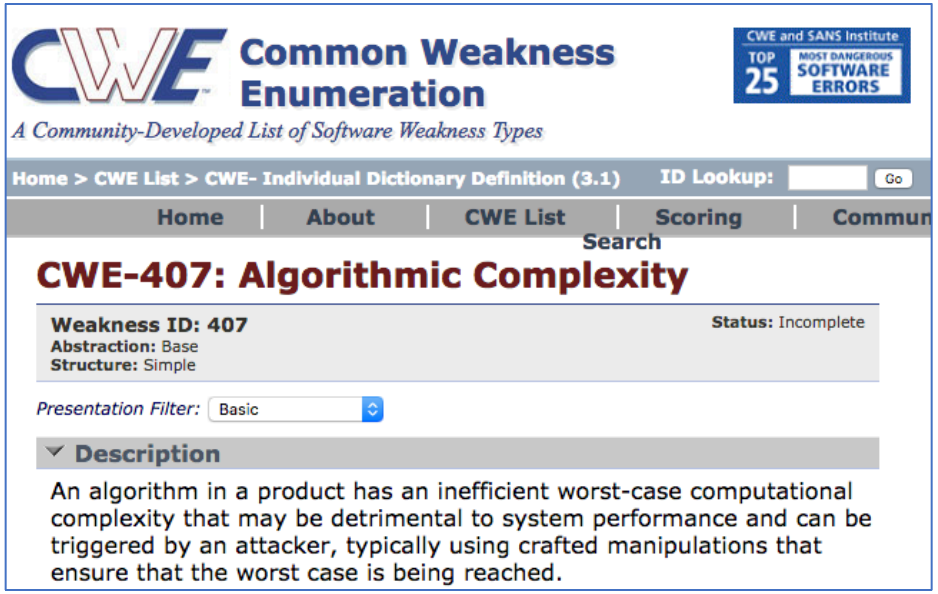
PerfFuzz: Automatically Generating Pathological Inputs

Caroline Lemieux, Rohan Padhye, Koushik Sen, Dawn Song
University of California, Berkeley

source: https://github.com/carolemieux/perffuzz

Nobody Expects Performance Problems

Performance Problems Have Consequences



CWE
Common Weakness Enumeration
A Community-Developed List of Software Weakness Types
CWE and SANS Institute TOP 25 MOST DANGEROUS SOFTWARE ERRORS
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CWE-407: Algorithmic Complexity

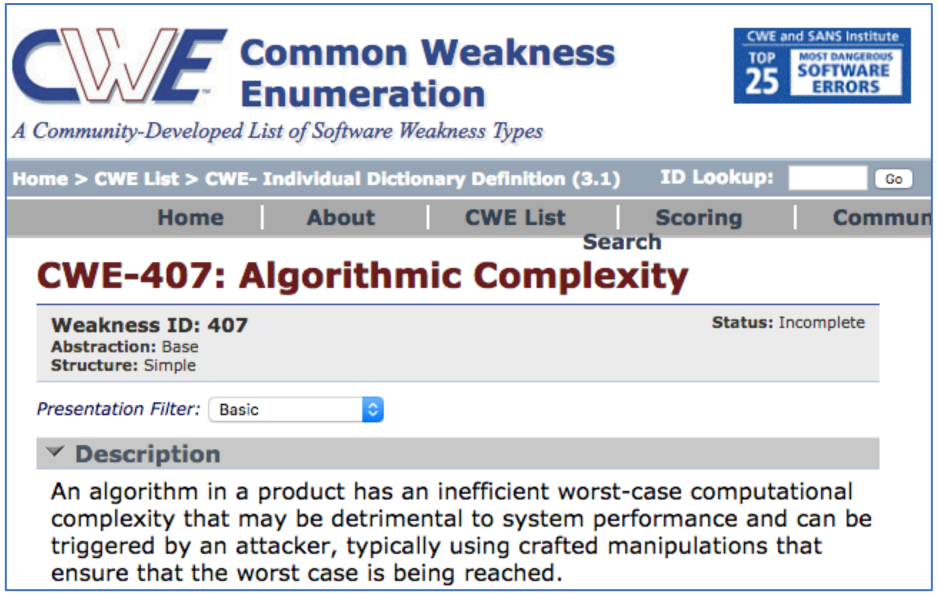
Weakness ID: 407
Abstraction: Base
Structure: Simple
Status: Incomplete

Presentation Filter: Basic

Description

An algorithm in a product has an inefficient worst-case computational complexity that may be detrimental to system performance and can be triggered by an attacker, typically using crafted manipulations that ensure that the worst case is being reached.

