FairFuzz: A Targeted Mutation Strategy for Increasing Greybox Fuzz Testing Coverage

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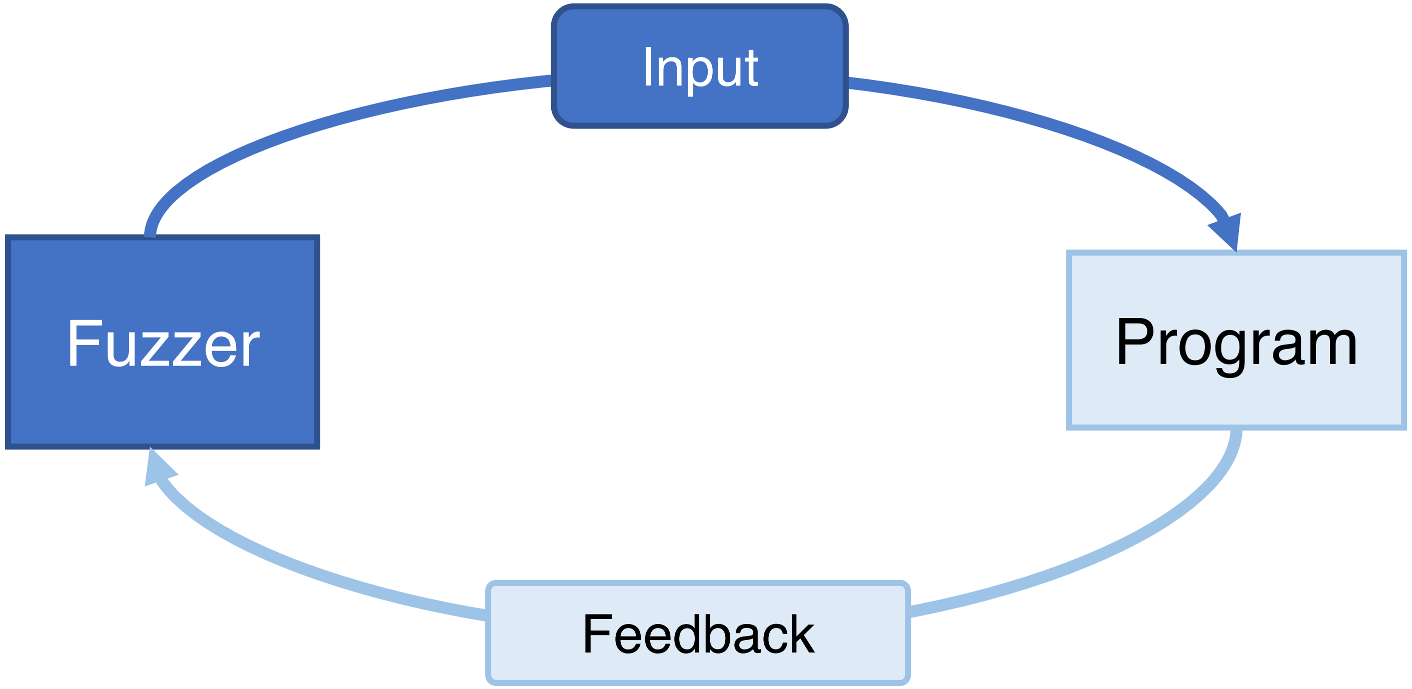
source: https://github.com/carolemieux/afl-rb

The Rise of Fuzz Testing

- Programs still have bugs.
- *Fuzz testing* has become very popular in practice and theory

Fuzzing in One Slide



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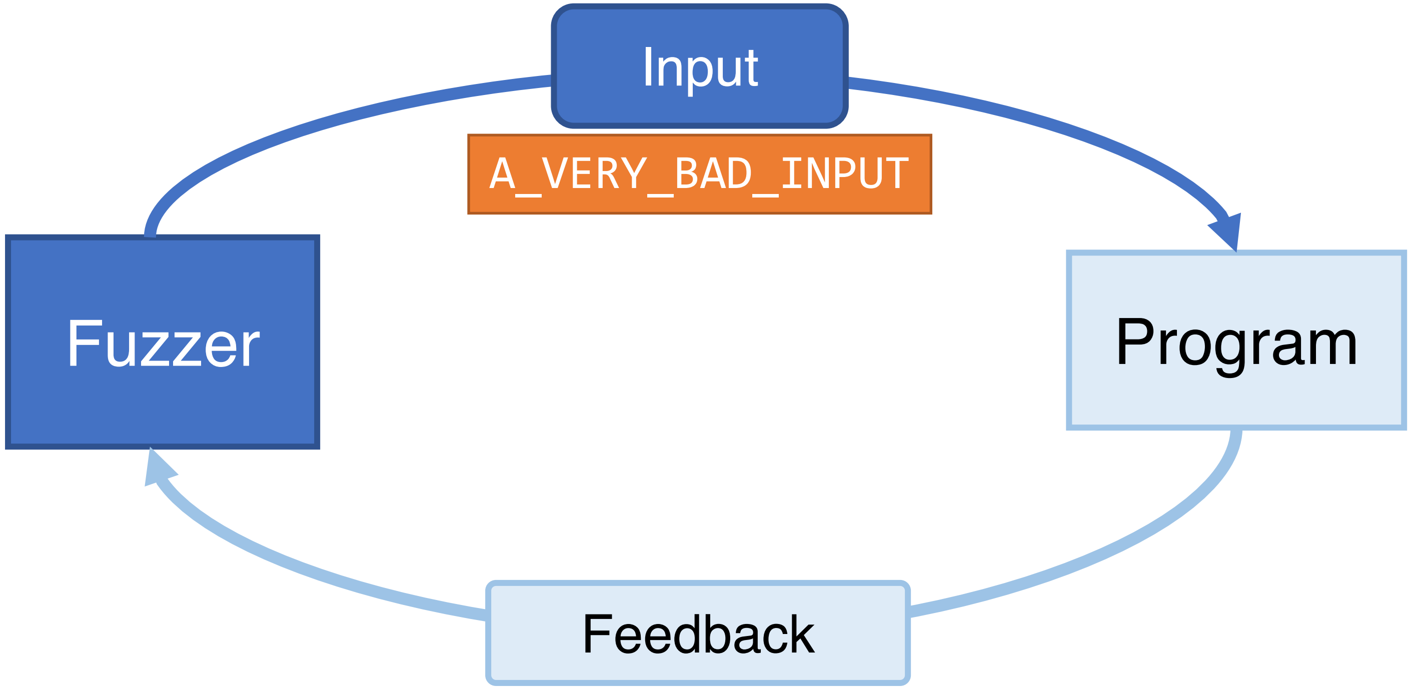

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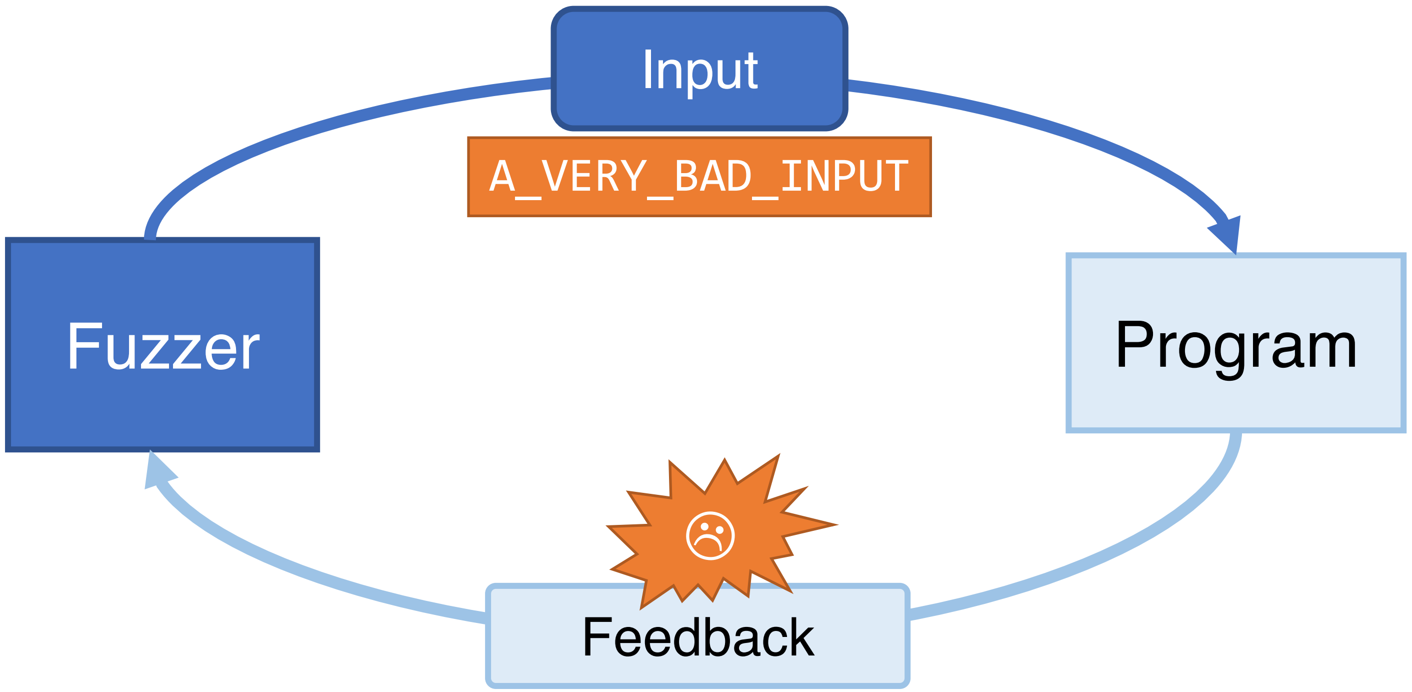

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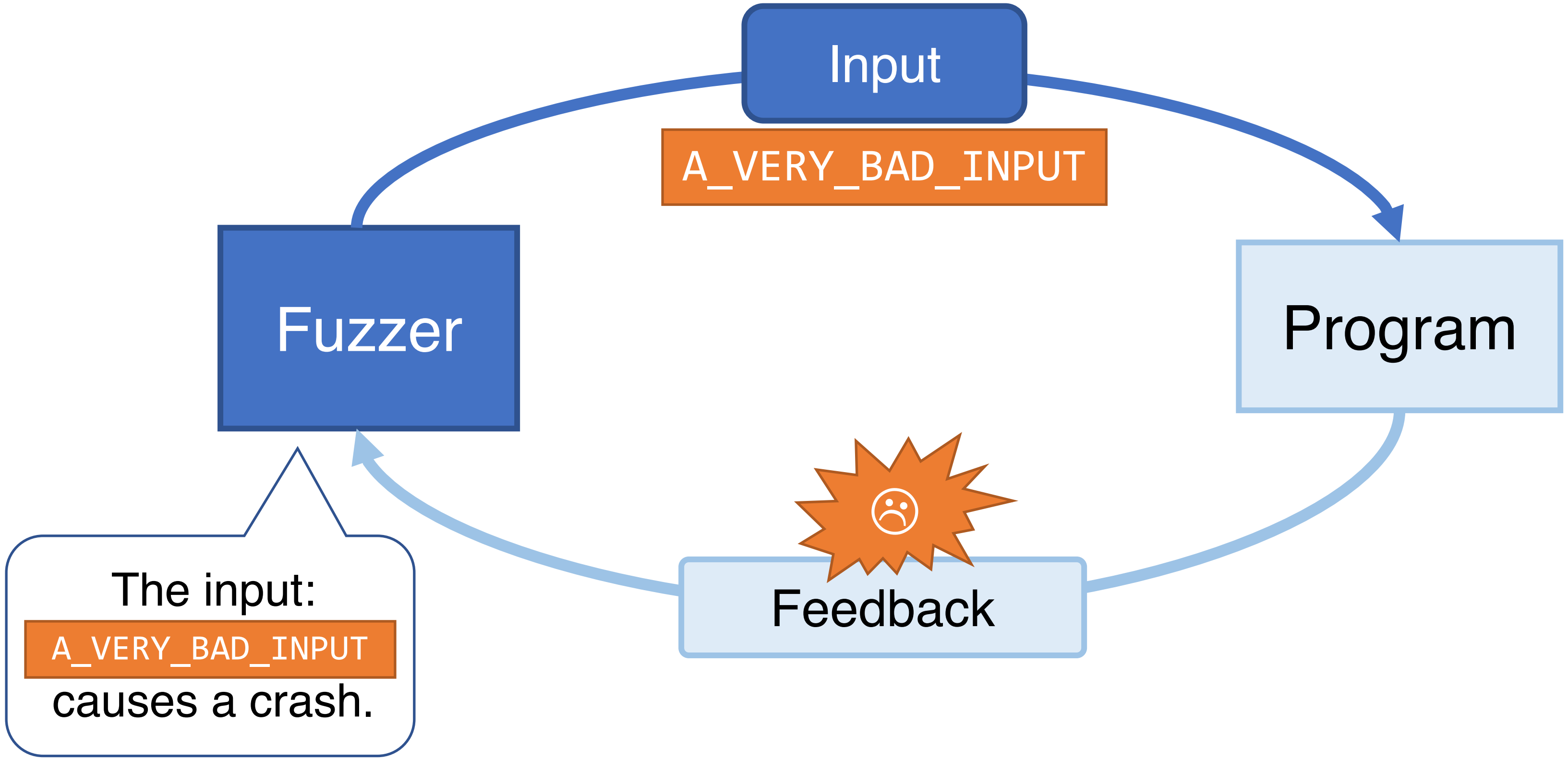
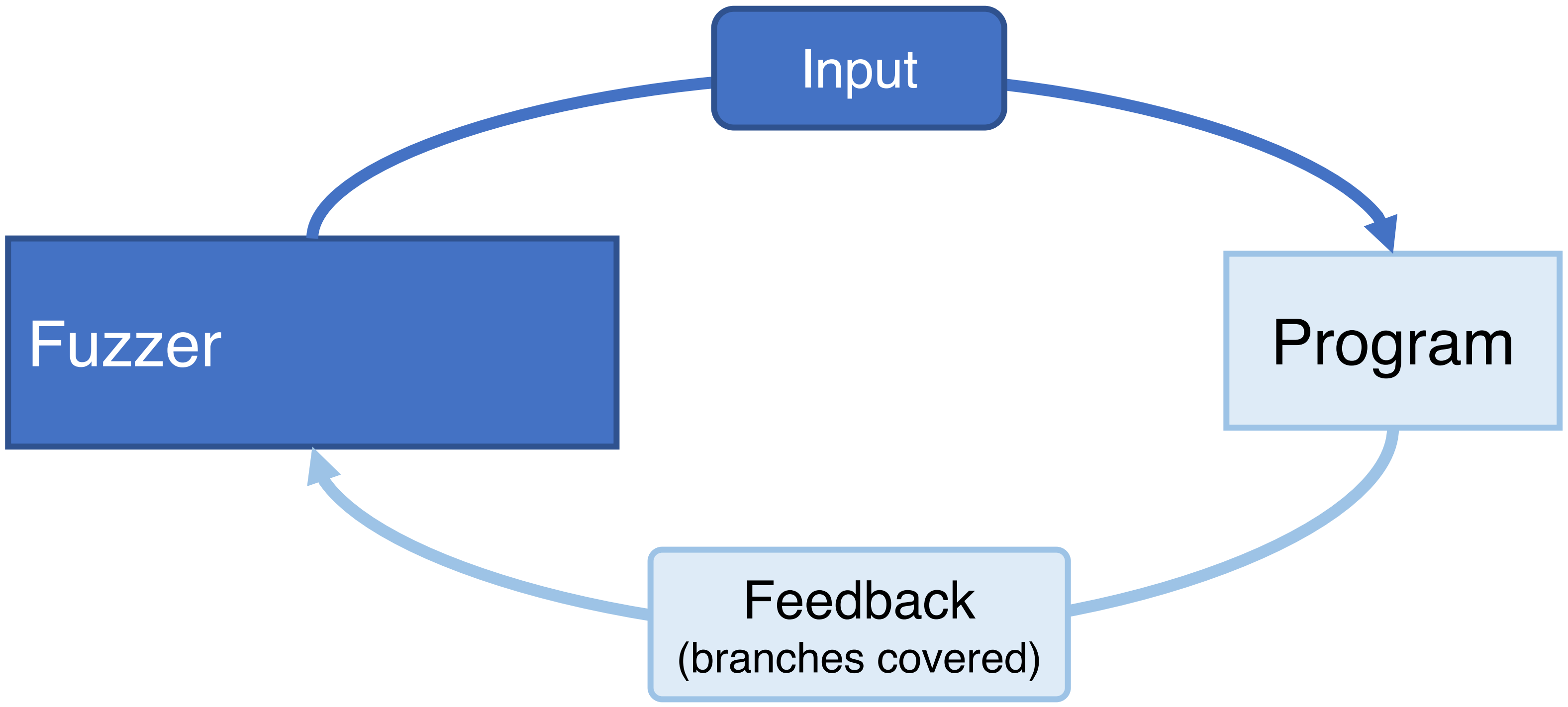


