# Quantitative Cyber-Security


**Colorado State University**

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**CSU Cybersecurity Center**

**Computer Science Dept**

# Term Project

All submissions should follow the 2-column *format for IEEE conference papers*.

- Proposal and sources: Oct 10
- Semi-final report: Nov 7
  - It should indicate that you have finished at least two-thirds of the work. It should include an abstract, discussion of background literature, a summary of the investigations/findings, any refinements of the proposal objectives as a result of the past study, what the final report will contain and the applicable references.
  - Technical details, equations/tables/plots/screen-shots
  - You must be aware of the current trends in research/industry.
- Slides: Due Nov 18 (more details later)
- Ten-minute oral presentation Nov 19-Dec 8

# Peer Interaction

- Your interaction with other student's research is a part of the class.
- You will need to review semi-final report of two fellow students
  - Identify main contributions
  - Strength/weaknesses
  - Suggestions for improvements
  - Suggested additional references
- Presentations: reviews and comments
- Your interaction will be evaluated

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# Research

- Understand the techniques and results in a chosen field
  - Examine articles from diverse  sources
  - Study selectively
- Identify current status, trends, unexplored issues
- Search for information
  - Multiple types of sources
  - Multiple key words
- Search “around” an article
  - Backward search: citations
  - Forward search: cited by (Google scholars)
  - Horizontal search: related publications

# Search Databases

Specific sources: database indexes

- Google Scholar
  - Forward links: Paper X Cited by
  - Backward Links: Paper X cites
- Researcher sites
  - Personal/Group Website
  - DBLP
  - Google Scholar: researcher
- CSU Library etc.

General (*accessible through CSU Library*)

- ACM Digital Library
- IEEEXplore Digital Library
- ScienceDirect etc

# Source types

- News (such as Google News)
- Conferences: held once a year, proceedings published
  - Conference, Symposium, …
- Industry publications
  - Magazines, blogs, white papers, product website
- Journals: published several times a year
  - Rigorously reviewed, long publication delay
  - Journal, Transactions, …
- Research groups
  - Industry, academic, consultants: web site
- Books: often well-known stuff
  - Research updates: monographs

# How to Read Papers: THE THREE-PASS APPROACH

- The first pass: Read (a large number)
  - the title, abstract, and introduction
  - section and sub-section headings, but ignore everything else
  - the conclusions
- The second pass: Read (an intermediate number)
  - figures, diagrams and other illustrations
  - mark relevant unread references for further reading
  - Do you need to read it in detail?
- The third pass: Read critically (closely related)
  - identify and challenge assumption and views
  - Loop up  references needed

Keshav, S., How to Read a Paper, ACM SIGCOMM, http://ccr.sigcomm.org/online/files/p83-keshavA.pdf

# Evaluation of Research

Similar to paper review for conferences/journals

- Significance and originality
  - Timeliness
  - Originality
- Thoroughness of research
  - Familiar with the field?
  - Has seen significant/recent papers?
- Depth of understanding displayed
- Presentation

# You Must Do Research

## Not enough:

- Summary of a couple of papers
- Summary of work of a single research group
- Rephrasing of existing surveys

## You must know (and should be able to answer related questions):

- Current state of the art
- Alternative approaches and how they can be evaluated
- Technology trend
- Find data describing the technology
- Existing issues and challenges

# Citing Sources

## “IEEE” “ACM” etc:

- These are professional organizations that organize numerous conferences and published journals
- You must specify the author, title of paper, specific names of conference/journal, associated details, date, page numbers
- A simple URL is not a valid citation
- URL not needed for conference, journal publications. Needed for on-line publications (Organizational reports, Industrial white-papers, News etc)

Omar H., Alhazmi and Yashwant K. Malaiya, "Application of vulnerability discovery models to major operating systems“, IEEE Transactions on Reliability, Volume: 57 , Issue: 1, pp. 14-22, March 2008,

Ambrose Andongabo, Ilir Gashi, "vepRisk - A Web Based Analysis Tool for Public Security Data", 13th European Dependable Computing Conference (EDCC) 2017, pp. 135-138, 2017.

