# NEUZZ: Efficient Fuzzing with Neural Program Smoothing

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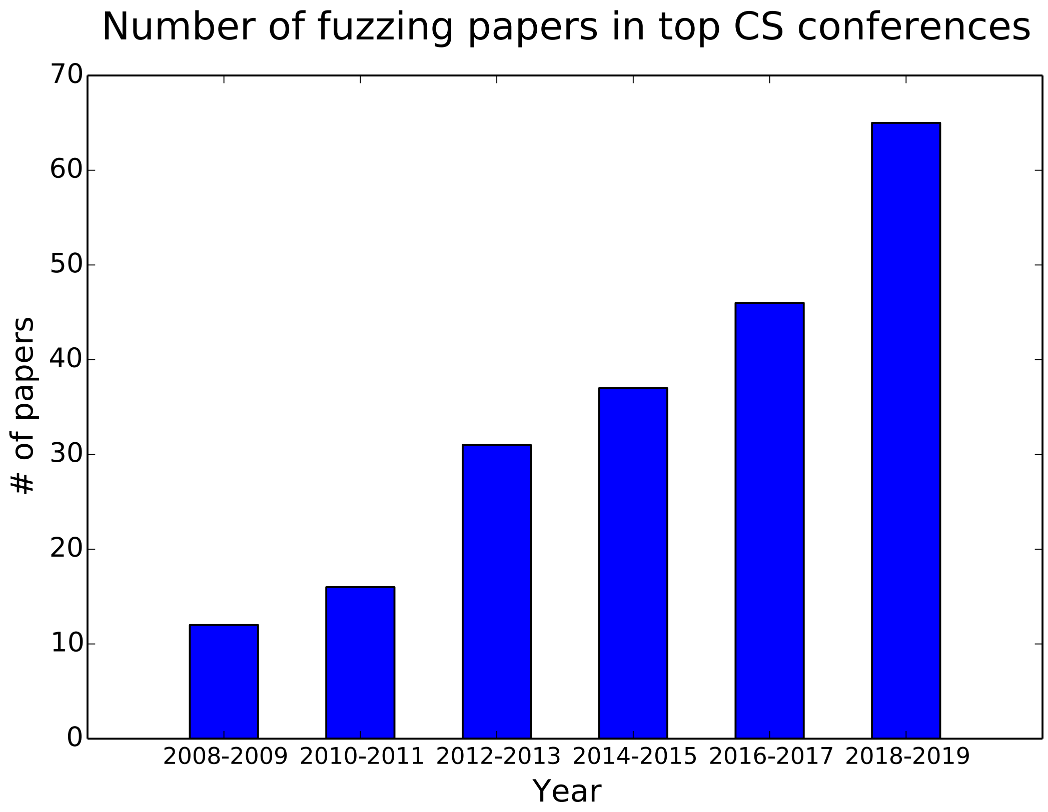
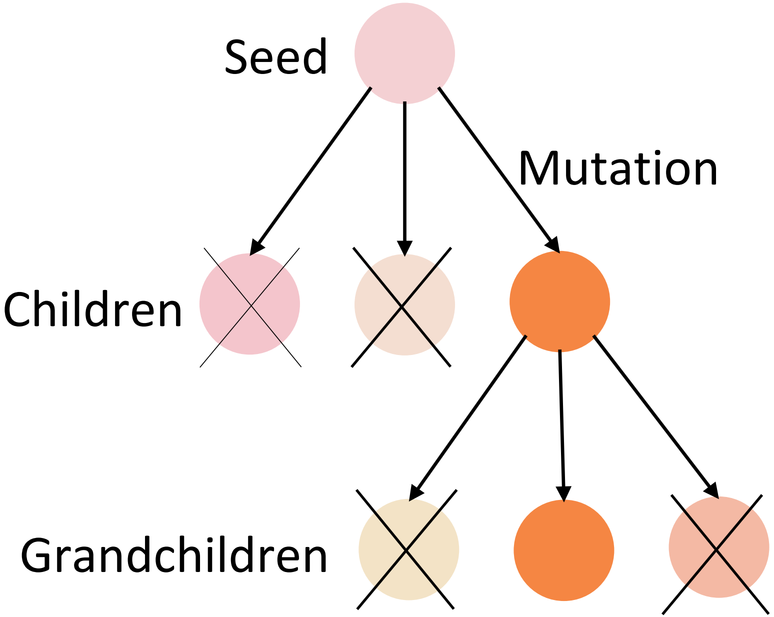
# Fuzzing: a popular way to uncover bugs