What Bugs Can Fuzzing Find?

- Most popular: basic correctness assertions (C/C++)
  - Segmentation faults
  - Anything address sanitizer can catch:
    - Buffer overflows
    - Use-after-frees
    - Etc…

Coverage-Guided (Greybox) Mutational Fuzzing



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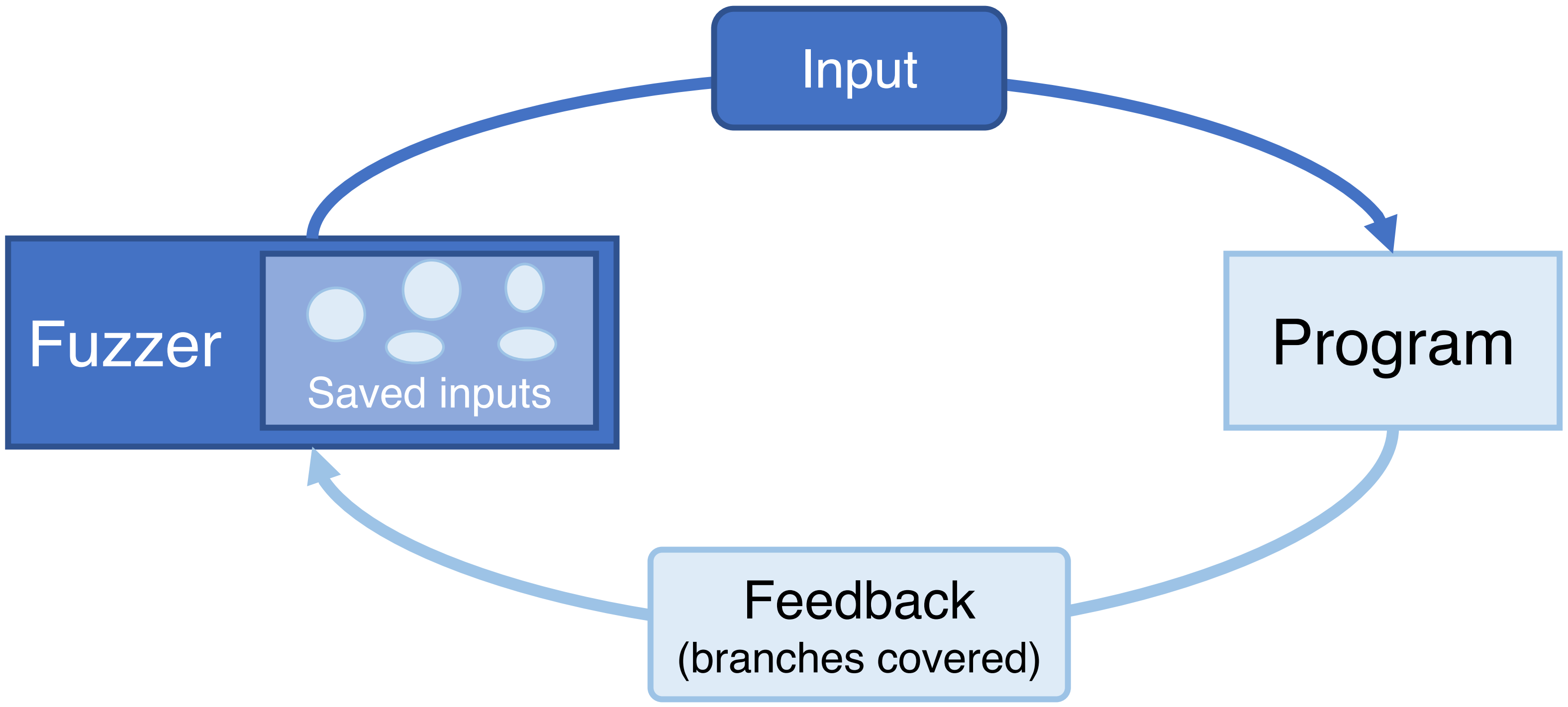

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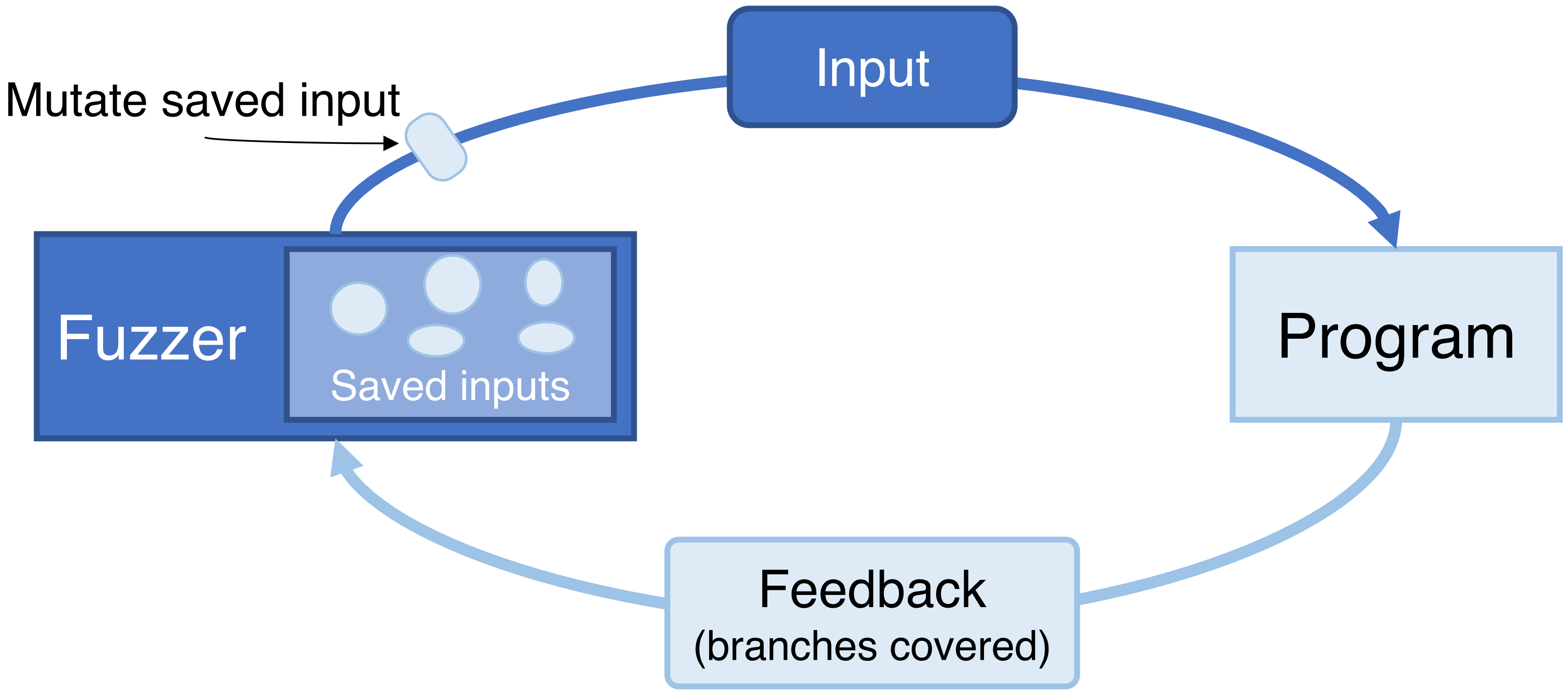

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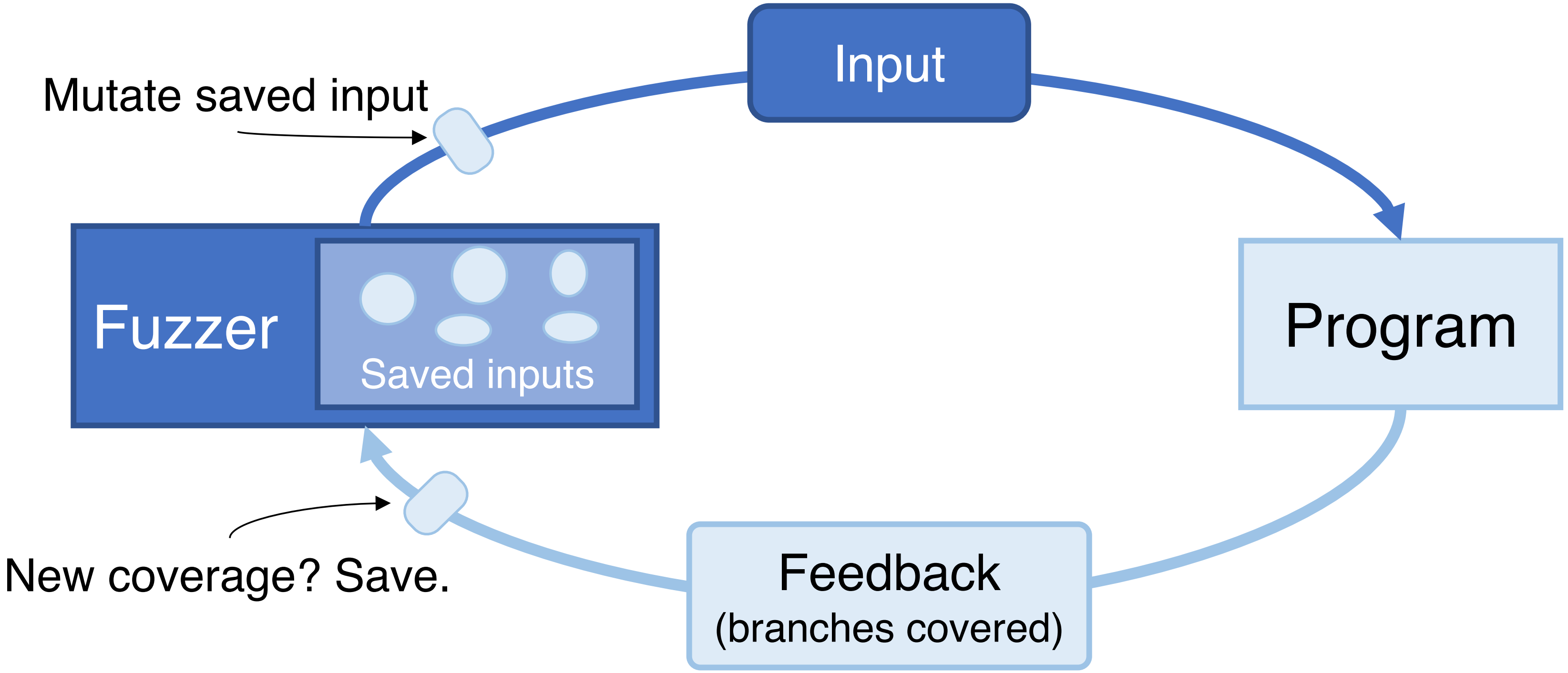

What's Missing? Uneven Fuzzing Coverage

Observation: some parts of the program easier to cover

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  }
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Uneven Fuzzing Coverage → Uncovered Code

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Result: some functionality wholly uncovered by fuzzing

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Why So Uneven?