# You must include

- Title, your name, class, year, professor’s name
- Abstract: What does it include and  why is it important
- Background:  Other existing work and background ideas
- Technical discussion: detailed presentation of findings with non-text material (equations, charts, plots, tables, algorithms etc.)
- Discussion of results
- Summary, future work
- References
- Appendix if any

# Projects

| | | |
|---|---|---|
| Dubois, Alexandre | 1 | economic tradeoffs due to security issues |
| Li, Jacinda | 6 | Analysis of Electronic Payment Systems |
| Pineiro Rivera, Luis | 6 | Security of Payment Systems |
| Mulligan, Brett | 10 | Fuzzing Open Source IoTProject |
| Chen, Sirius | 11 | secure containers |
| Liu, Zijuan | 11 | Security in Virtualized Systems |
| Al Amin, Md | 12 | Ransomware |
| Neumann, Don | 12 | Ransomware |
| Haynes, Katherine | 13 | DeepNeural Networks to Improve Phishing Detection |
| Rodriguez, Luis | 13 | Quantitative Examination of Phishing |
| Zhao, Qingyi | 13 | phishing |
| Weaver, Austen | 14 | Cost and Cause of U.S. Government Security Breaches |
| Eswaran, Suraj | 15 | CYBER INSURANCE |
| Alqurashi, Saja | 19 | CS networkusing Mitre ATT&CK |
| Gowdanakatte, Shwetha | 19 | ATT&CKFramework and Vulnerability detection forIndustrial Control System |
| Kotian, Siddhi | 20 | Effectiveness of Penetration Testing |
| Padalia, Dhruv | 20 | effectiveness of Penetration Testing |
| Shang, Tony | 24 | deep neural networks todetect DDOS attack |
| Cheng, YaHsin | 25 | Cyber Criminals |
| Houlton, Sarah | 25 | Cyber Crime and Criminals |
| Jepsen, Waylon | 25 | North Korea’s Cyber Criminals |
| Petkar, Jayesh Umesh | 26 | Smartphone Security Model and Vulnerabilities |
| Ravichandran, Shree Harini | 26 | Smartphone Security Model |
| Paudel, Upakar | sp | Security Posture of Various Android based IoT |

# Presentations

- 10-minute presentations, 2 minutes for Q/A/C
  - Suggest max 15 slides
  - Mention your name when asking questions
- One joint project with 2 students
  - 2x presentation time
- Multiple independent projects on the same topic
  - Coordinate to minimize overlap in the presentation

# Problem: Password guessing

How easy it is to guess a password?

- If your keyboard has R= 95 unique characters,
- randomly constructing a password from that whole set, 12-character password, then L = 12.
- $95^{12}$= 540,360,087,662,636,962,890,625 passwords