[Liang et al. 2019]

# Evolutionary Fuzzing




Advantage: easy to implement

Disadvantage: inefficient

- Random mutations are not effective
- Often get stuck in long sequence of wasteful mutations

Hard to find scalable and adaptive heuristics for guided mutation

# A new approach to fuzzing

# Fuzzing: An Optimization Problem

$x$ ⇨ a program input $x \in X$

$F(x)$ ⇨ # of bugs found by input $x$

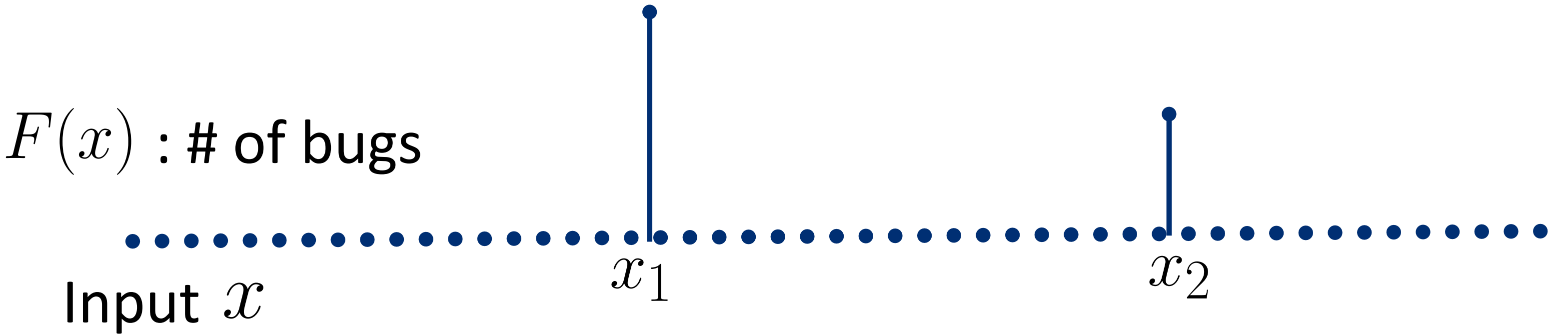
$C(X)$ ⇨ generate *K* inputs from input space $X$