Some branches hard to hit by naively mutated inputs

Input satisfying if:

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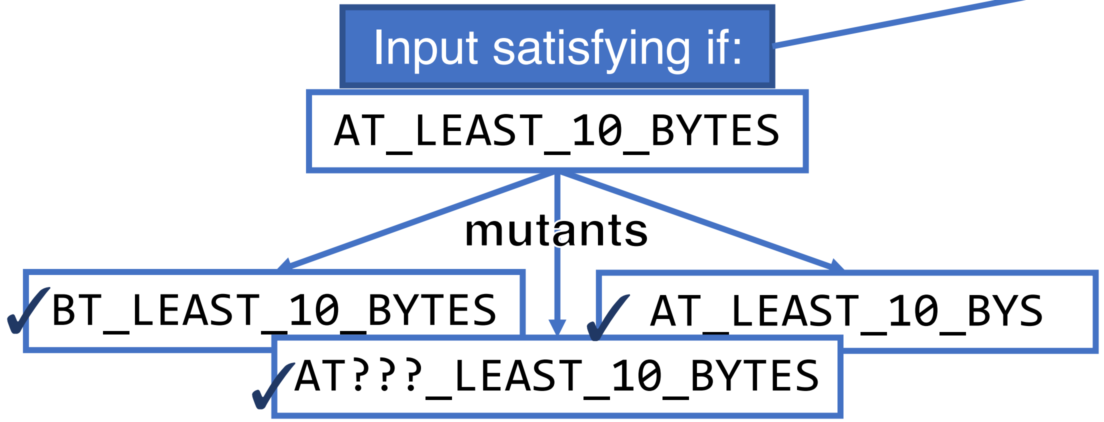


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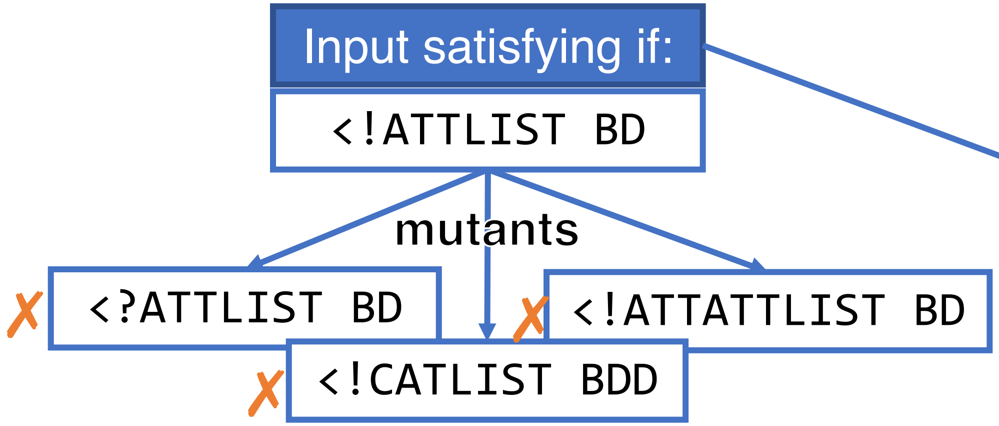


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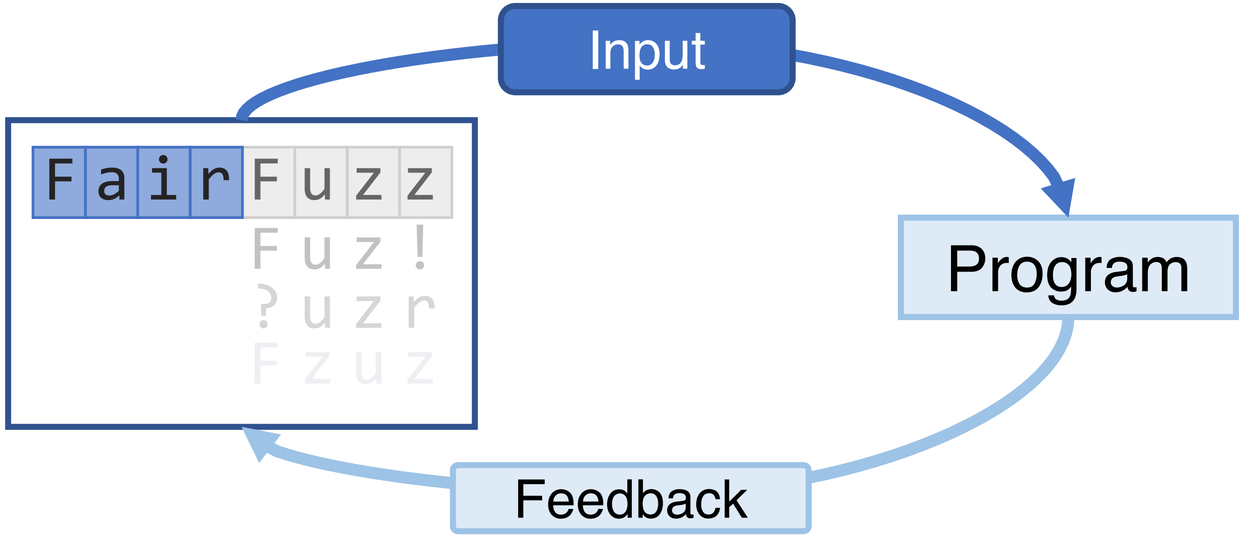
Our Method: FairFuzz

Utilize existing greybox info

To target rarely-exercised code → increase coverage



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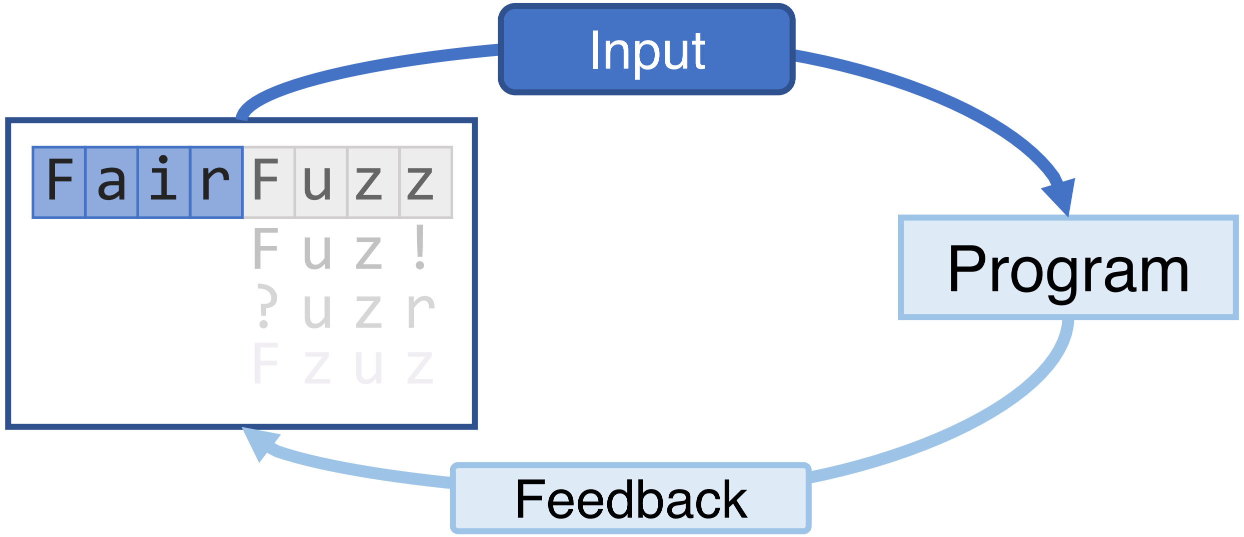

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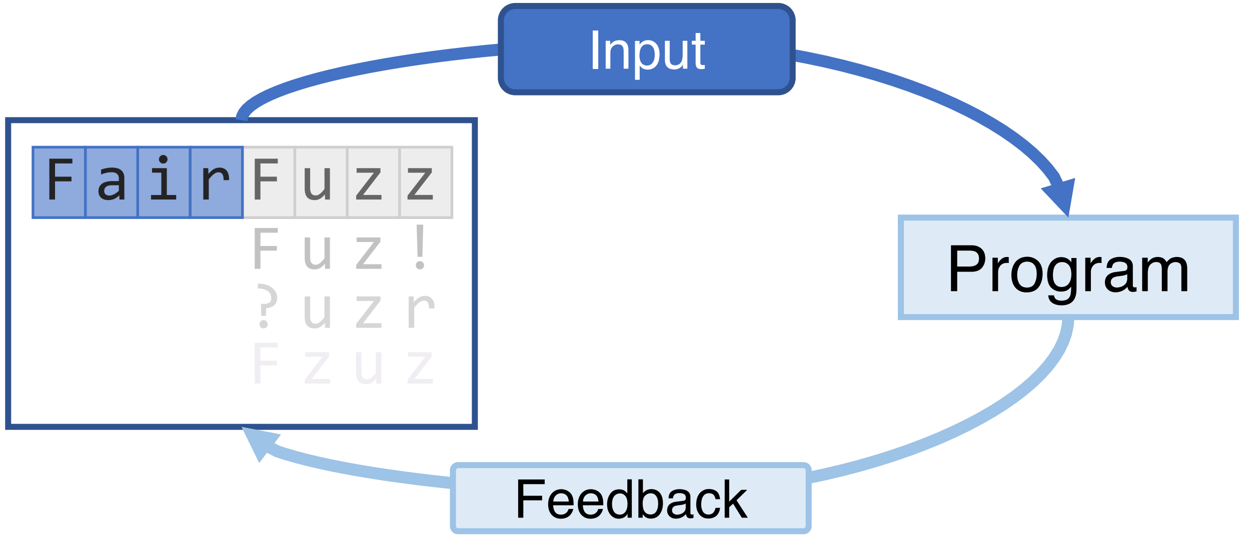
- **Identify**: branches hit by few inputs (rare branches)
- **Identify**: where input can be mutated and hit branch



Method

Recap: AFL

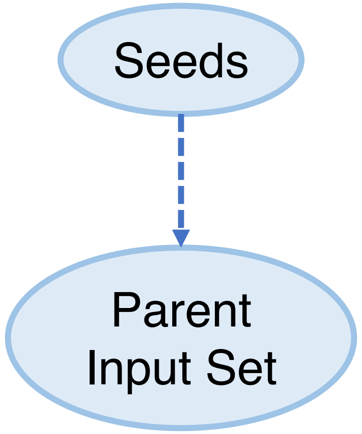
- AFL [1]: Popular coverage-guided greybox fuzzer
- Fuzzes programs taking in file or stdin
- Easy to use (just compile program with afl-gcc or afl-clang)
- Has found many bugs in practice

[1] http://lcamtuf.coredump.cx/afl/

AFL Method

Seeds

AFL Method



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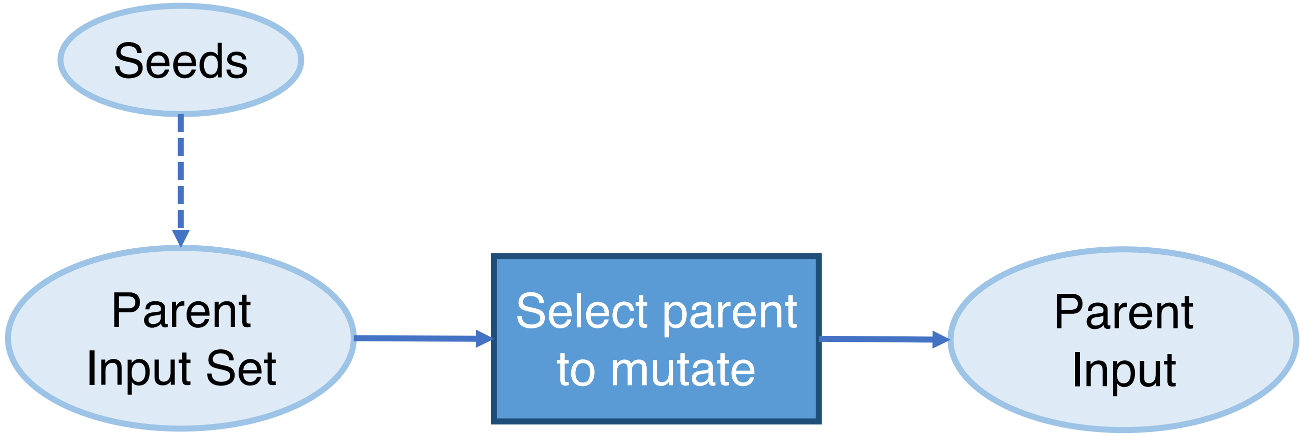