**Entropy** = $\log_2(R^L)$ = 78.9 bits assuming passwords are created randomly

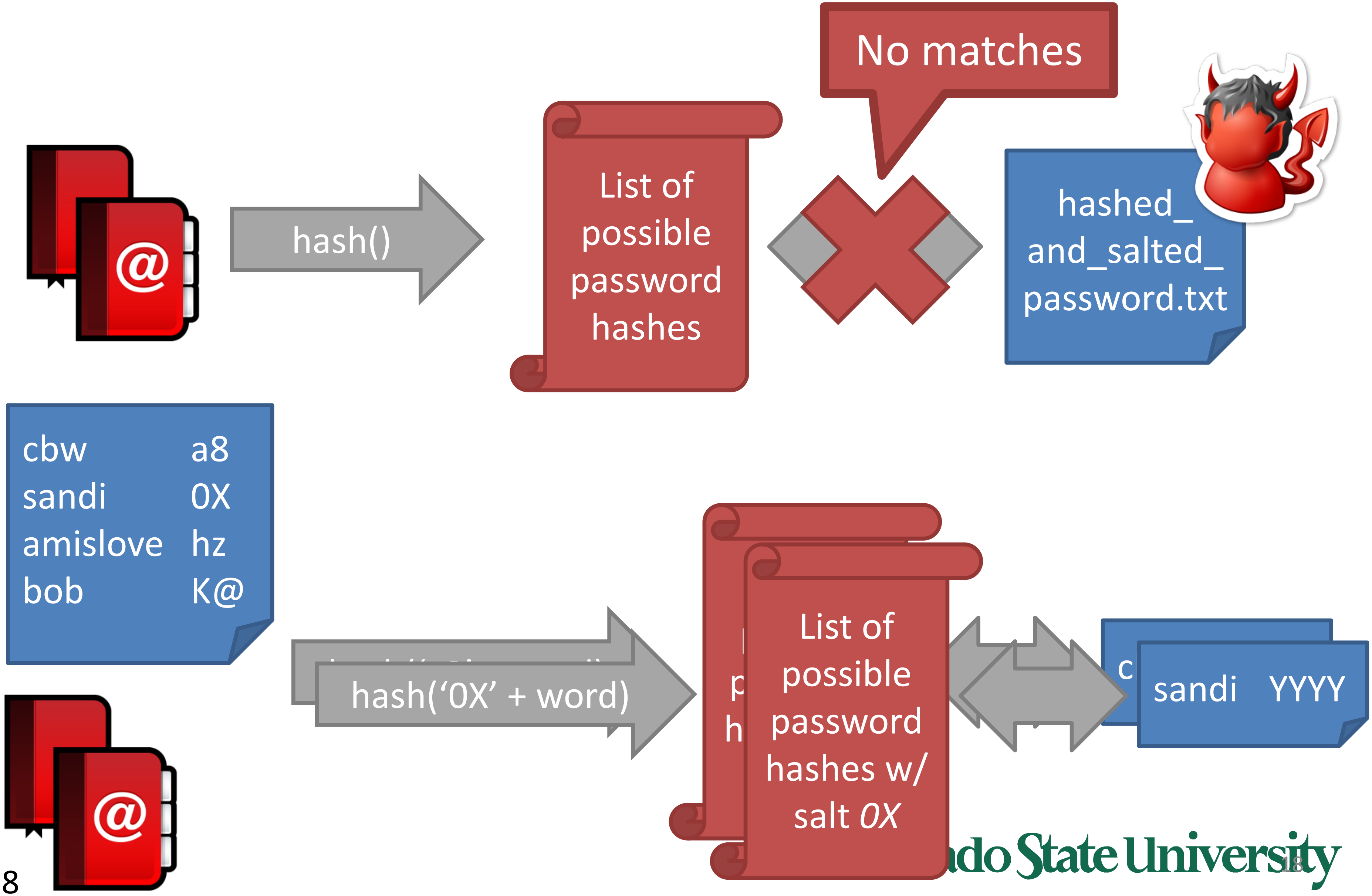
Ascii is 8 bits. Thus about $2^{12x8}$

- Non-randomness makes password guessing easier.
- Measures of password strength proposed and used

Password guessing at login? Can be defeated by

- Limited number of tries: 3-5
- Blocking attempts from unknown/suspected IP addresses

# Attacking Salted Passwords



# Quantitative Security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**CS 559**

**Fuzzing**


**CSU Cybersecurity Center**
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# Fuzzing vs. Testing

## User Testing

Run program on many **normal** inputs, look for bad things to happen

**Goal:** Prevent **normal users** from encountering errors

## Fuzzing

Run program on many **abnormal** inputs, look for bad things to happen

**Goal:** Prevent **attackers** from encountering exploitable errors

Ack: Stanford, Columbia

# Types of Fuzzing

- **Mutation-based (Dumb) fuzzing**
  - Add anomalies to existing good inputs (e.g., test suite)
- **Generative (Smart) fuzzing**
  - Generate inputs from specification of format, protocol, etc
- **Evolutionary (Responsive) fuzzing**
  - Leverage program instrumentation, code analysis
  - Use response of program to build input set

# Mutation-Based Fuzzing

**Basic Idea**

- Take known good input and add anomalies
- Anomalies may be completely random or follow some heuristics
  - Large integers or strings
  - Randomly flip bits