Performance Problems Have Consequences



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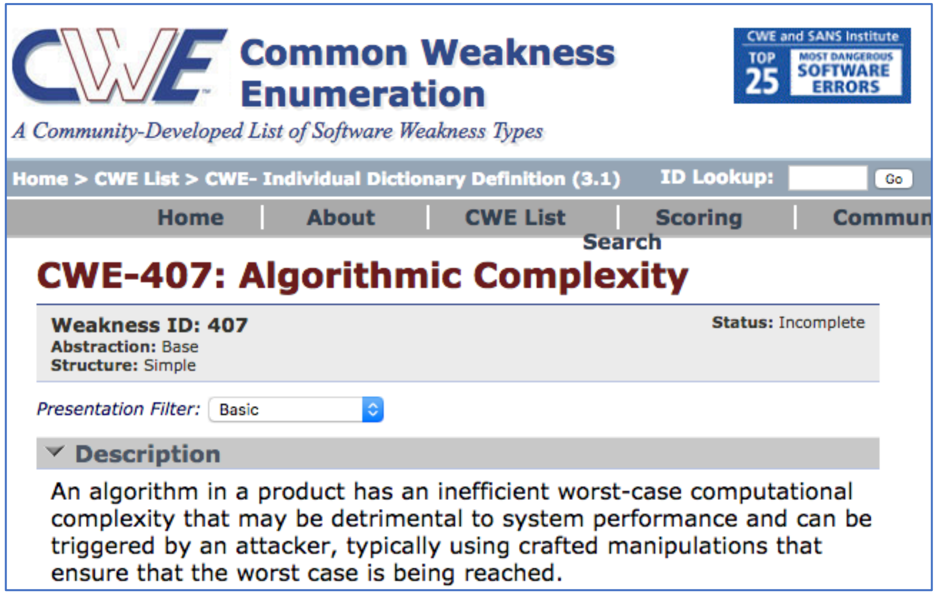
poor user experience

Performance Problems Have Consequences



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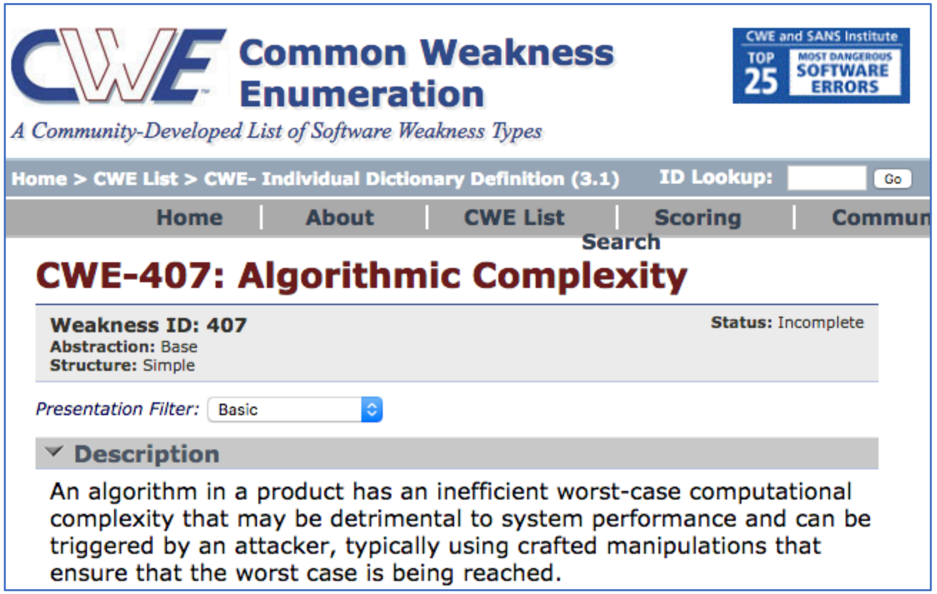
poor user experience

excessive resource consumption

Performance Problems Have Consequences

security vulnerabilities (DoS)