**Maximize** $\displaystyle\sum_{x \in C(X)} F(x)$

Find **C(X)** that can maximize total no. of bugs

$F(x)$ is discrete and hard to optimize

# Fuzzing: An Optimization Problem




Hard to find inputs like $x_1$ and $x_2$
among flat plateaus

# Fuzzing: An Optimization Problem

$x$ ⇨ a program input $x \in X$

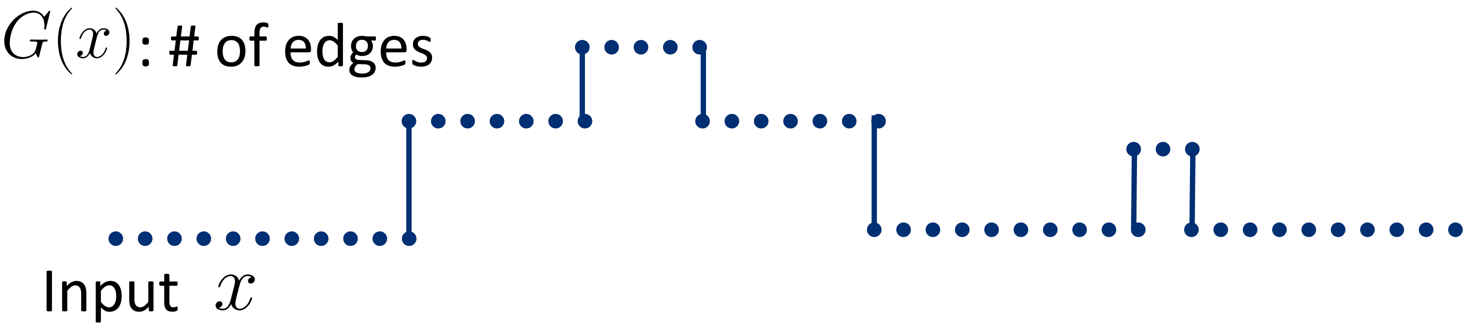
$G(x)$ ⇨ edge coverage of input $x$

$C(X)$ ⇨ generate *K* inputs from input space $X$

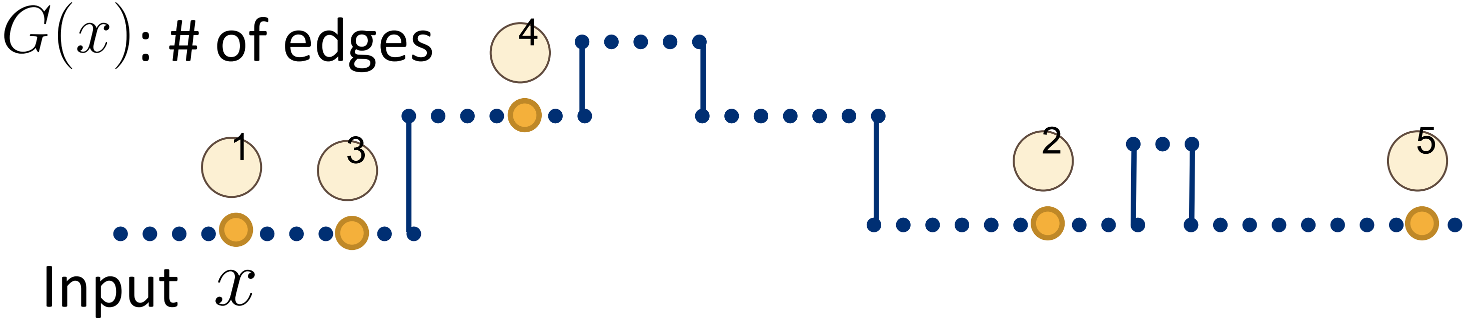
**Maximize** $\displaystyle\sum_{x \in C(X)} G(x)$