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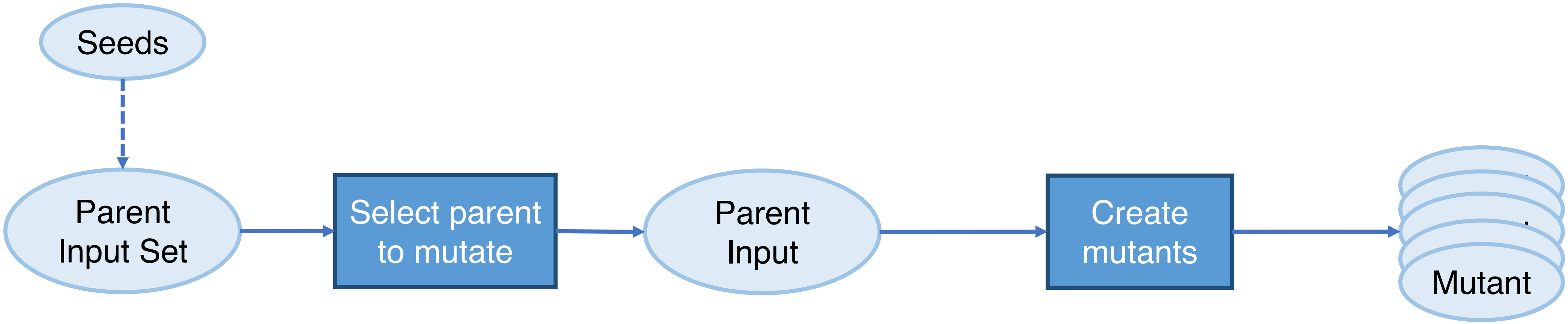
Parent Input Set
Select parent to mutate
Parent Input

AFL Method



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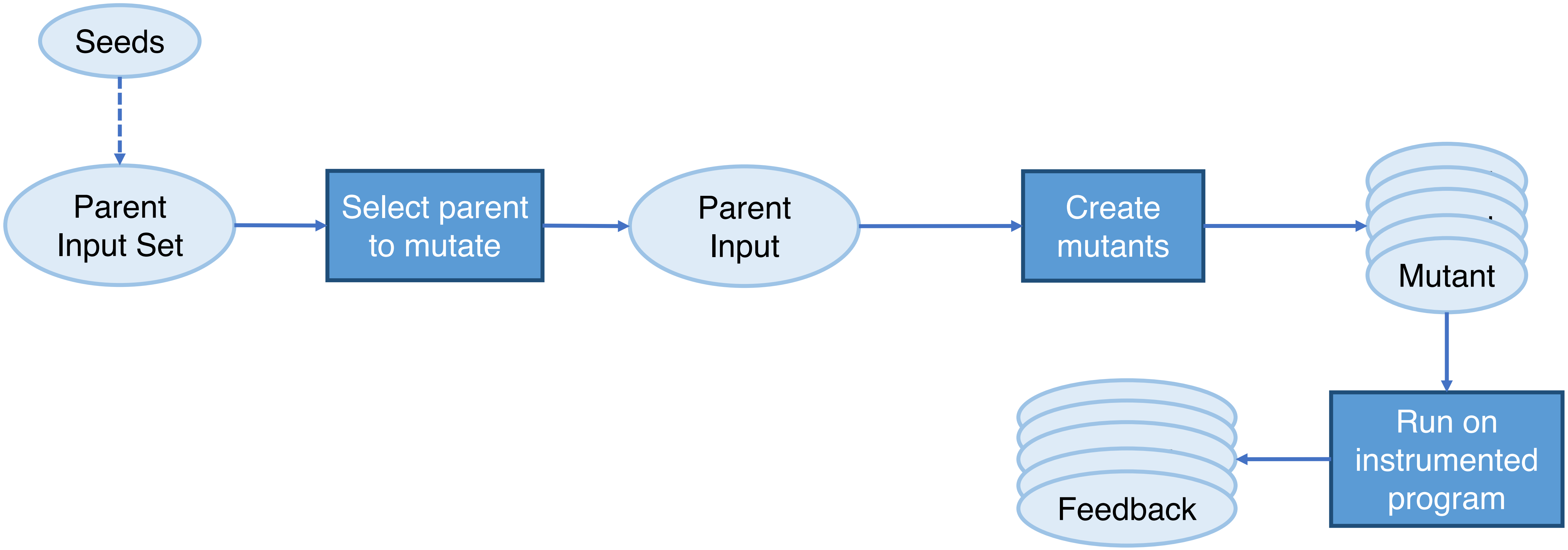

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Feedback

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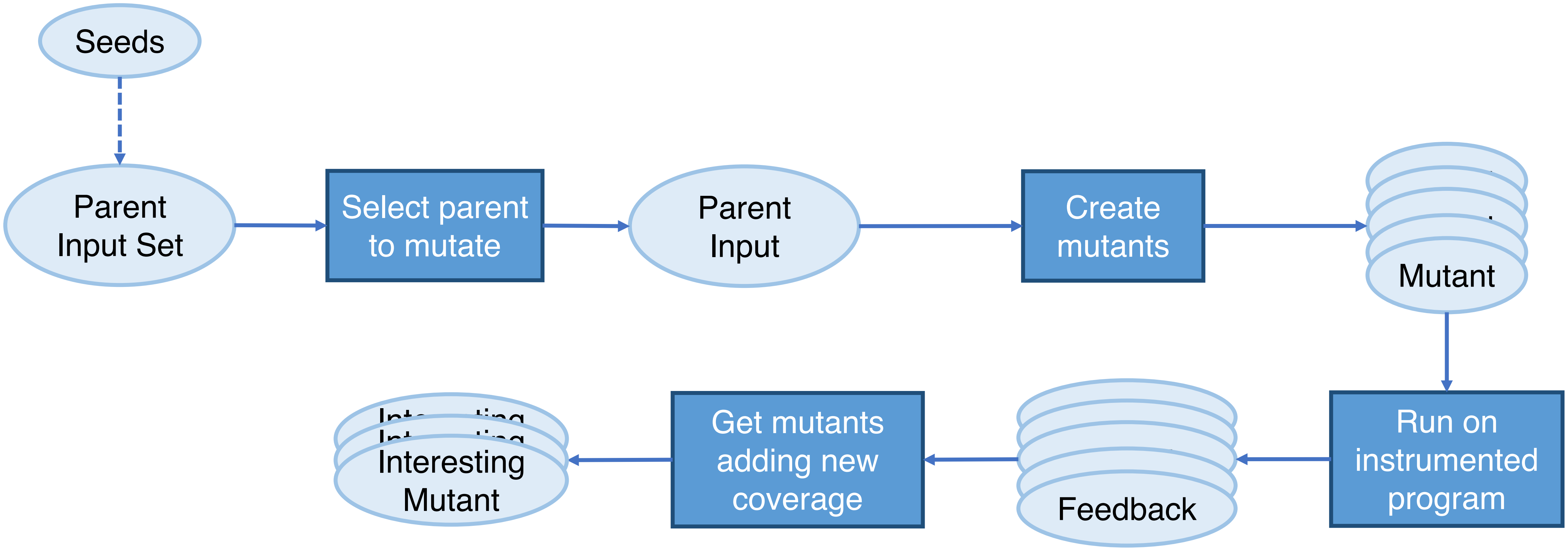

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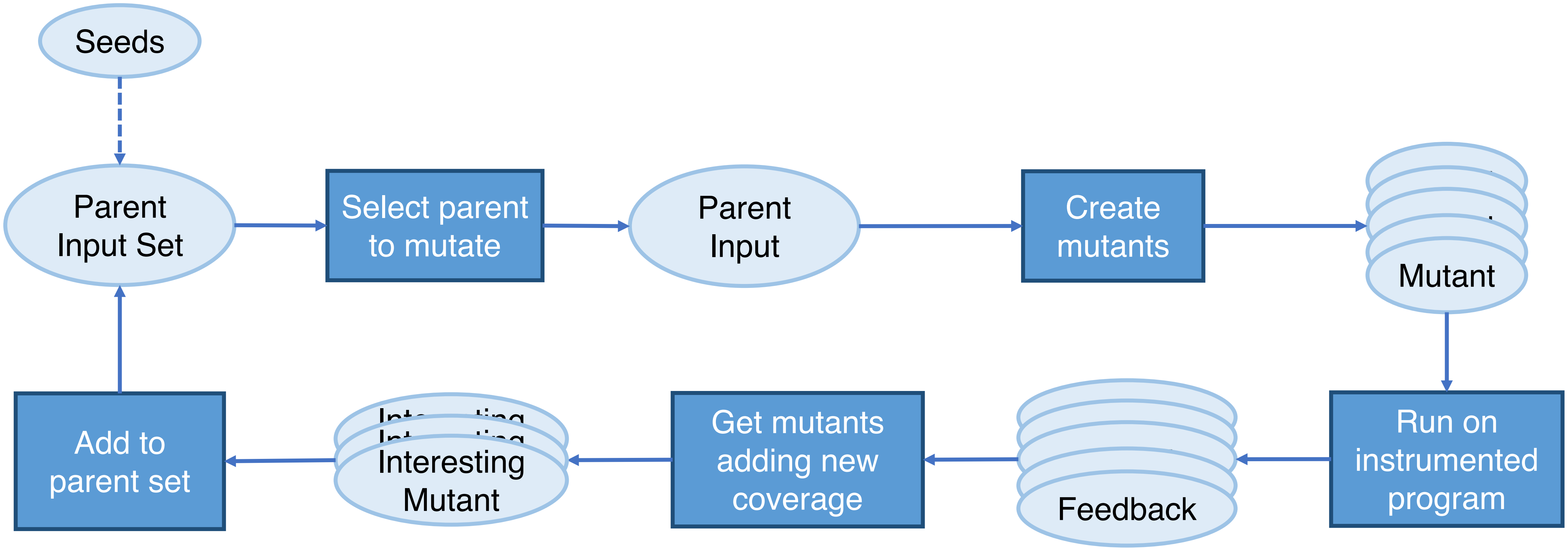

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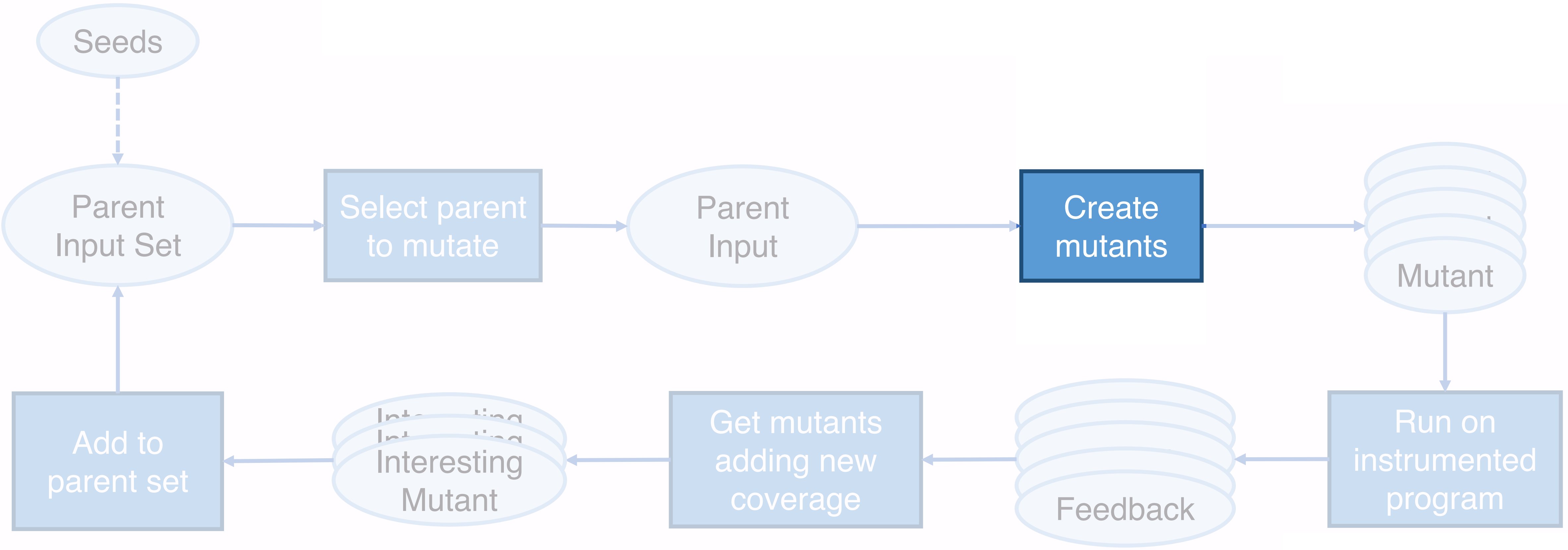

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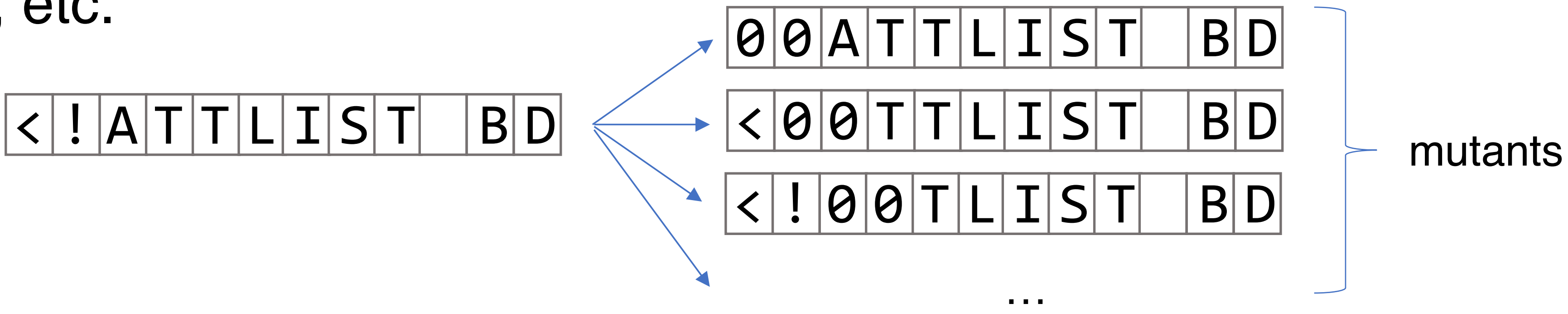