# HTTP Fuzzing Example

**Standard HTTP GET Request**

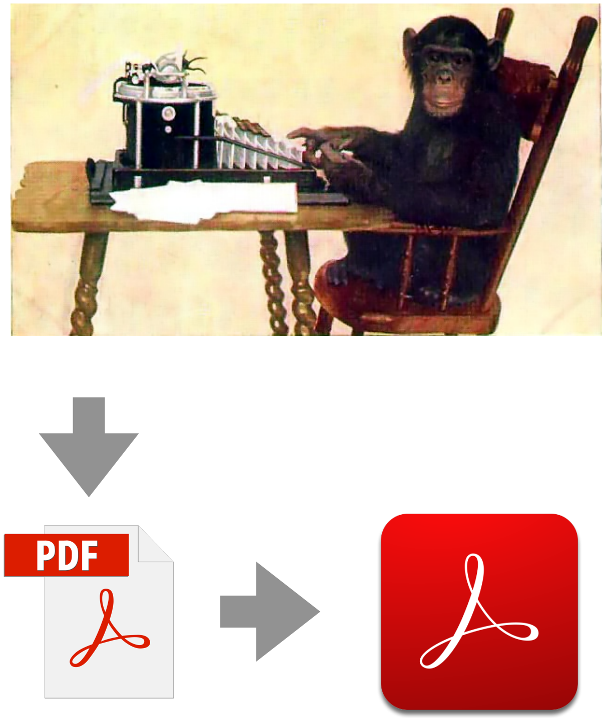
```
GET /index.html HTTP/1.1
```

**Anomalous Requests**

```
GEEEE…EET /index.html HTTP/1.1
GET ///////index.html HTTP/1.1
GET %n%n%n%n%n%n.html HTTP/1.1
GET /AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA.html
HTTP/1.1
GET /index.html HTTTTTTTTTTTTTP/1.1
GET /index.html HTTP/1.1.1.1.1.1.1.1
df%w3rasd8#r78jskdflasdjf
4isg8swksdfskdflsdgmsf$gkjs
```

# Fuzzing PDF Reader

- Download 100s of random PDF files
- Mutate content in the PDF file:
  - flip bits
  - increase size of integers or strings
  - remove data
- Limited by the functionality that the existing files happened to use — unlikely to hit less commonly tested code paths



# Mutation-Based Fuzzing

**Basic Idea**

- Take known good input and add anomalies
- Anomalies may be completely random or follow some heuristics

**Advantages**

- Little or no knowledge of the structure of the inputs is assumed
- Requires little to no set up time

**Disadvantages**

- Dependent on the inputs being modified
- May fail for protocols with checksums, challenge-response, etc.