Find **C(X)** that can maximize total number of edges

# Fuzzing: An Optimization Problem



# Evolutionary optimization



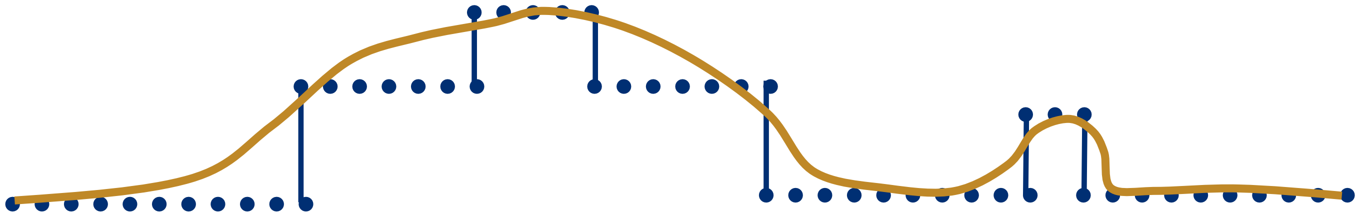

Random mutation is not efficient

# Gradient-guided Optimization

Smooth Approximation + Gradient-guided Mutation

$G(x)$ : # of edges

$H(x)$ : smooth approximation of $G(x)$

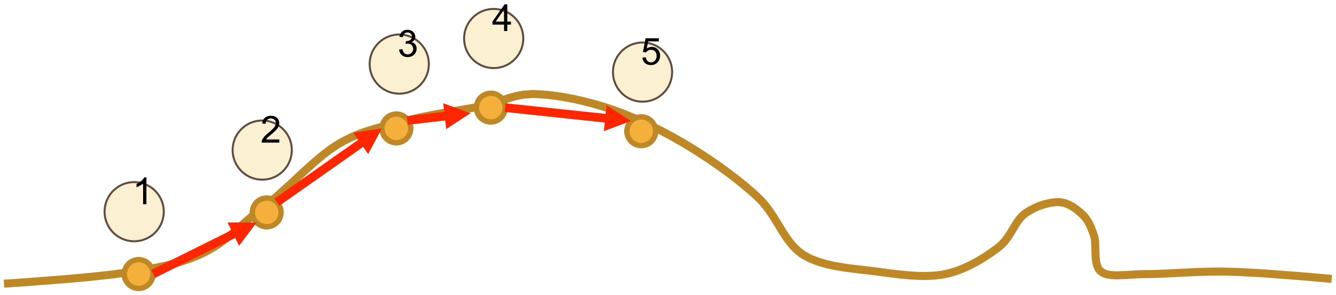


Input $x$

# Gradient-guided Optimization

Smooth Approximation + Gradient-guided Mutation

$H(x)$ : smooth approximation of $G(x)$




Input $x$

# Smooth Approximation

**Problem:**

How to smoothly approximate G(x)?

**Universal Approximation Theorem:**

A NN can approximate any continuous function

**Neuzz Solution:**

Use a NN to learn a smooth H(x)

# Gradient-guided Mutation

**Why gradient guidance?**

Gradient indicates critical parts of input

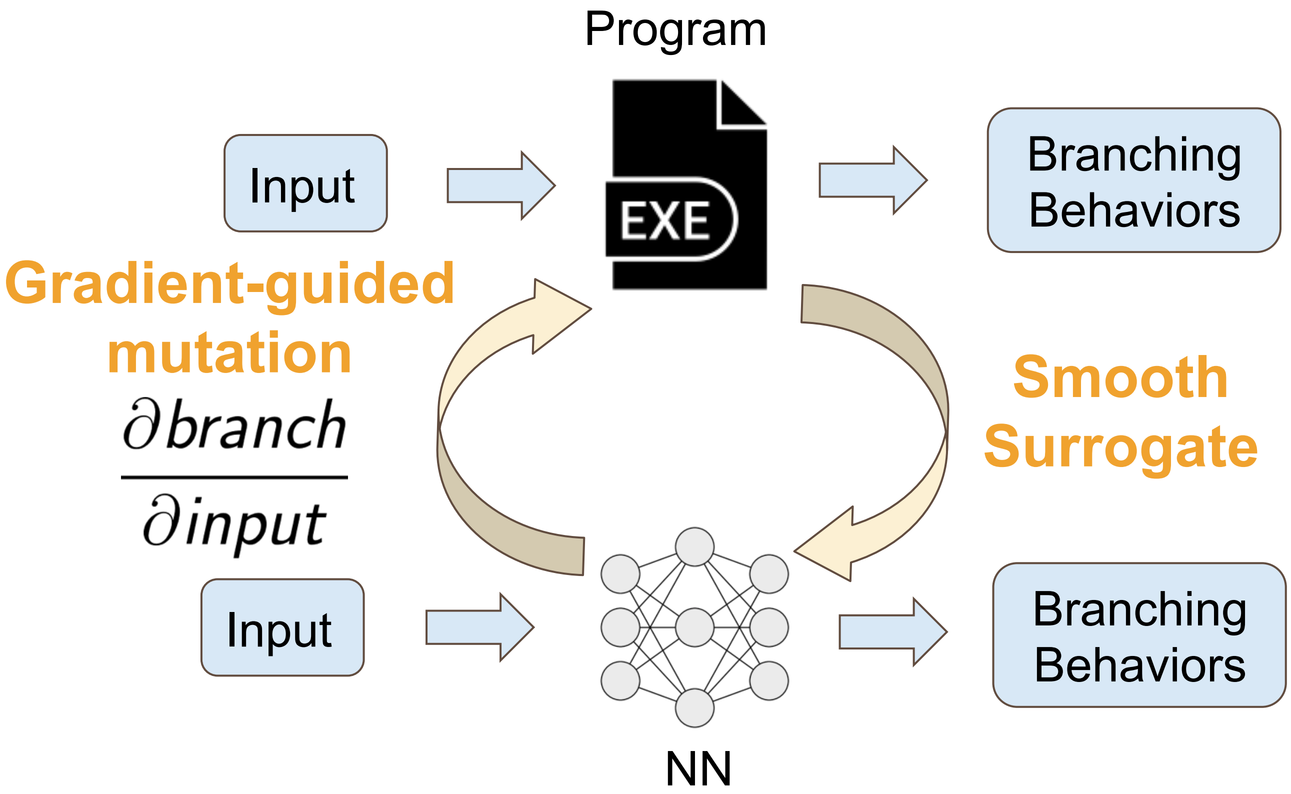
**What are critical parts of the input?**