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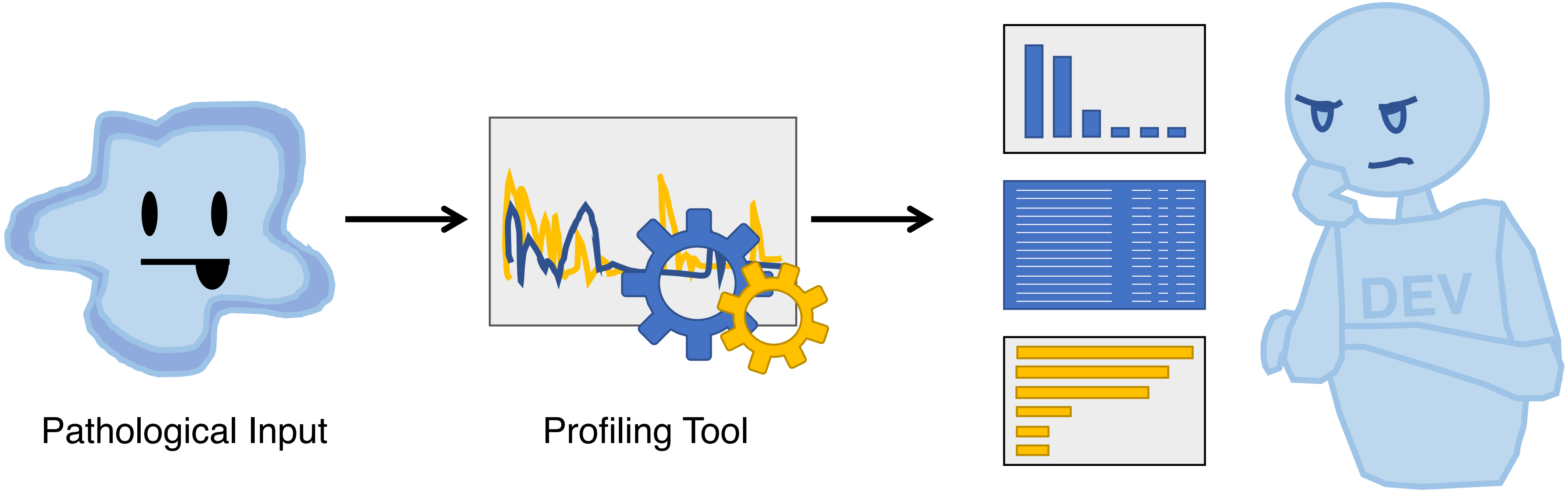
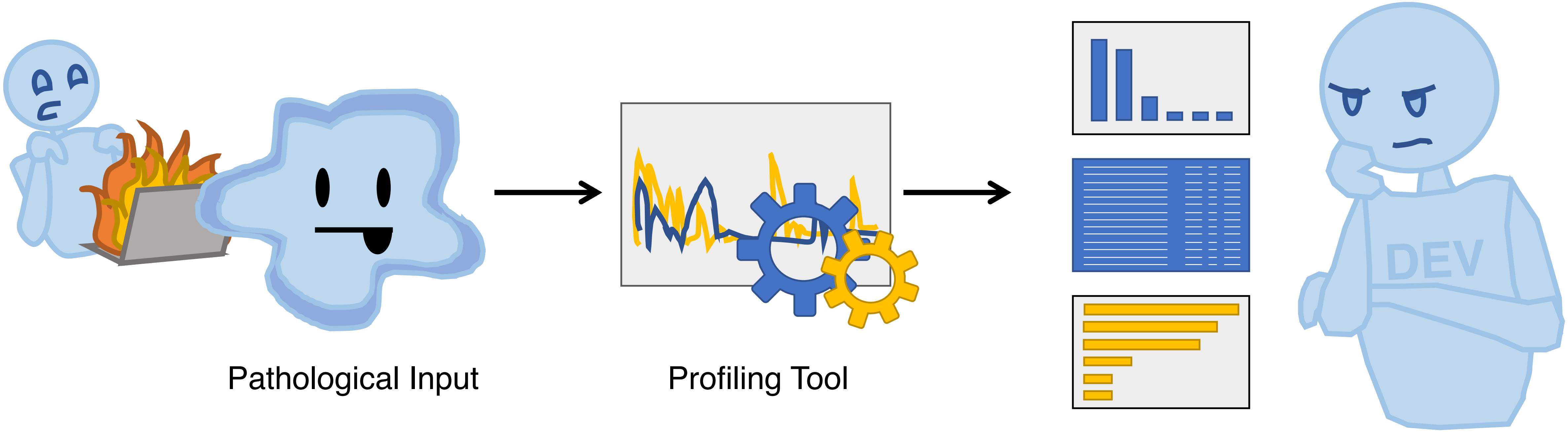
Alleviating Performance Problems