# Generation Based Fuzzing

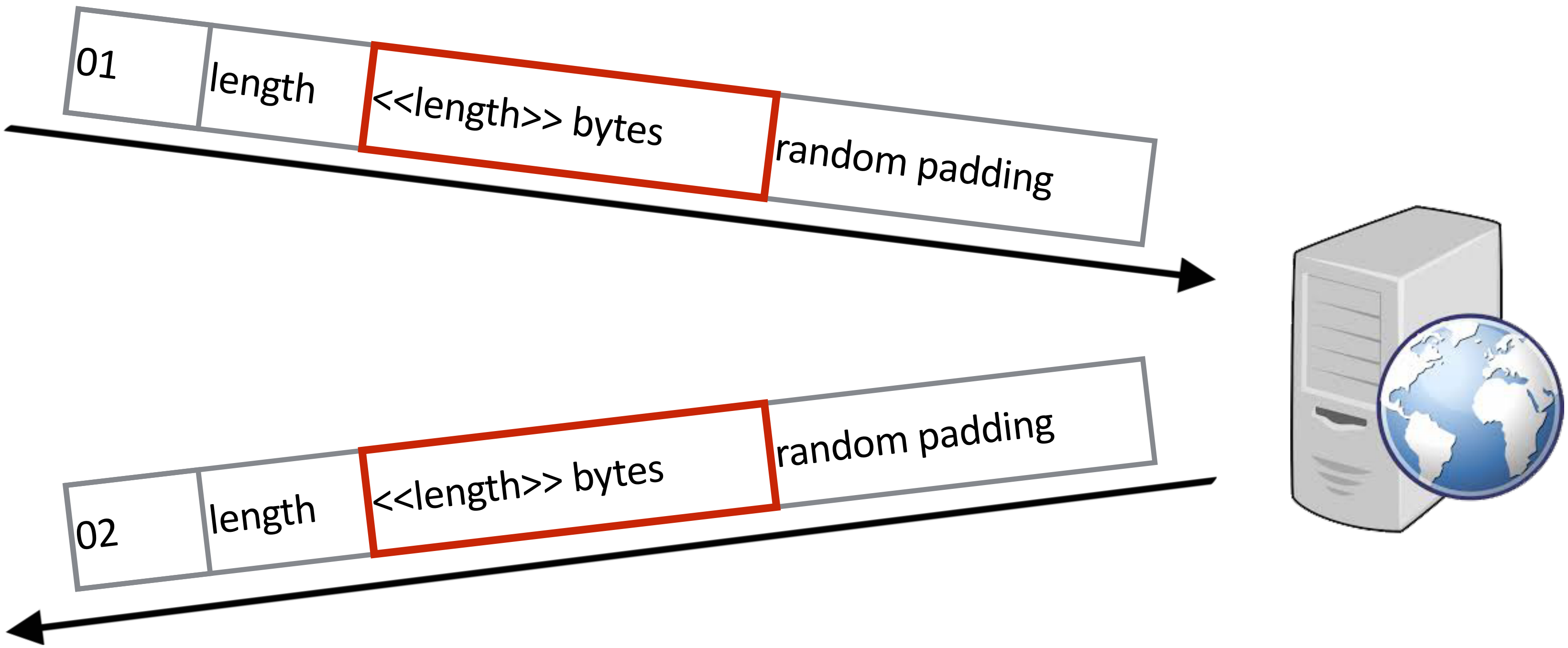
## Basic Idea

- Test cases are generated from protocol description: RFC, spec, etc.
- Anomalies are added to each possible spot in the inputs
- Knowledge of protocol should give better results than random fuzzing

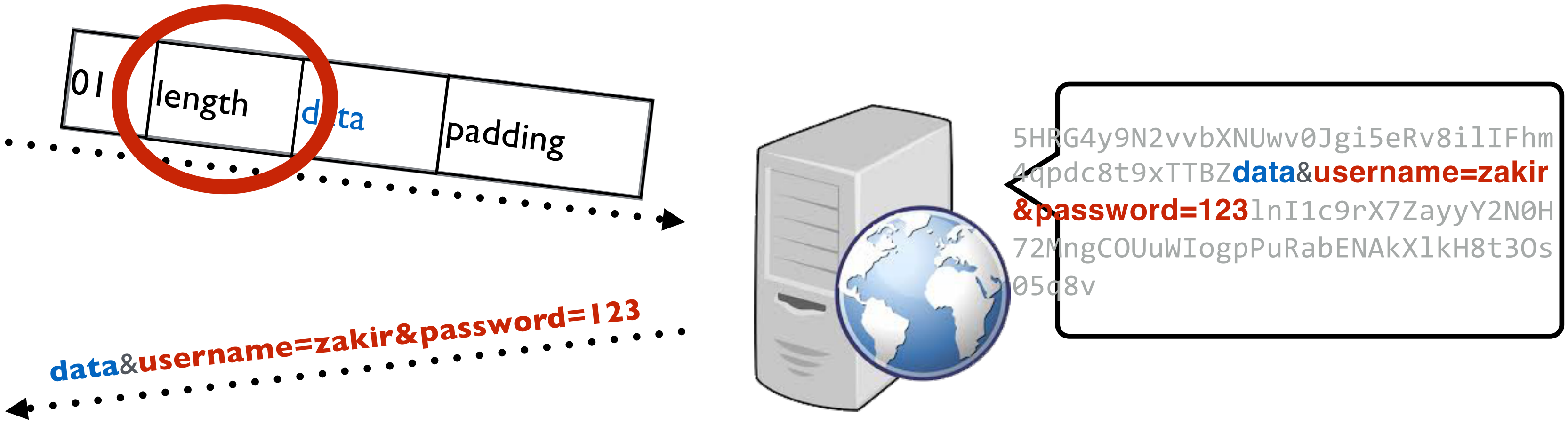
```
<!--  A.  Local file header -->
  <Block name="LocalFileHeader">
    <String name="lfh_Signature" valueType="hex" value="504b0304" token="true" mut
    <Number name="lfh_Ver" size="16" endian="little" signed="false"/>
    ...
    [truncated for space]
    ...
    <Number name="lfh_CompSize" size="32" endian="little" signed="false">
      <Relation type="size" of="lfh_CompData"/>
    </Number>
    <Number name="lfh_DecompSize" size="32" endian="little" signed="false"/>
    <Number name="lfh_FileNameLen" size="16" endian="little" signed="false">
      <Relation type="size" of="lfh_FileName"/>
    </Number>
    <Number name="lfh_ExtraFldLen" size="16" endian="little" signed="false">
      <Relation type="size" of="lfh_FldName"/>
    </Number>
    <String name="lfh_FileName"/>
    <String name="lfh_FldName"/>
    <!--  B.  File data -->
    <Blob name="lfh_CompData"/>
  </Block>
```