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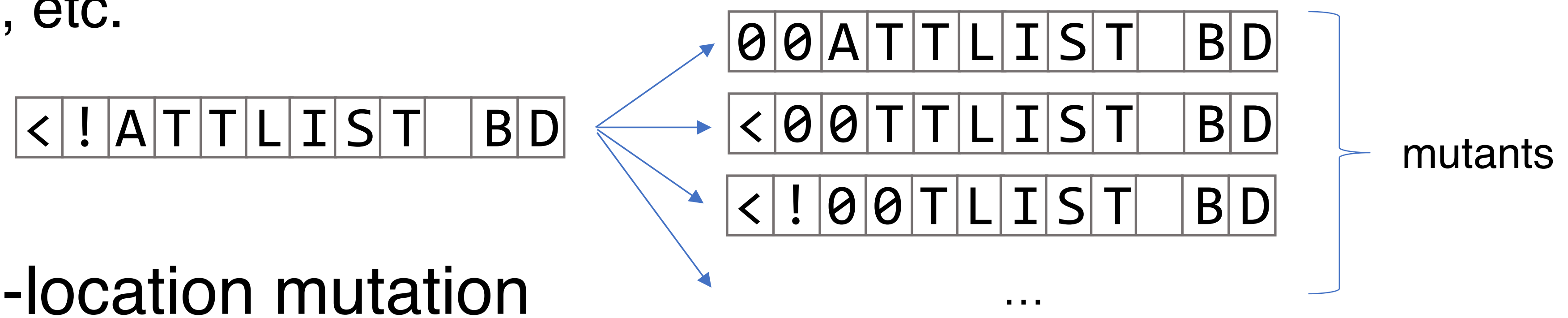

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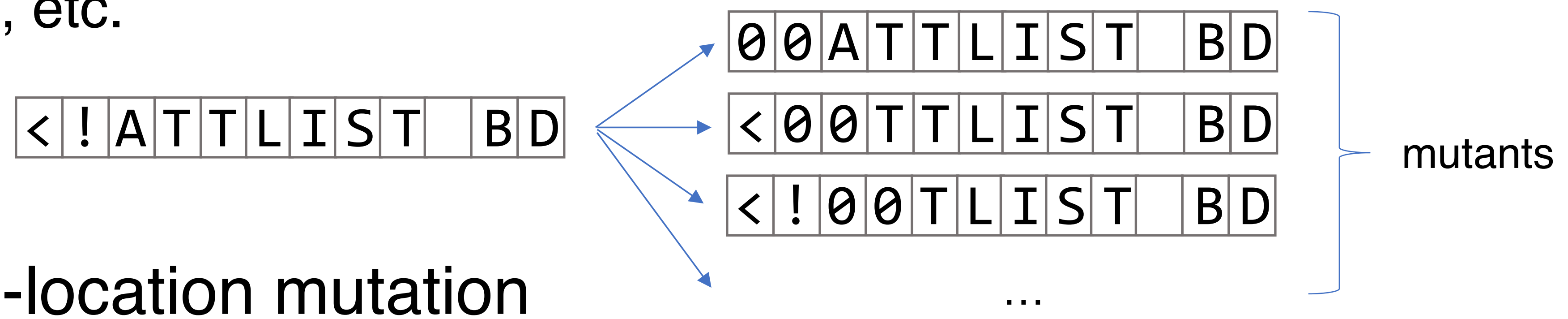

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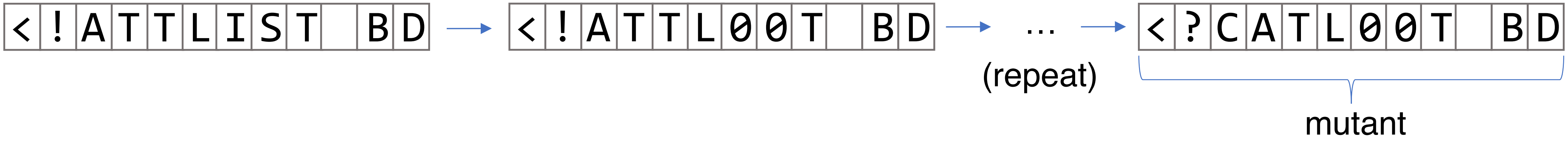

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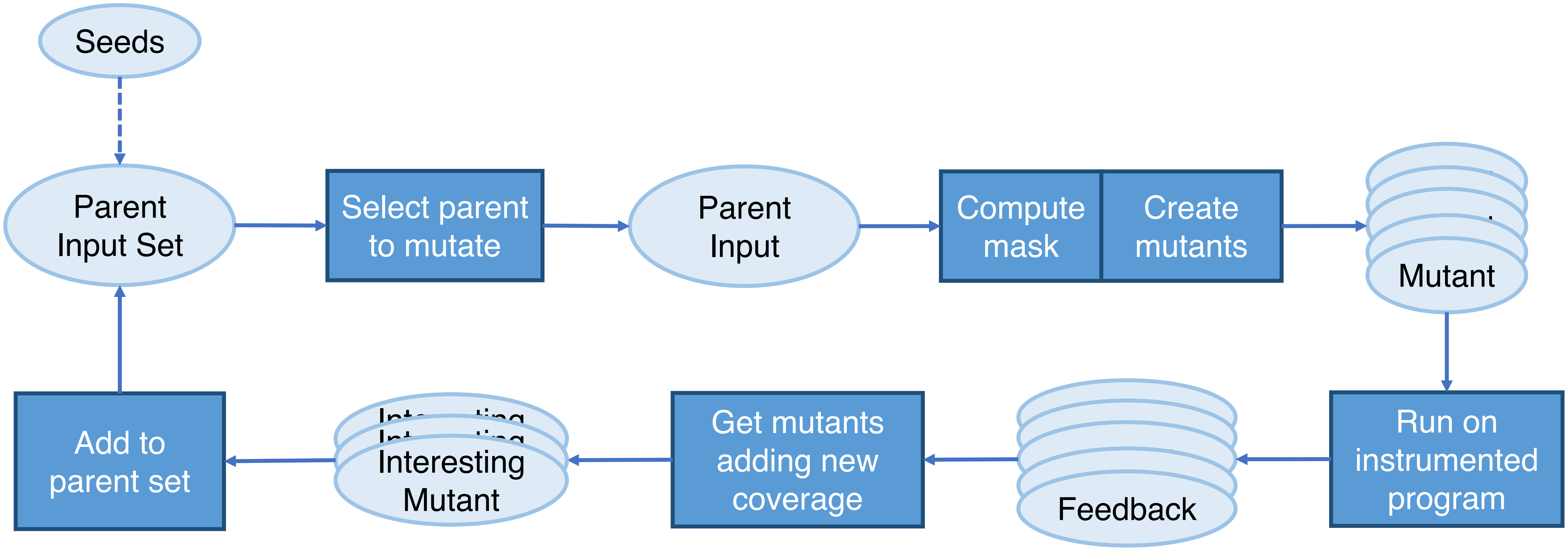
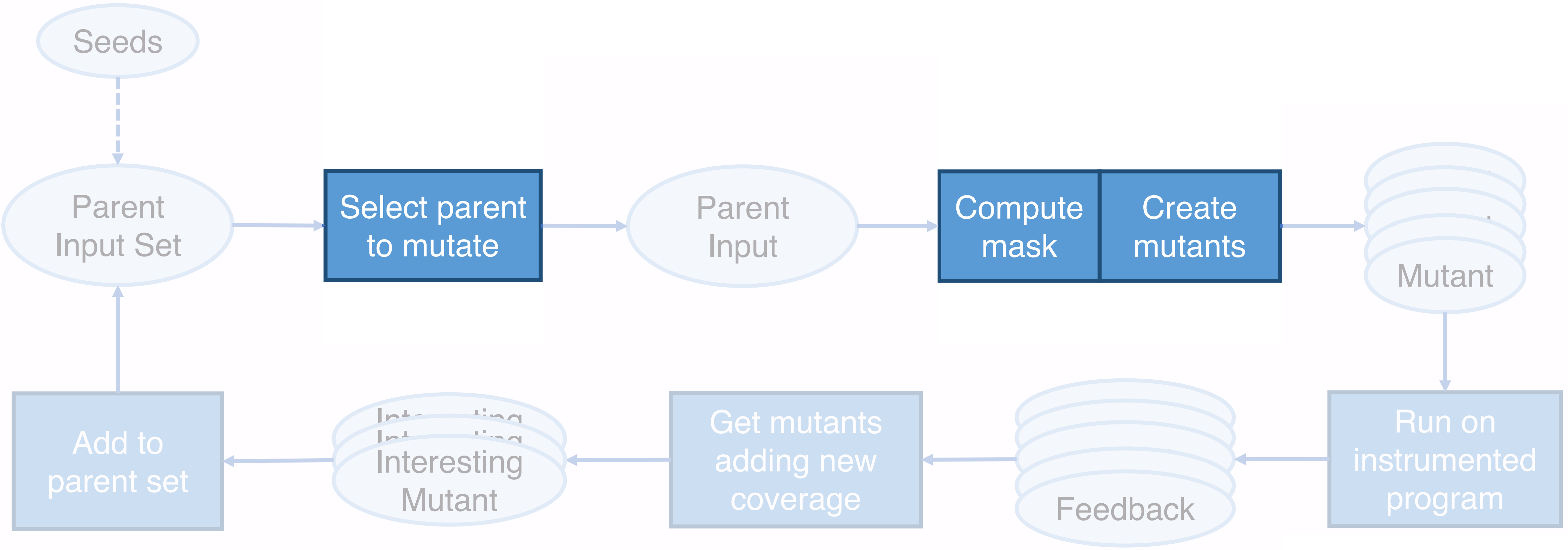


FairFuzz Method – Key Differences



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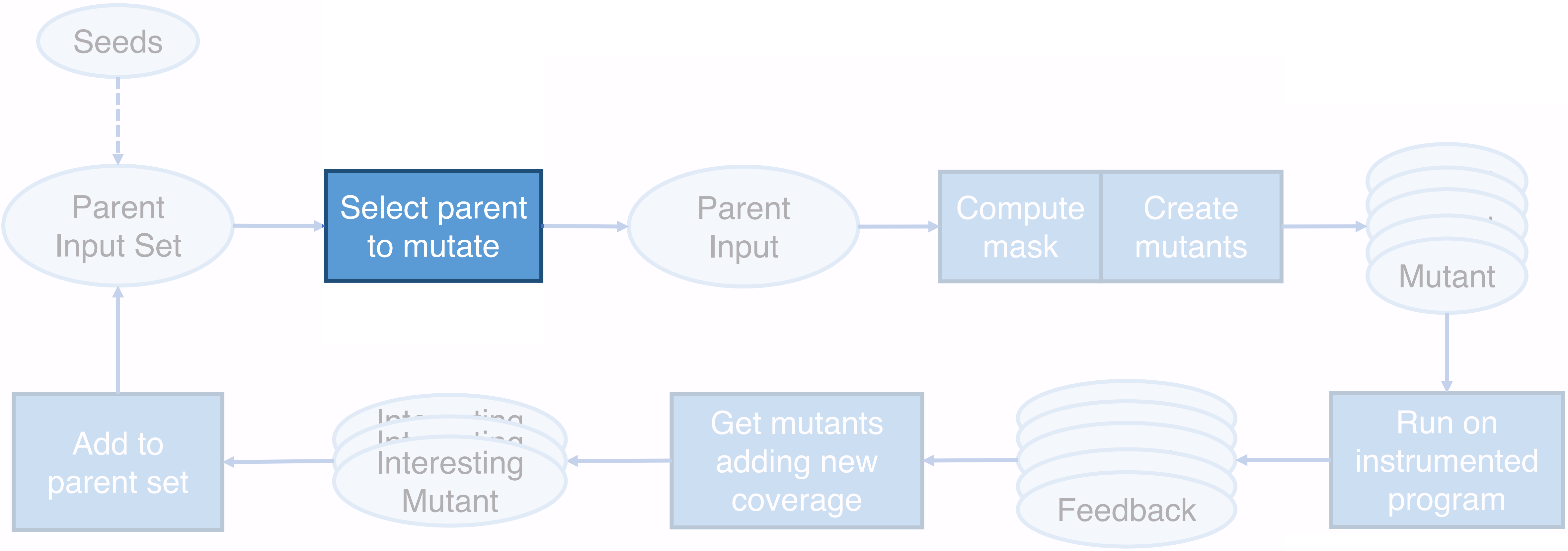

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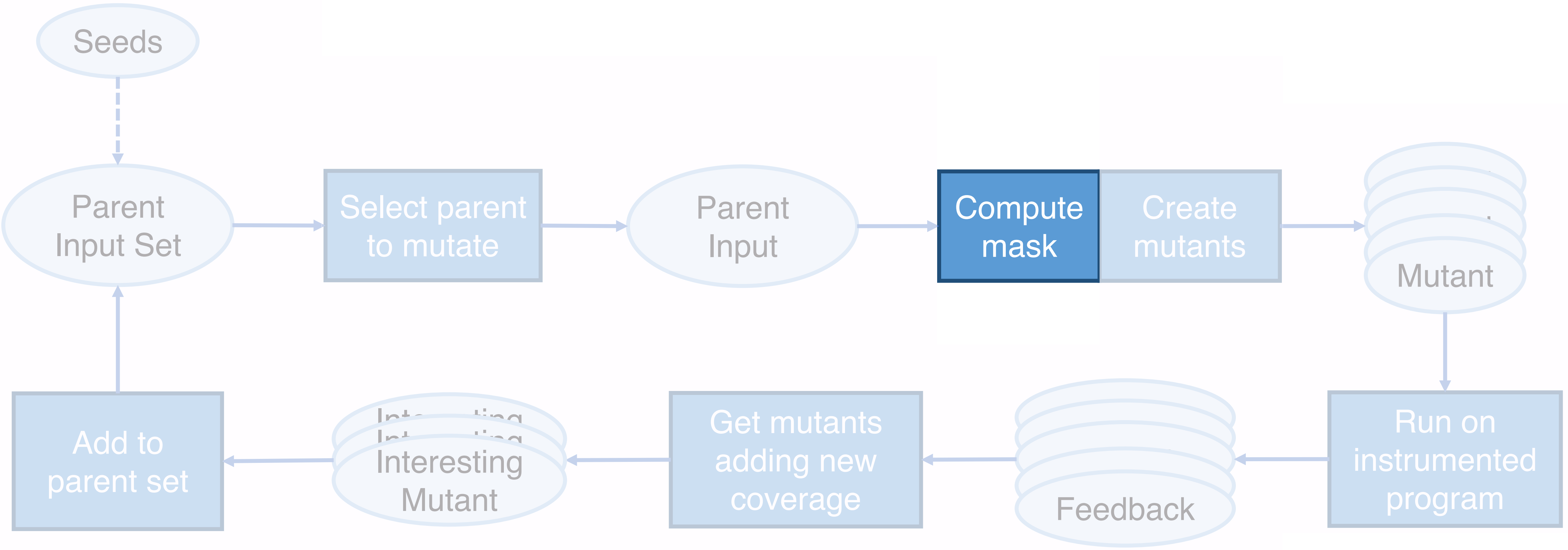