Critical parts of input affect program branches

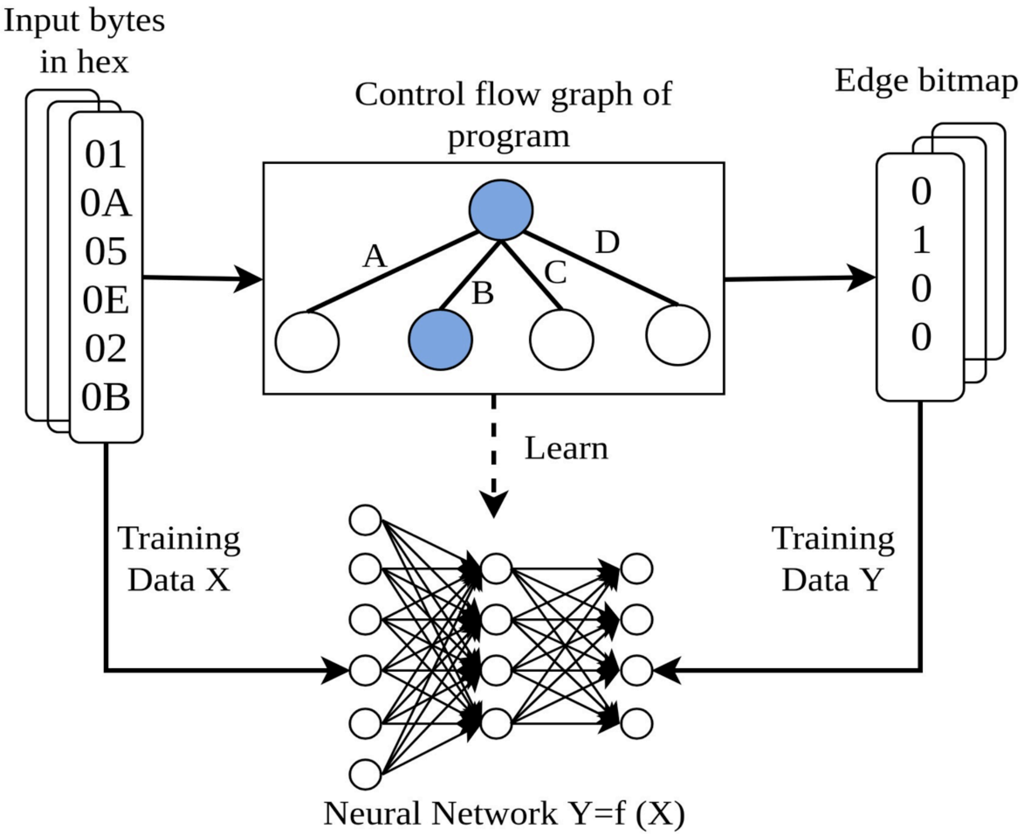
**How gradient-guided mutation works?**

Focus mutations on the critical parts of the input

# Main Idea behind Neuzz



# A Peek Into NN Model



# Generalization to Unseen branches

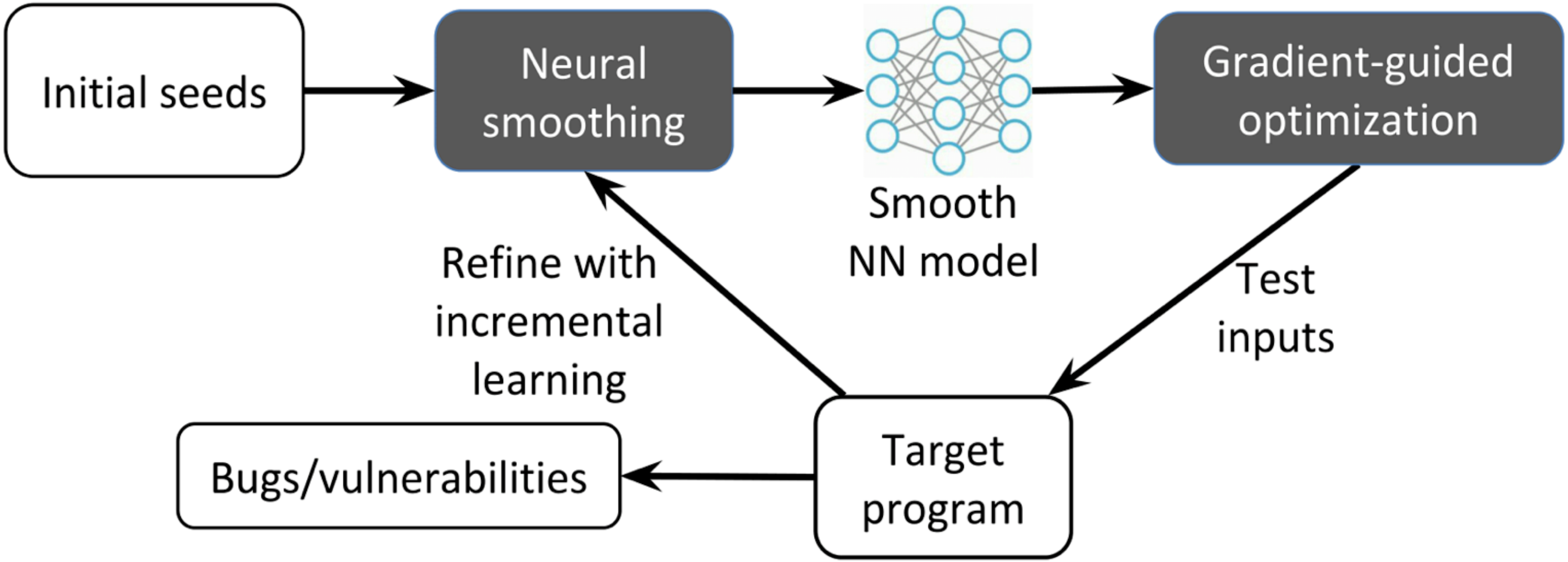
**Observations:**

- Real world program inputs have critical parts