# Generation Example: TLS Heartbeat

**Heartbeat** Extension for the Transport Layer Security:
to test and keep alive secure communication links
without the need to renegotiate the connection each time



# Generation Example: TLS Heartbeat




Heartbleed Vulnerability: server trusts user provided length field and echoes back memory contents following request data

# Mutation-based vs. Generation-based

- Mutation-based fuzzer
  - Pros: Easy to set up and automate, little to no knowledge of input format required
  - Cons: Limited by initial corpus, may fall for protocols with checksums and other hard checks
- Generation-based fuzzers
  - Pros: Completeness, can deal with complex dependncies (e.g, checksum)
  - Cons: writing generators is hard, performance depends on the quality of the spec

# How much fuzzing is enough?

- Mutation-based-fuzzers may generate an infinite number of test cases. When has the fuzzer run long enough?
- Generation-based fuzzers may generate a finite number of test cases. What happens when they're all run and no bugs are found?
- Sometimes every anomalous test case triggers the same (boring) bug?

# Charlie Miller's 5 Lines

In 2010, Charlie Miller fuzzed

- Adobe Acrobat,
- Apple Preview,
- Powerpoint, and
- Open Office

by downloading PDF and PPT files and five lines of simple fuzzing:

```
numwrites =
random.randrange(math.ceil((float(len(buf)) /
FuzzFactor))) + 1
for j in range(numwrites):
  rbyte = random.randrange(256)
  rn = random.randrange(len(buf))
  buf[rn] = "%c"%(rbyte)
```

# Charlie Miller's 5 Lines

**Collect a large number of pdf files**

- Aim to exercise all features of pdf readers
- Found 80,000 PDFs on Internet

**Reduce to smaller set with apparently equivalent code coverage**

- Used Adobe Reader + Valgrind in Linux to measure code coverage
- Reduced to 1,515 files of 'equivalent' code coverage (Test compaction)
- Same effect as fuzzing all 80k in 2% of the time

**Randomly changed selected bytes to random values in files**

- Produce ~3 million test cases from 1,500 files

**Use standard common tools to determine if crash represents a exploit**

- Acrobat: 100 unique crashes, 4 actual exploits 4%
- Preview: 250 unique crashes, 60 exploits (tools may over-estimate) 24%

# Code Coverage

What if we tried to build tests that try to reach code in the program?

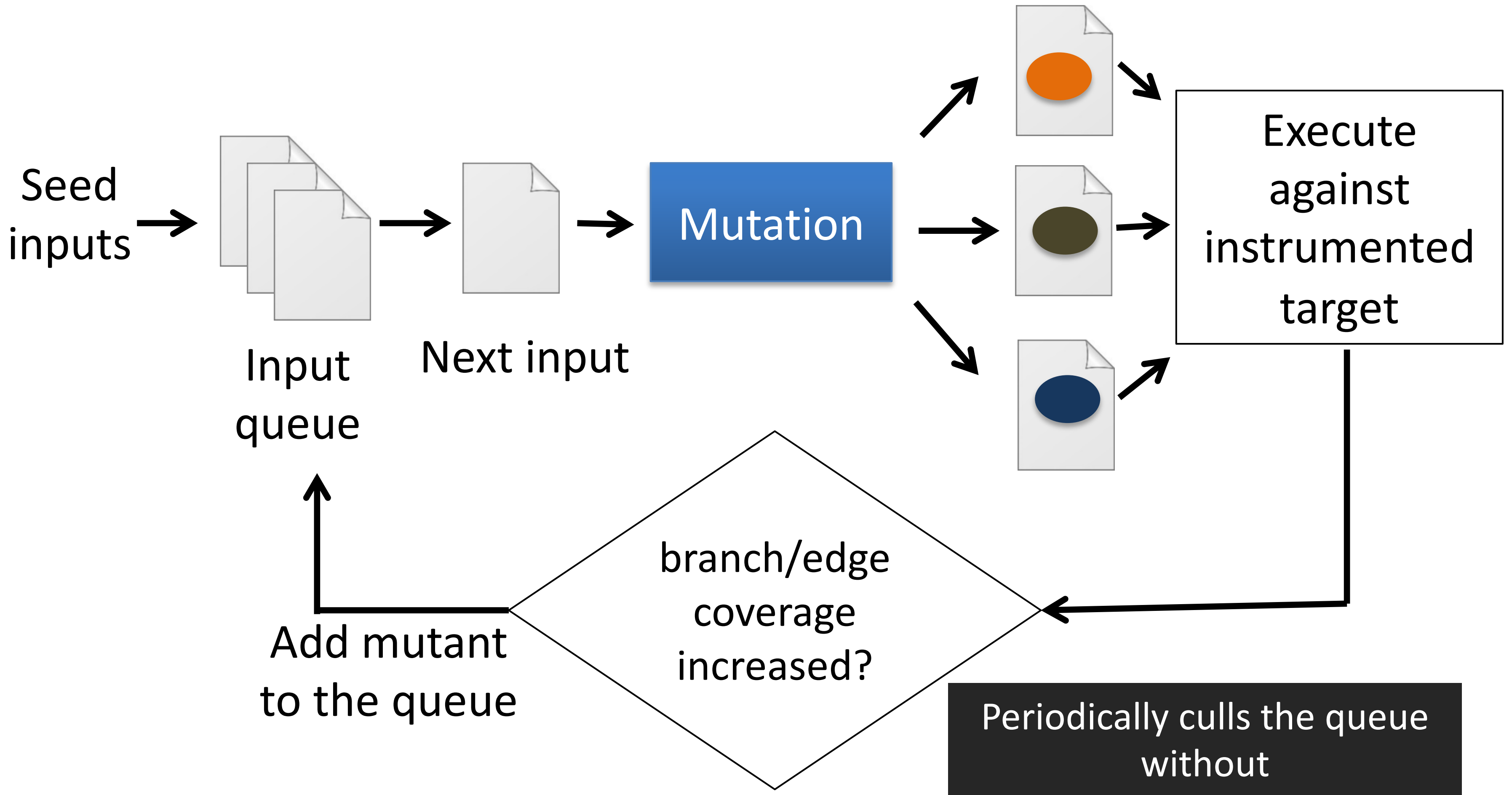
Code coverage is a metric which can be used to determine how much code has been executed.