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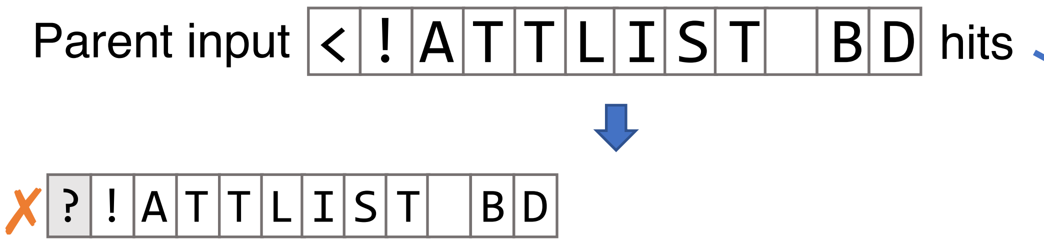


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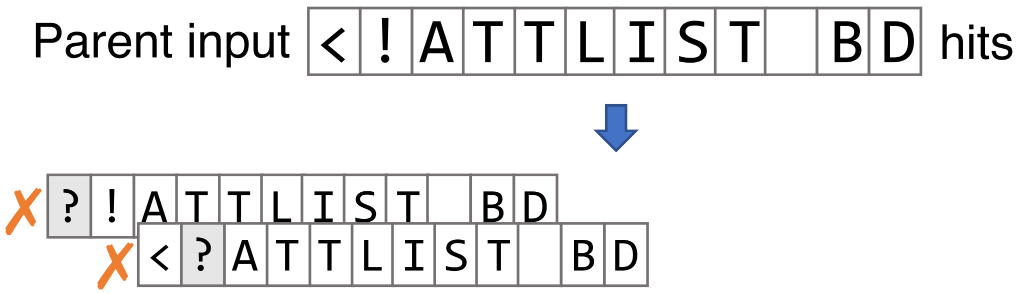


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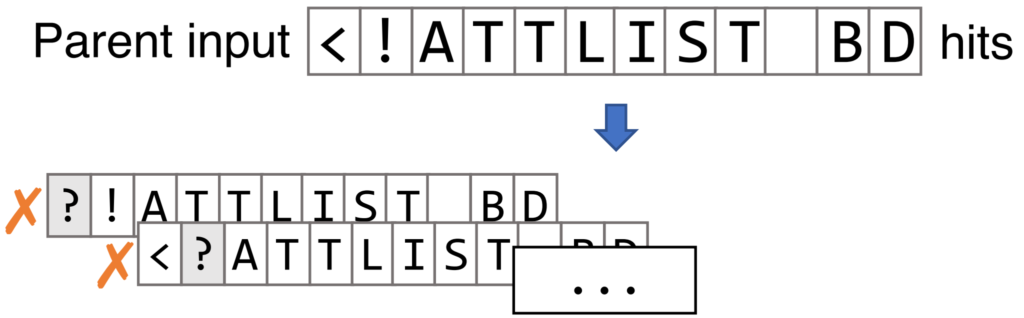


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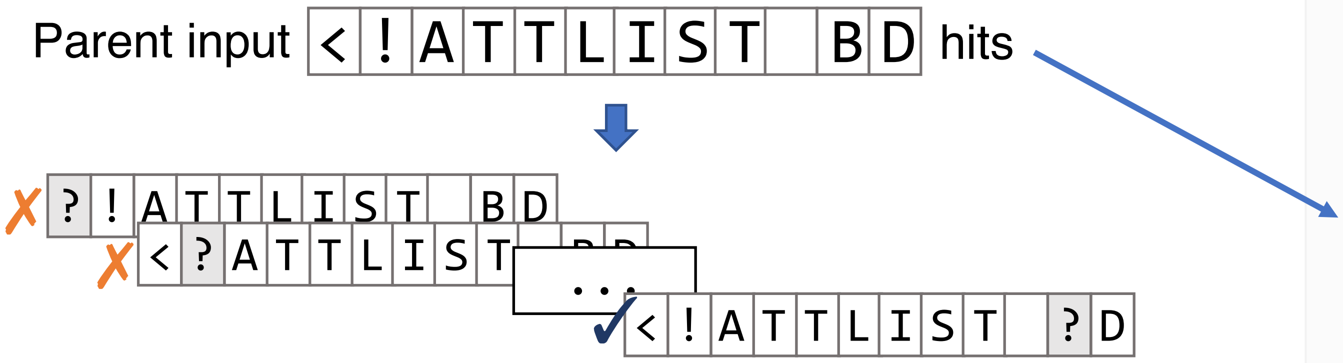


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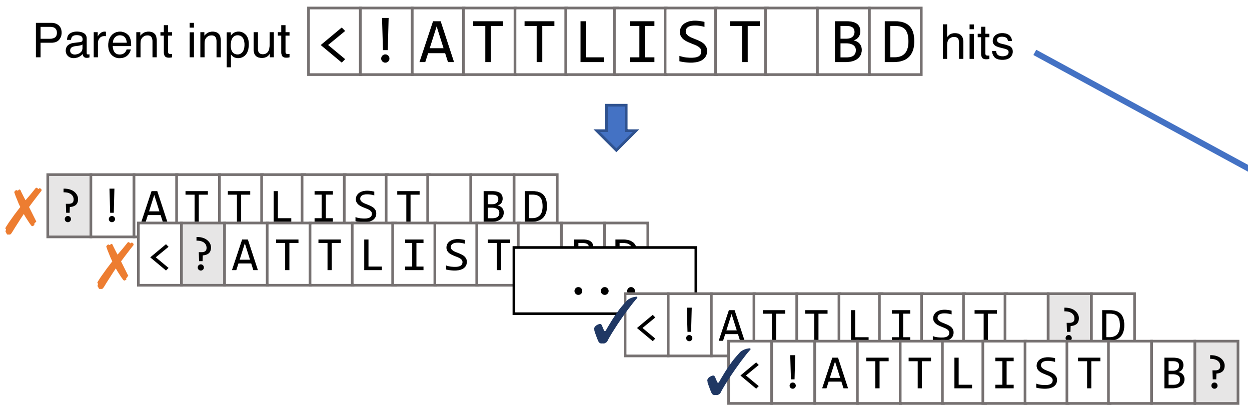


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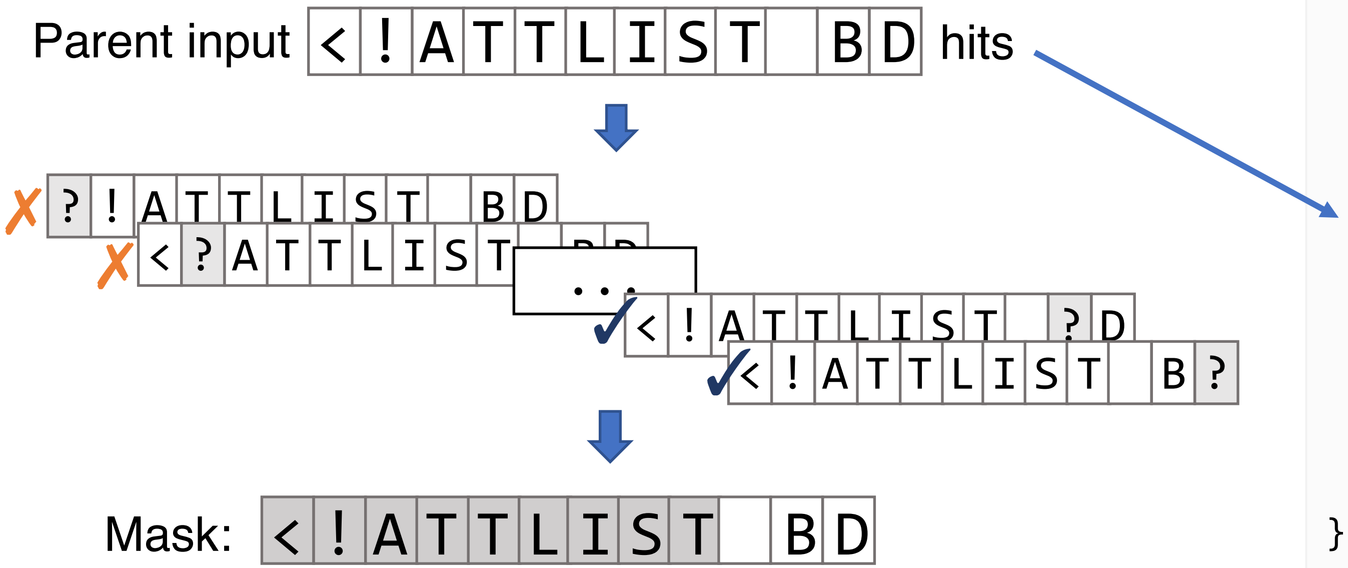


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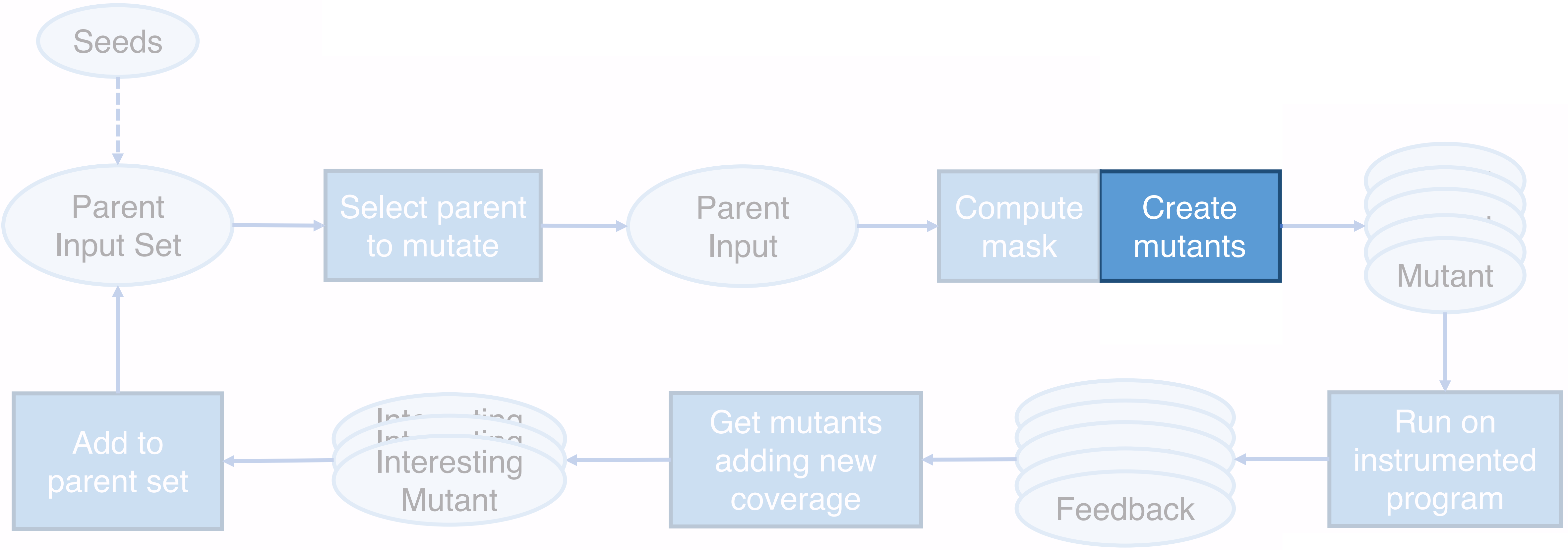
FairFuzz Method – Targeting Mutations



FairFuzz Method – Targeting Mutations

- Fixed-location mutation
  - Don’t produce mutants at locations in mask

<	!	A	T	T	L	I	S	T		B	D

- Random-location mutation
  - Choose random locations outside mask

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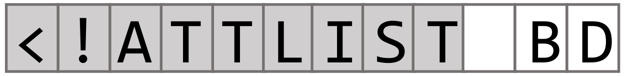