- Most of branches are affected by the critical parts

**Neuzz Solution:**

- Identify critical parts based on observed branches
- Perform more mutations on the critical part of inputs to explore unseen branches

# Design of NEUZZ

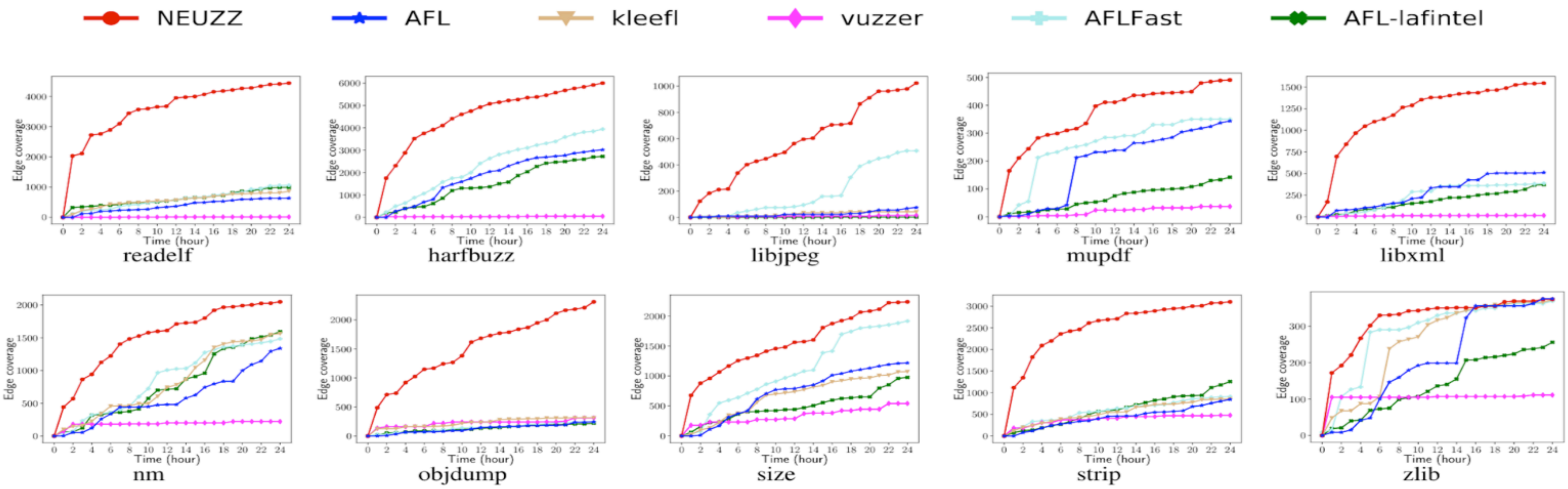


# Evaluation

- 10 real world programs
- Lava-M and DARPA CGC datasets
- Comparison with RNN-based fuzzers
- Performance of different model choices

