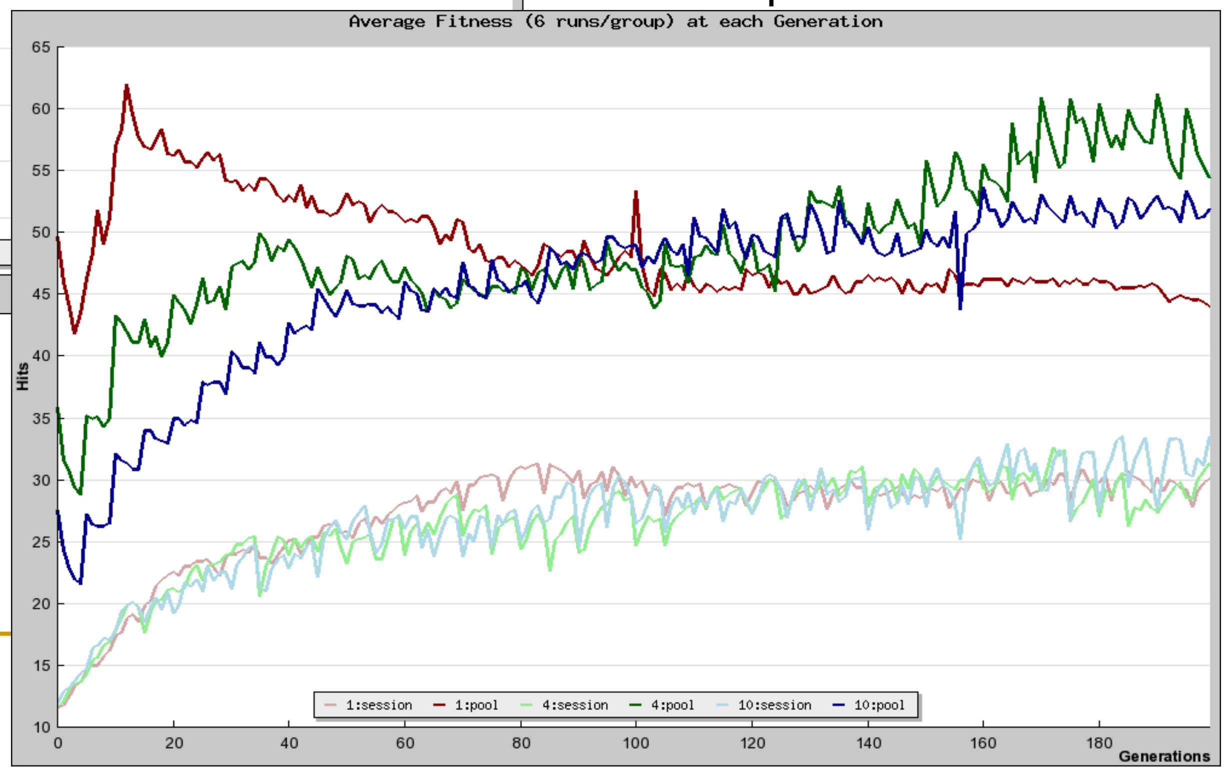


GFTP Pool Effects – Avg over 6 runs

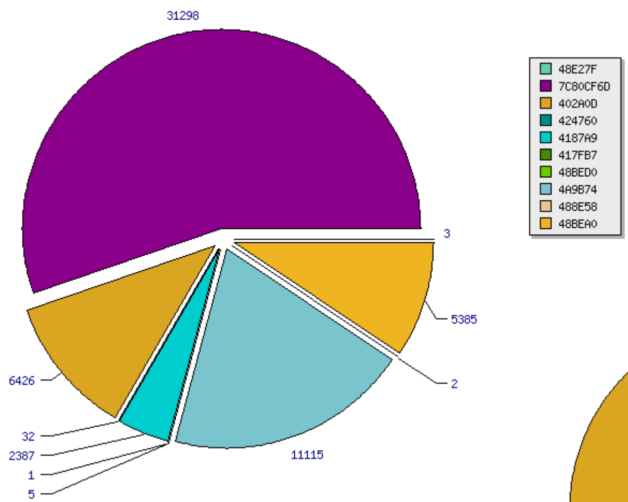


Best of Pool and Session

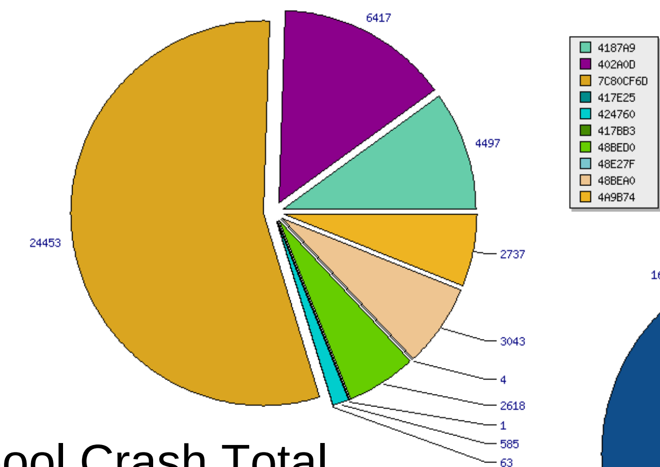
Average fitness of pool and session



Crash Results – For all Runs

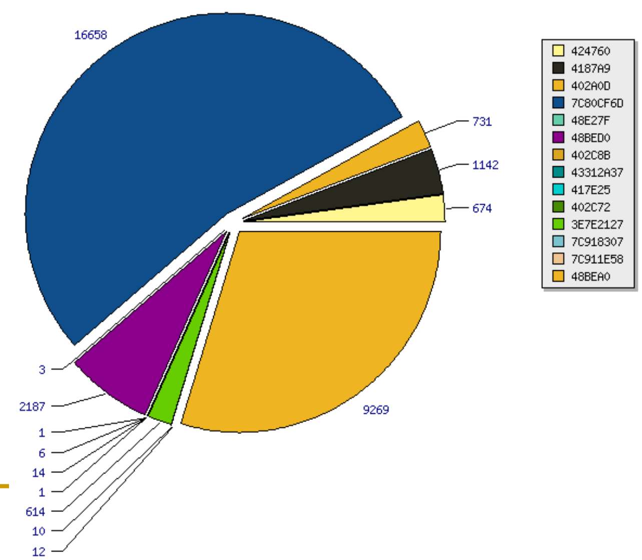


1-pool Crash Total



4-pool Crash Total

10-pool Crash Total



Challenges and Future Work

- Modifying EFS to work on files as well
- How does its performance compare with existing fuzzing technologies?
  - What is the probability to find various bug types as this is the final goal of this research
    - What bugs can be found and in what software?
- The fuzzing technology to use seems to depend on the application and general domain robustness (i.e. min work to get a bug)
  - File fuzzing == dumb fuzzing
  - Network apps == Intelligent (RFC aware) fuzzing

Challenges and Future Work (cont.)

- PIDA files are great but a pain
  - Binary could be obfuscated, encrypted, or IDA just doesn't do well with it. Considered MSR, that there are issues there as well.
- Speed
  - Auto-detecting the optimal session-wait to determine if funcs or BBs is more parcticle
- Binary Protocols
  - Need more testing here
- Normal testing challenges
  - Monitoring, Instrumentation, logging, statistics, etc.

References:

1. J. DeMott, R. Enbody, W. Punch, “Revolutionizing the Field of Grey-box Attack Surface Testing with Evolutionary Fuzzing”, BlackHat and Defcon 2007
2. P. McMinn and M. Holcombe, “Evolutionary Testing Using an Extended Chaining Approach”, ACM Evolutionary Computation, Pgs 41-64, Volume 14, Issue 1 (March 2006)
3. J. DeMott, “Benchmarking Grey-box Robustness Testing Tools with an Analysis of the Evolutionary Fuzzing System (EFS)”, continuing PhD research

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- Family (Wonderful wife and two boys that think I'm the coolest.)
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