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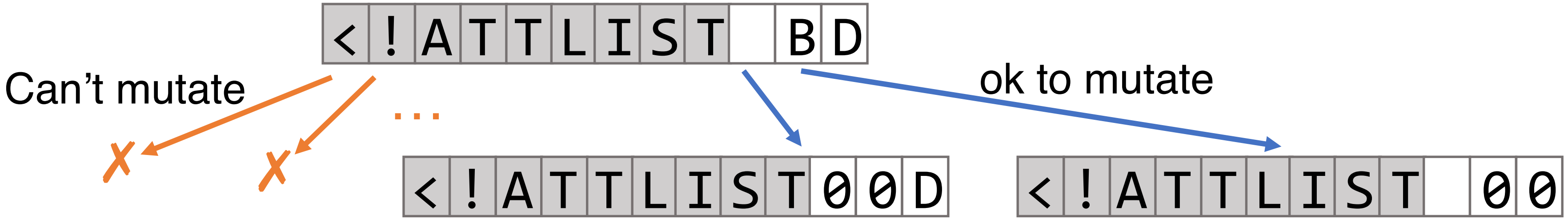

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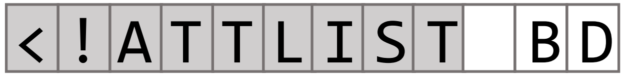

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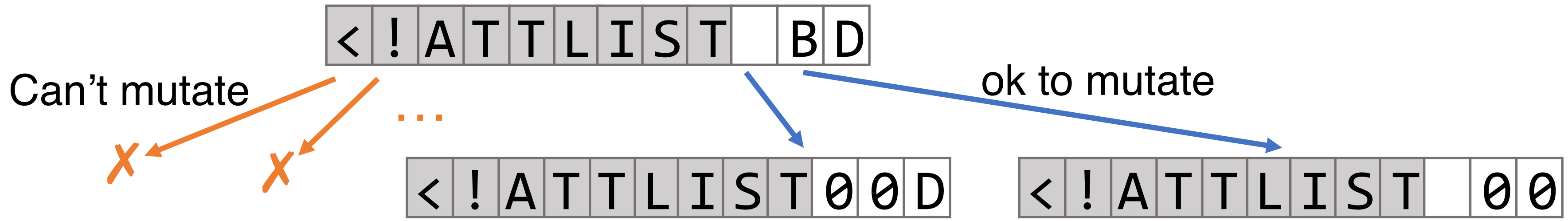

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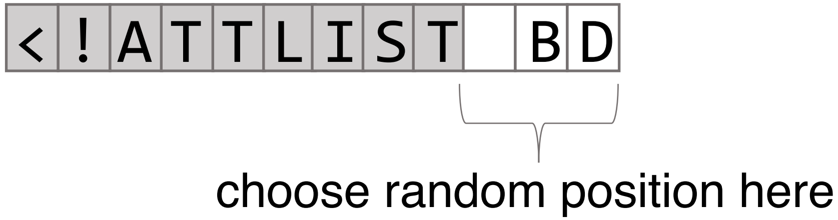


Evaluation

Evaluation – Tools Compared

- **FairFuzz**: our tool, with highest-performing settings
- AFL: vanilla AFL, default settings
- FidgetyAFL: AFL with highest-performing settings
- AFLFast.new: AFLFast with highest-performing settings

[1] Zalewski, Michał. http://lcamtuf.coredump.cx/afl/

[2] Böhme et al. Coverage-based Greybox Fuzzing as Markov Chain. CCS'16.

Evaluation - Benchmarks

`djpeg`
`readpng`

FidgetyAFL benchmarks

`mutool draw`
`xmllint`

More complex input structures

`tcpdump`
`c++filt`
`objdump`
`readelf`
`nm`

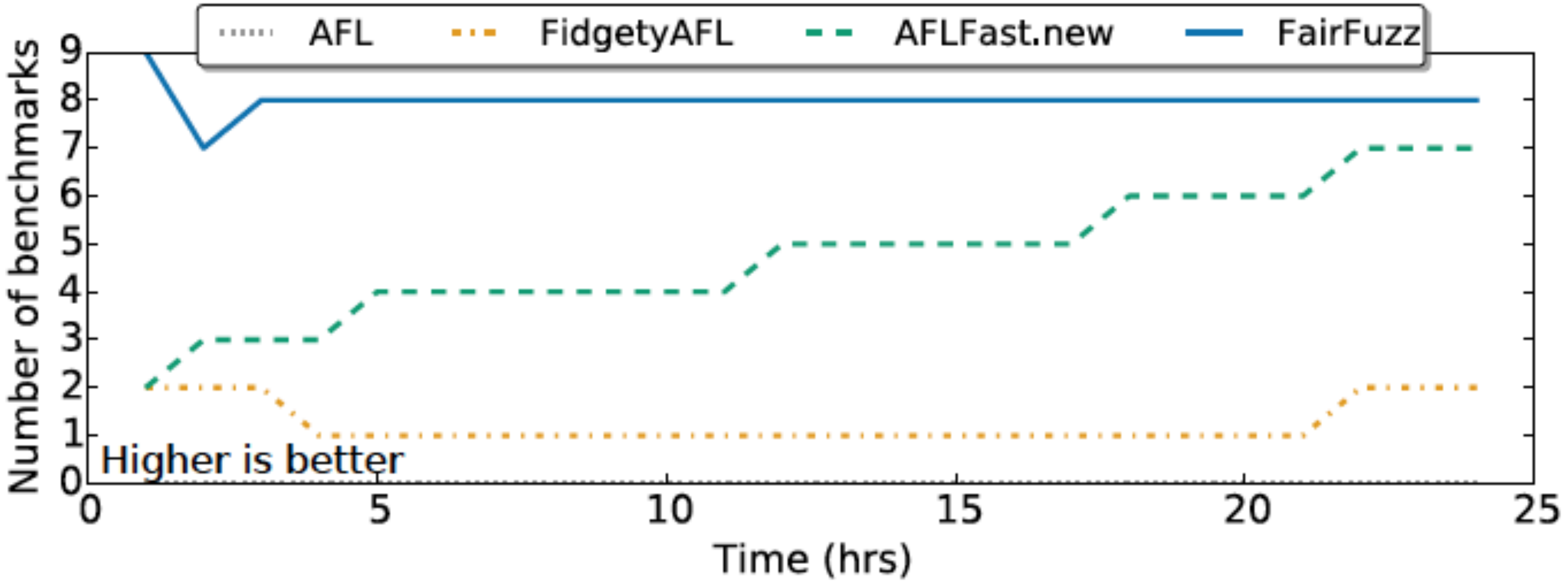
AFLFast benchmarks

Evaluation Setup

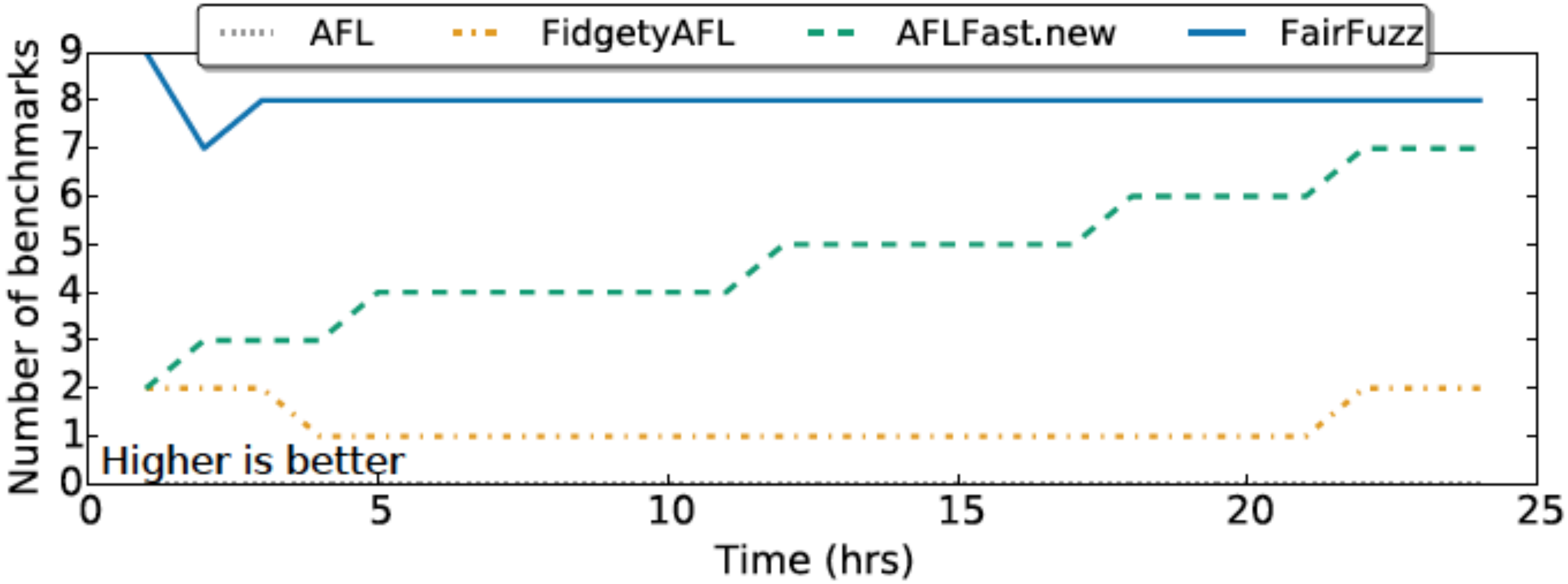
For each benchmark:

- Run each technique 24hrs
- Start with 1 valid seed file
- No dictionaries
- Repeat runs 20x
    - Calculated *confidence intervals*