# Evaluations: Edge Coverage
# NEUZZ vs. state-of-the-art fuzzers

10 real world applications for 24 hours




NEUZZ achieves on average 3x more edge coverage than other fuzzers

# Evaluations: Bug Finding
# NEUZZ vs. state-of-the-art fuzzers

| Programs | AFL | AFLFast | VUzzer | KleeFL | AFL-laf-intel | NEUZZ |
|---|---|---|---|---|---|---|
| **Detected Bugs per Project** | | | | | | |
| readelf | 4 | 5 | 5 | 3 | 4 | 16 |
| nm | 8 | 7 | 0 | 0 | 6 | 9 |
| objdump | 6 | 6 | 0 | 3 | 7 | 8 |
| size | 4 | 4 | 0 | 3 | 2 | 6 |
| strip | 7 | 5 | 2 | 5 | 7 | 20 |
| libjpeg | 0 | 0 | 0 | 0 | 0 | 1 |
| **Detected Bugs per Type** | | | | | | |
| out-of-memory | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ |
| memory leak | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| assertion crash | ✗ | ✓ | ✗ | ✗ | ✓ | ✓ |
| interger overflow | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ |
| heap overflow | ✓ | ✗ | ✗ | ✗ | ✗ | ✓ |
| Total | 29 | 27 | 7 | 14 | 26 | 60 |

NEUZZ finds the most number of bugs and all 5 bug types including two new CVEs

# Evaluations: Lava-M and CGC

Lava-M dataset

| | base64 | md5sum | uniq | who |
|---|---|---|---|---|
| #Bugs | 44 | 57 | 28 | 2,136 |
| FUZZER | 7 | 2 | 7 | 0 |
| SES | 9 | 0 | 0 | 18 |
| VUzzer | 17 | 1 | 27 | 50 |
| Steelix | 43 | 28 | 24 | 194 |
| Angora | 48 | 57 | 29 | 1,541 |
| AFL-laf-intel | 42 | 49 | 24 | 17 |
| T-fuzz | 43 | 49 | 26 | 63 |
| NEUZZ | 48 | 60 | 29 | 1,582 |

DARPA CGC dataset

| Fuzzers | AFL | Driller | NEUZZ |
|---|---|---|---|
| Bugs | 21 | 25 | 31 |

NEUZZ outperforms state-of-the-art fuzzers on LAVA-M and CGC

# Evaluations: NEUZZ vs. RNN-based Fuzzer

| Programs | Edge Coverage | | | Training Time (sec) | | |
|---|---|---|---|---|---|---|
| | NEUZZ | RNN | AFL | NEUZZ | RNN | AFL |
| readelf -a | 1,800 | 215 | 213 | 108 | 2,224 | NA |
| libjpeg | 89 | 21 | 28 | 56 | 1,028 | NA |
| libxml | 256 | 38 | 19 | 95 | 2,642 | NA |
| mupdf | 260 | 70 | 32 | 62 | 848 | NA |

NEUZZ achieves 6x more edge coverage and 20x less training time

# Evaluations: Effect of Different NNs

Edge coverage for 1M mutations

| Programs | Linear Model | NN Model | NN + Incremental |
|---|---|---|---|
| readelf -a | 1,723 | 1,800 | 2,020 |
| libjpeg | 63 | 89 | 159 |
| libxml | 117 | 256 | 297 |
| mupdf | 93 | 260 | 329 |

NEUZZ achieves best performance with NN+Incremetal learning

# Key Takeaways of NEUZZ

- Use NN gradients to identify the critical locations of program inputs
- Focus mutations on the critical locations
- Minimize runtime overhead by using simple feed-forward neural networks
- Retrain the network incrementally to find new critical locations

# Github Repo

NEUZZ is available at
https://github.com/Dongdongshe/neuzz

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