Pathological Input

Profiling Tool

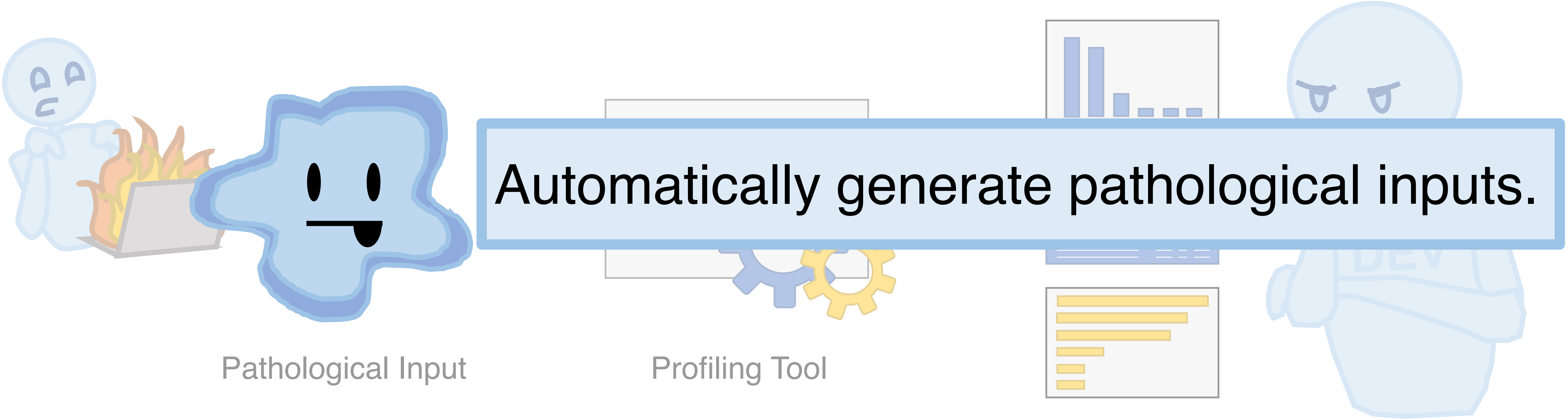
Alleviating Performance Problems



Pathological Input

Profiling Tool

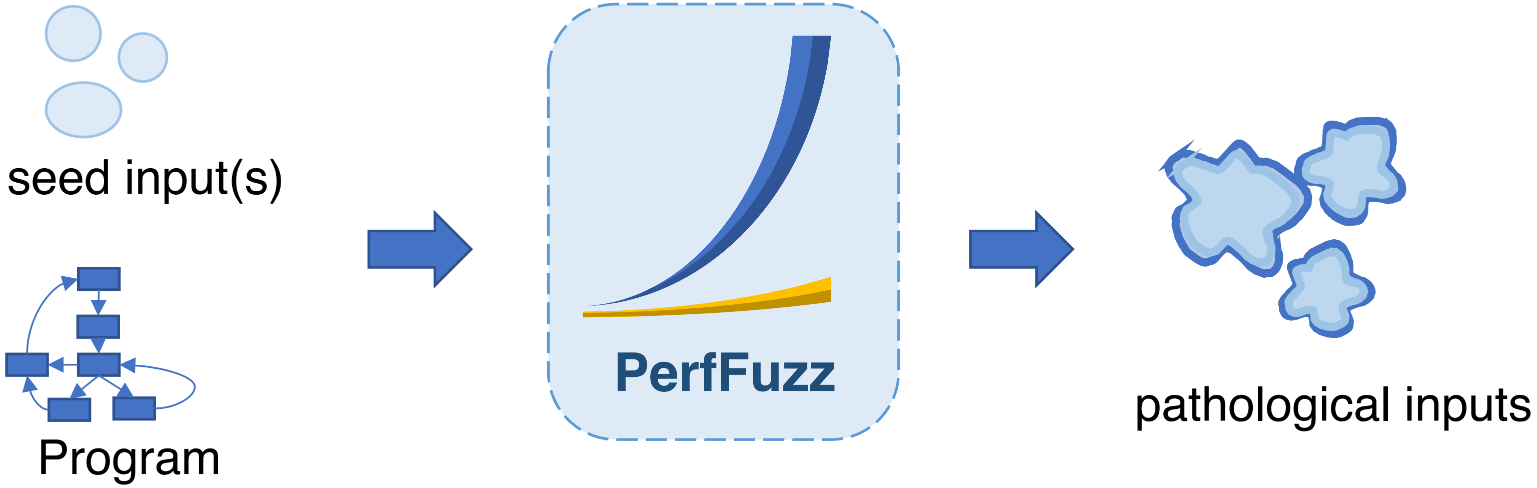
PerfFuzz Goal



Automatically generate pathological inputs.

PerfFuzz

- A **feedback-directed mutational fuzzing** tool
- Uses **performance feedback** to produce pathological inputs



seed input(s)