- **Function coverage:** Has each function in the program been called?
- **Edge coverage:** Has every edge in the Control flow graph been executed?
- **Branch coverage:** Has each branch of each control structure been executed?
- **Predicate coverage:** Has each boolean expression been evaluated to true and false?

# Coverage-guided gray-box fuzzing

- Special type of mutation-based fuzzing
  - Run mutated inputs on instrumented program and measure code coverage
  - Search for mutants that result in coverage increase
  - Often use genetic algorithms, i.e., try random mutations on test corpus and only add mutants to the corpus if coverage increases
  - Examples: AFL, libfuzzer

# American Fuzzy Lop (AFL)




Periodically culls the queue without affecting total coverage

# Evolutionary Fuzzing

**Basic Idea:**

Generate inputs based on the structure and response of the program

- **Autodafe:** Prioritizes based on inputs that reach dangerous API functions
- **EFS (**Evolving **Fuzzer** System**):** Generates test cases based on code coverage metrics

Typically  instrument program with additional instructions to track what code has been reached — or, if no source is available, track with Valgrind.

# Tools

**Two influential tools**

cross_fuzz — specifically targeted at browser and generating complex DOM sequences

American Fuzzy Lop (AFL) — most everything else

# AFL Algorithm

American fuzzy lop (AFL) 2013 initial /2019 stable Michał Zalewski, Google/Snap

- Load user-supplied initial test cases into the queue,
- Take next input file from the queue,
- Attempt to trim the test case to the smallest size that doesn't alter the measured behavior of the program,
- Repeatedly mutate the file using a balanced and well-researched variety of traditional fuzzing strategies,
- If any of the generated mutations resulted in a new state transition recorded by the instrumentation,
  - add mutated output as a new entry in the queue.
- Go to 2.

# Fuzzing challenges

- How to seed a fuzzer?
  - Seed inputs must cover different branches
  - Remove duplicate seeds covering the same branches
  - Small seeds are better.

- Some branches might be very hard to get past as the # of inputs staisfying the conditions are very small
  - Manually/automatically transform/remove those branches

# Fuzzing rules of thumb

- Input-format knowledge is very helpful
- Generational tends to beat random, better specs make better fuzzers
- Each implementation will vary, different fuzzers find different bugs
  - More fuzzing with is better
- The longer you run, the more bugs you may find
  - But it reaches a plateau and saturates after a while
- Best results come from guiding the process
- Notice where you are getting stuck, use profiling (gcov, lcov)!