Summary Results – Coverage Leaders

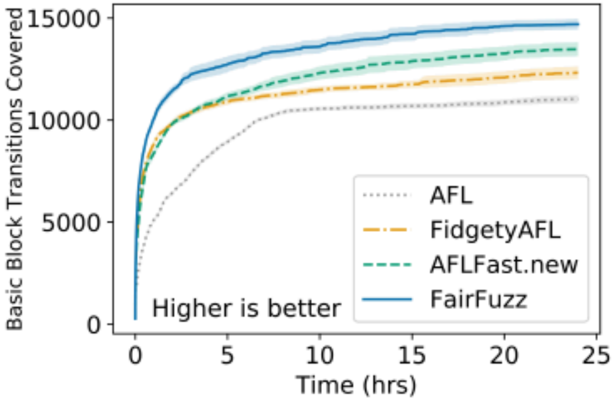


Summary Results – Coverage Leaders

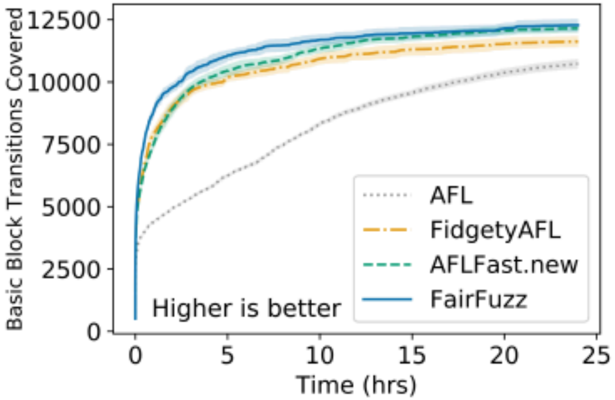


→ FairFuzz achieves the highest coverage fast, for nearly all benchmarks

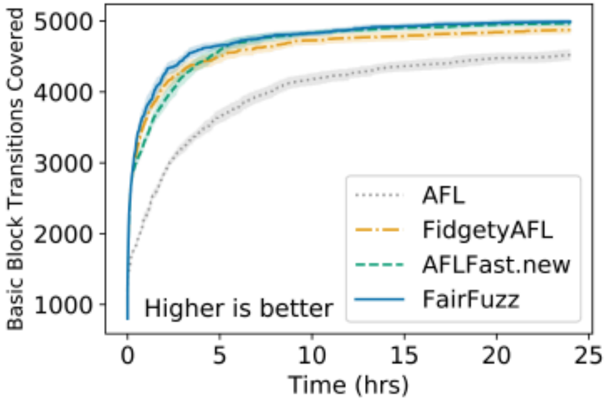
Branch Coverage Over Time



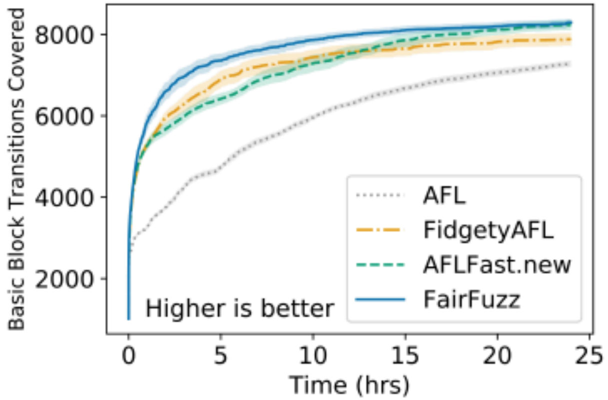
(a) tcpdump



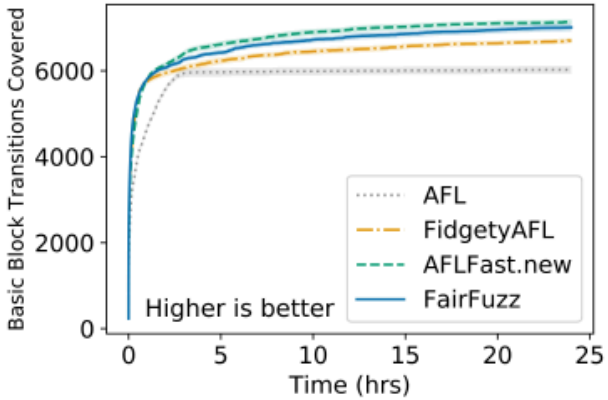
(b) readelf



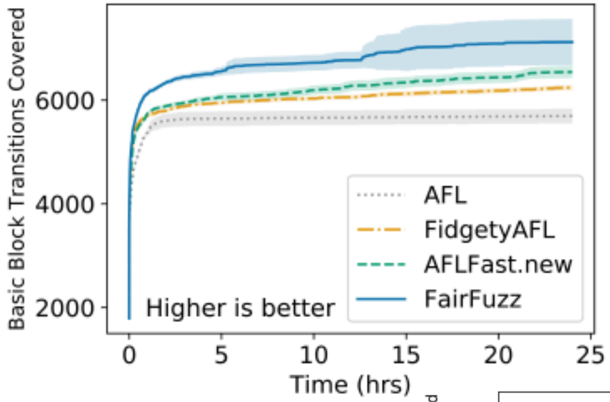
(c) nm



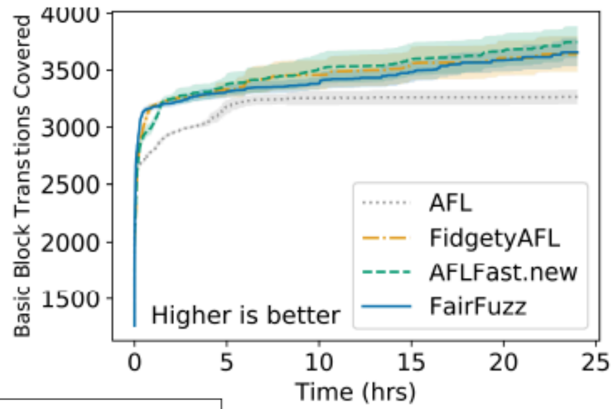
(d) objdump



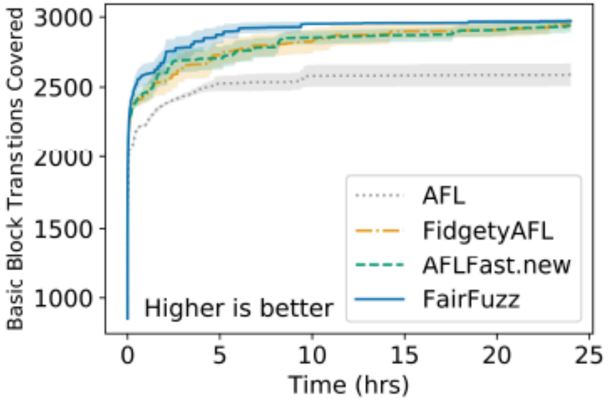
(e) c++filt



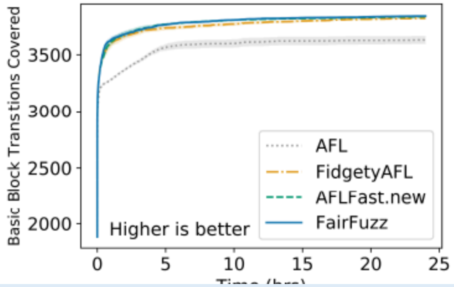
(f) xmllint



(h) djpeg

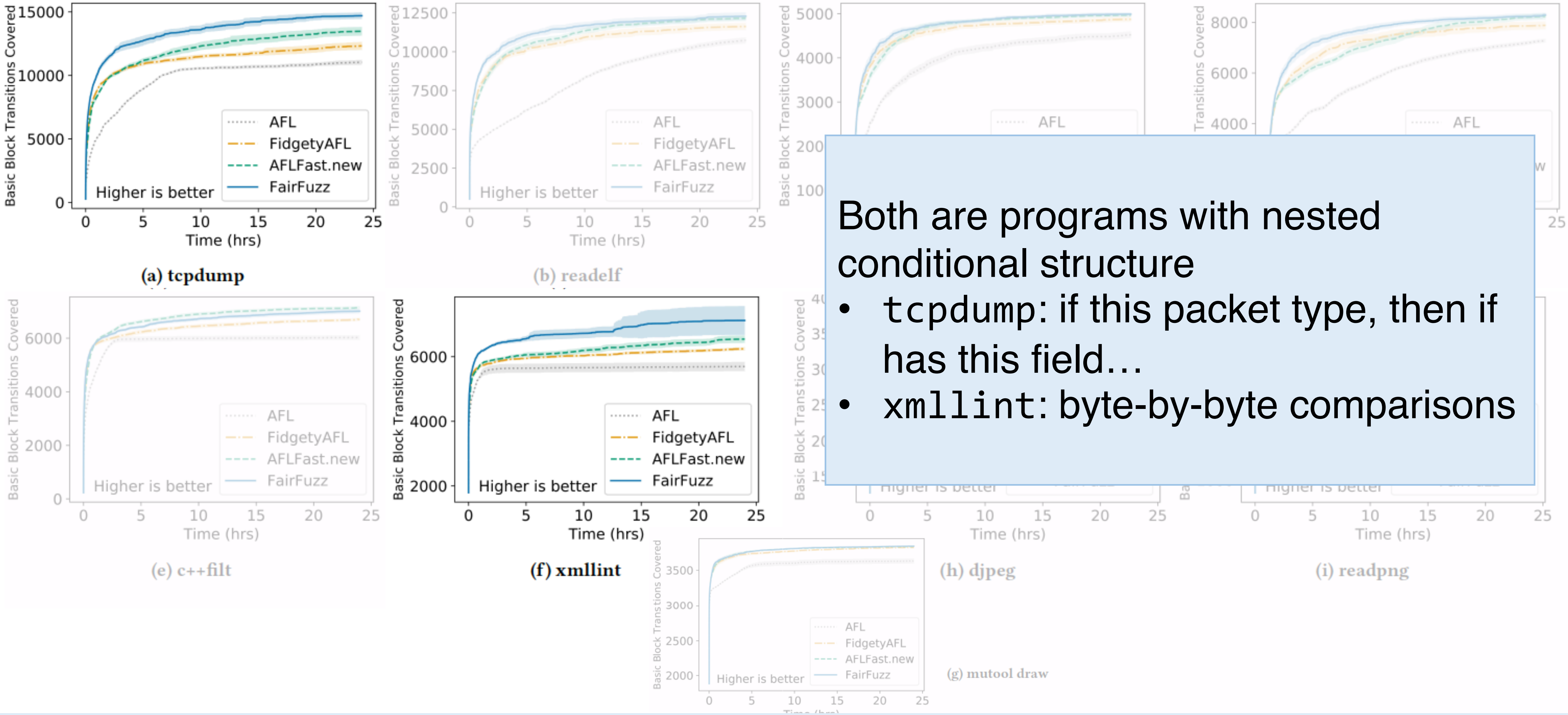


(i) readpng



(g) mutool draw

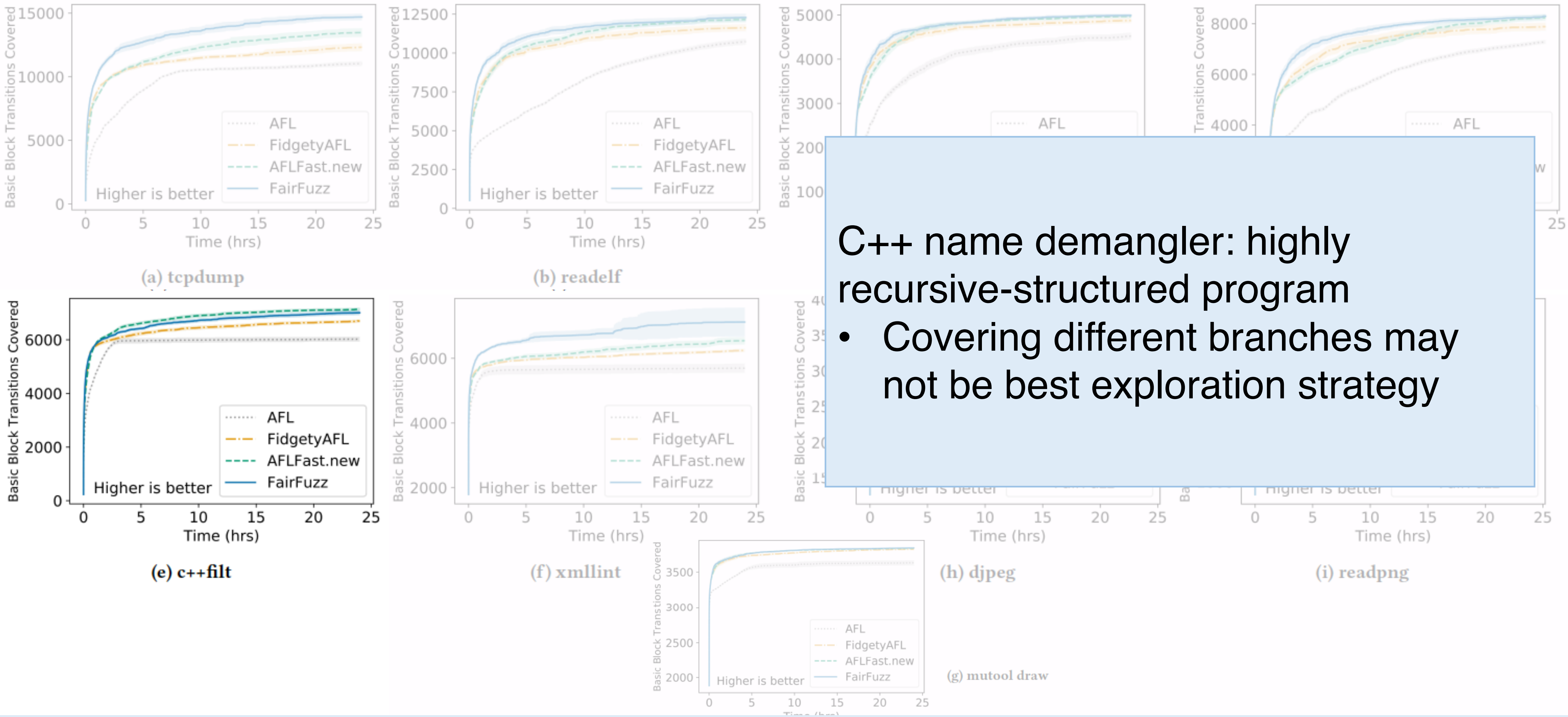
Where Does FairFuzz Perform Much Better?



Both are programs with nested conditional structure

- `tcpdump`: if this packet type, then if has this field…
- `xmllint`: byte-by-byte comparisons

Where Doesn’t FairFuzz Perform As Well?



C++ name demangler: highly recursive-structured program

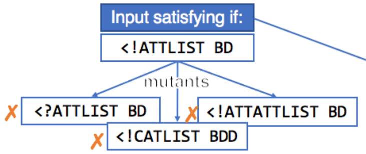
- Covering different branches may not be best exploration strategy

Conclusion

code: github.com/carolemieux/afl-rb slides: carolemieux.com/fairfuzz_ase18_slides.pdf

Why So Uneven?

Some branches hard to hit
by naively mutated inputs

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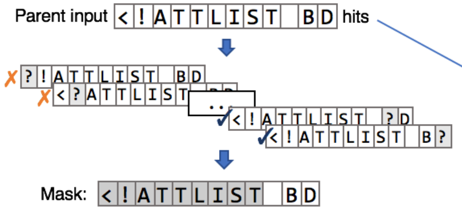
FairFuzz Method – Computing Branch Mask

- Flip each byte, check if mutated input still hits target branch

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- Easily integrated with fixed-location mutation phases of fuzzers

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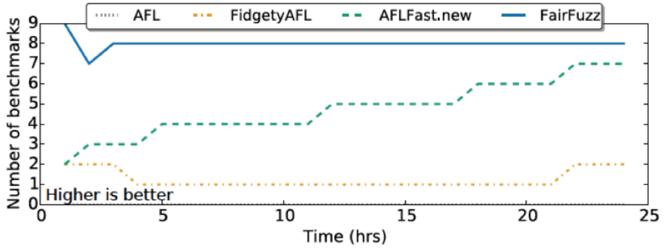

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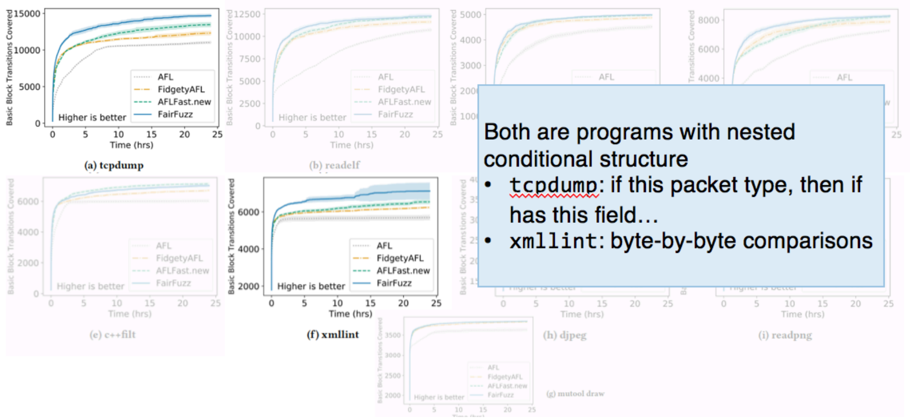

Both are programs with nested conditional structure

- `tcpdump`: if this packet type, then if has this field…
- `xmllint`: byte-by-byte comparisons

Branch Mask Performance

For a subset of benchmarks, run a cycle with “shadow run”:

- For each selected input, create mutants
  - (1) without branch mask
  - (2) without branch mask
- Compare % of inputs hitting target branch:
  - Average over all inputs selected for mutation in cycle

Branch Mask Performance

- Mask substantially increases % of inputs hitting target branch

	Fixed-Location Mutants		Random-Location Mutants	
	With Mask	Without Mask	With Mask	Without Mask
`xmllint`	90.3%	22.9%	32.8%	2.9%
`tcpdump`	98.7%	72.8%	36.1%	9.0%
`c++filt`	96.6%	14.8%	34.4%	1.1%
`readelf`	99.7%	78.2%	55.5%	11.4%
`readpng`	97.8%	39.0%	24.0%	2.4%
`objdump`	99.2%	66.7%	46.2%	7.6%