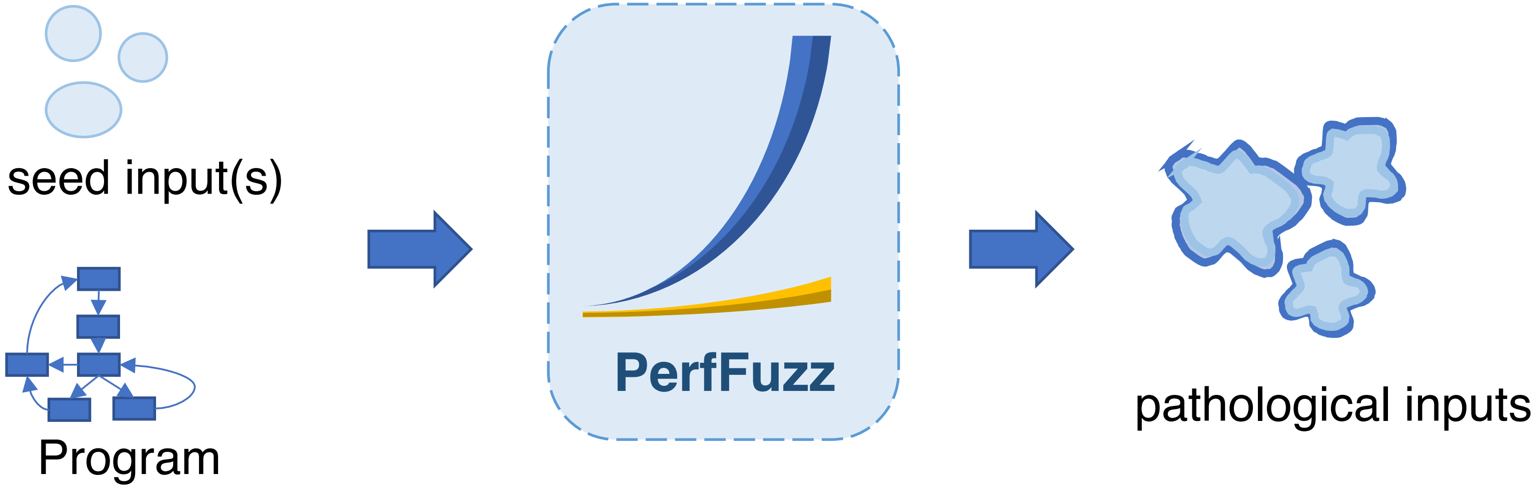
Program

PerfFuzz

pathological inputs

PerfFuzz

- A **feedback-directed mutational fuzzing** tool
  - **Fuzzing**: sends inputs to program
  - **Mutational**: creates new inputs by mutating saved inputs
  - **Feedback-directed**: saves inputs if program gives *interesting* feedback



seed input(s)

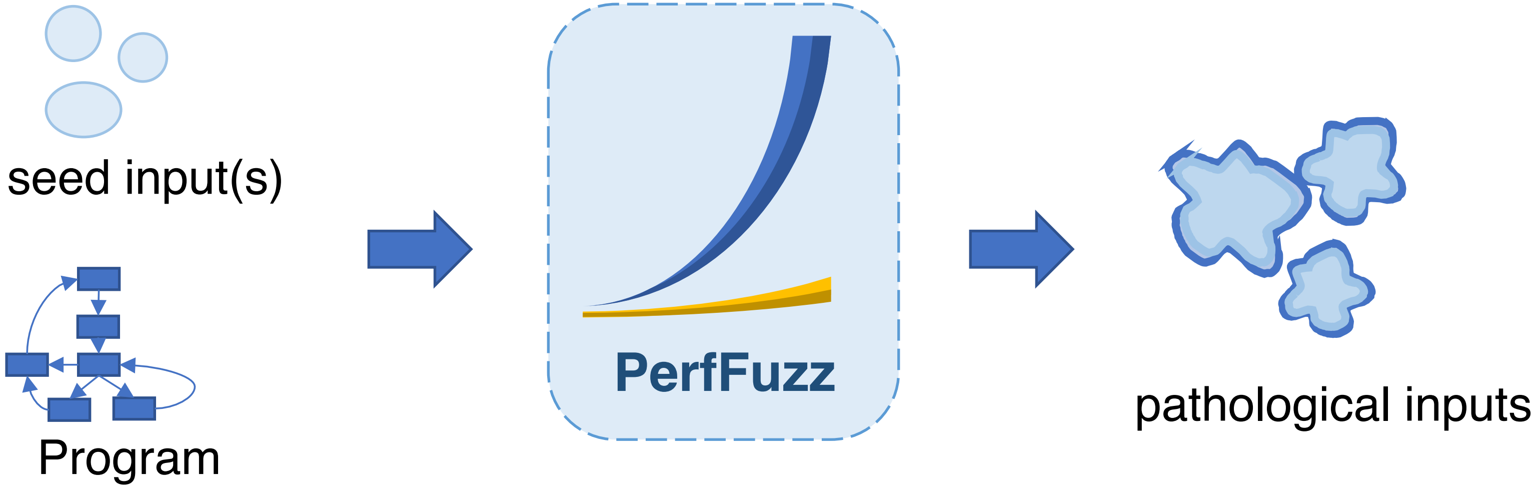
Program

PerfFuzz

pathological inputs

PerfFuzz

- A **feedback-directed mutational fuzzing** tool
- Uses **performance feedback** to produce pathological inputs
  - **First idea**: interesting if longer execution time, path length [1]
  - **PerfFuzz**: interesting if higher execution count of any given CFG edge



seed input(s)

Program

PerfFuzz

pathological inputs

[1] T. Petsios, J. Zhao, A. D. Keromytis, and S. Jana. 2017. SlowFuzz: Automated Domain-Independent Detection of Algorithmic Complexity Vulnerabilities. CCS '17.

Example Program: Word Frequency (`wf`)

- Count # occurrences of words in a string

input:

```
the quick brown the dog
```

output:

```
brown: 1
dog: 1
quick: 1
the: 2
```

- `wf` shipped with Fedora Linux had real performance bugs

Example Program: Word Frequency (wf)

- Count # occurrences of words in a string

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output:

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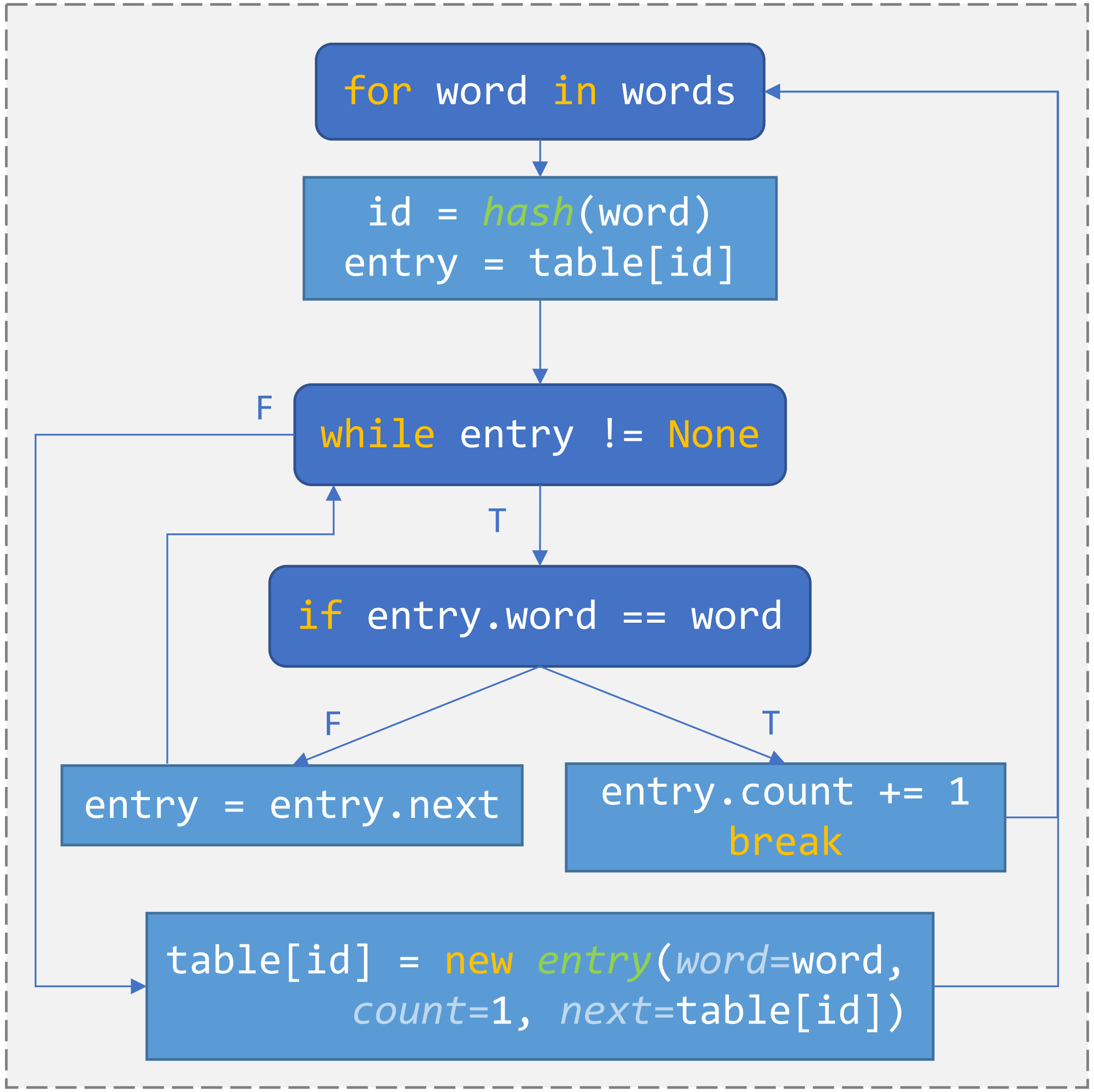

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for word in words
id = hash(word)
entry = table[id]
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if entry.word == word
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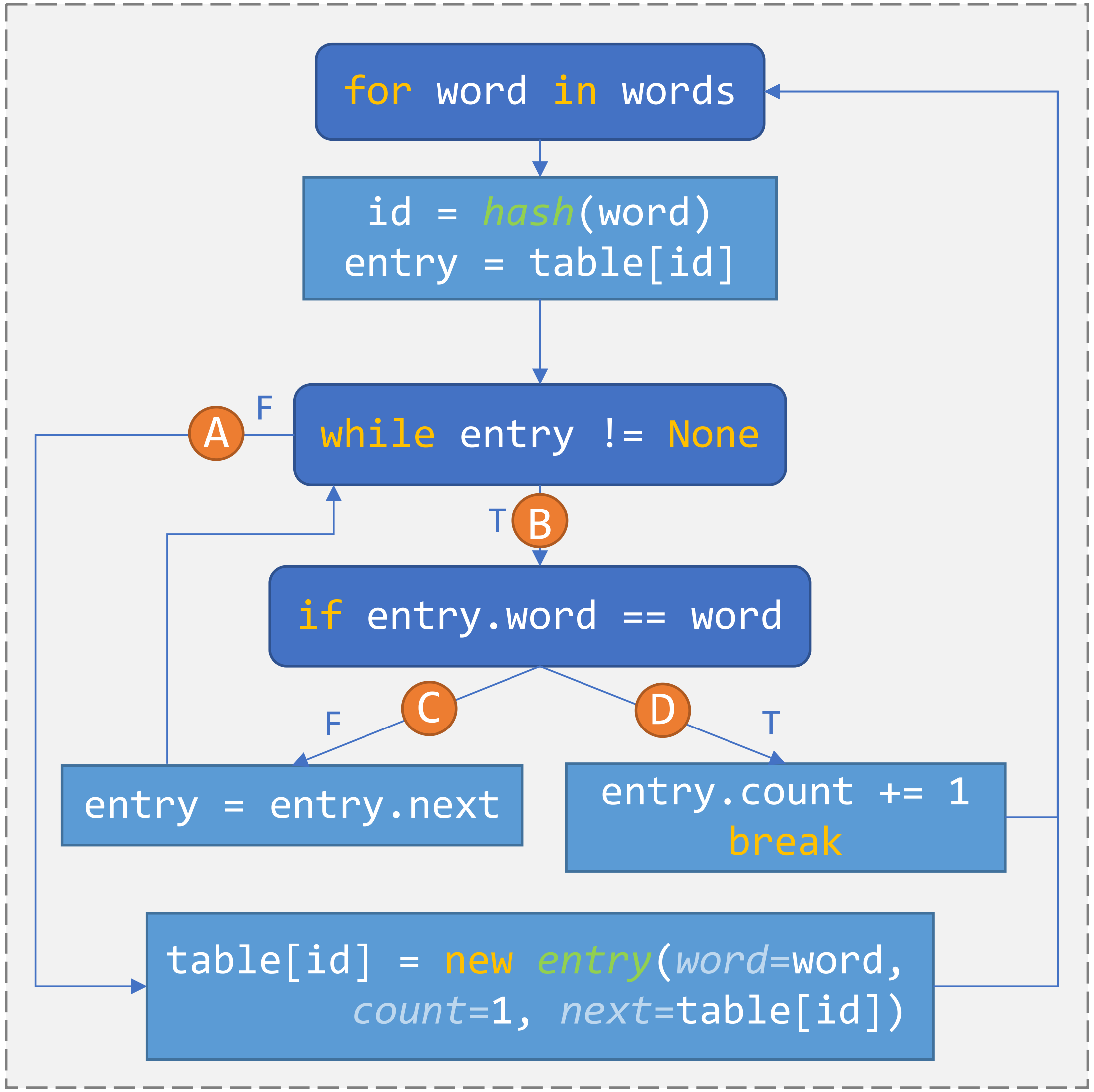
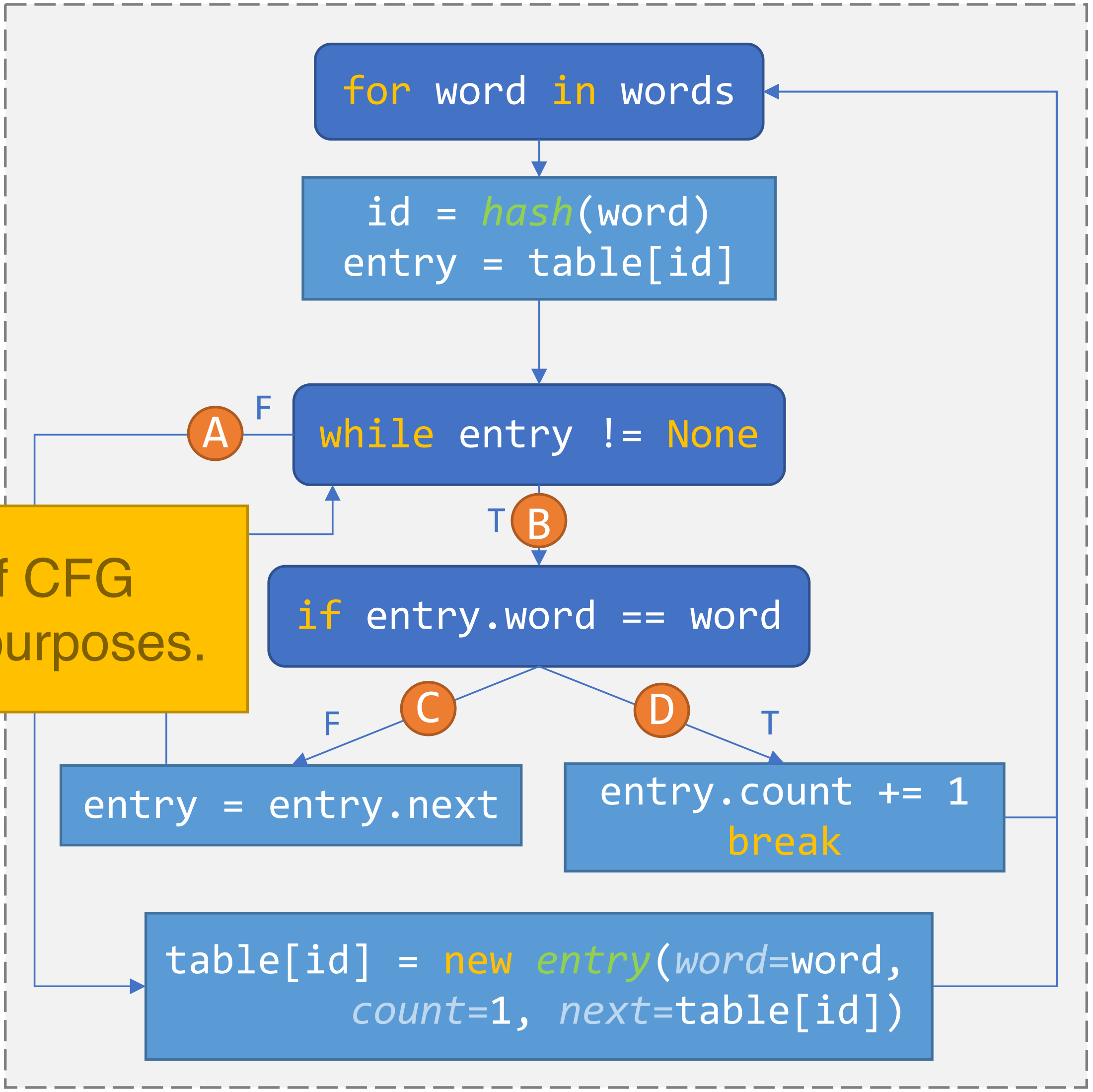
```

wf Performance Response



wf Performance Response



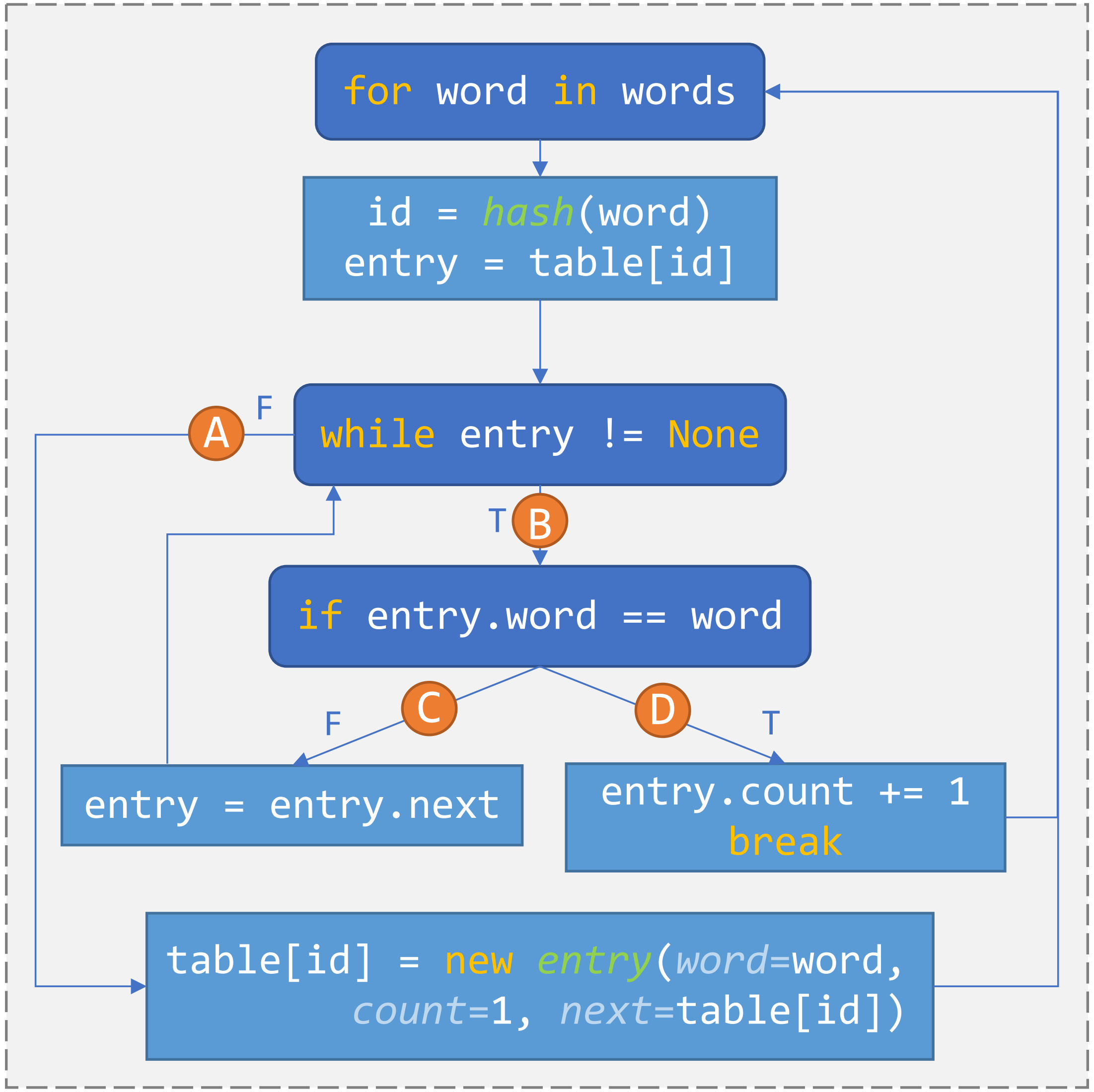
→ We look at a subset of CFG edges for illustration purposes.

wf Performance Response

- Usual case:

```
the quick brown the dog
```

Edge	# Hits
A	
B	
C	
D	



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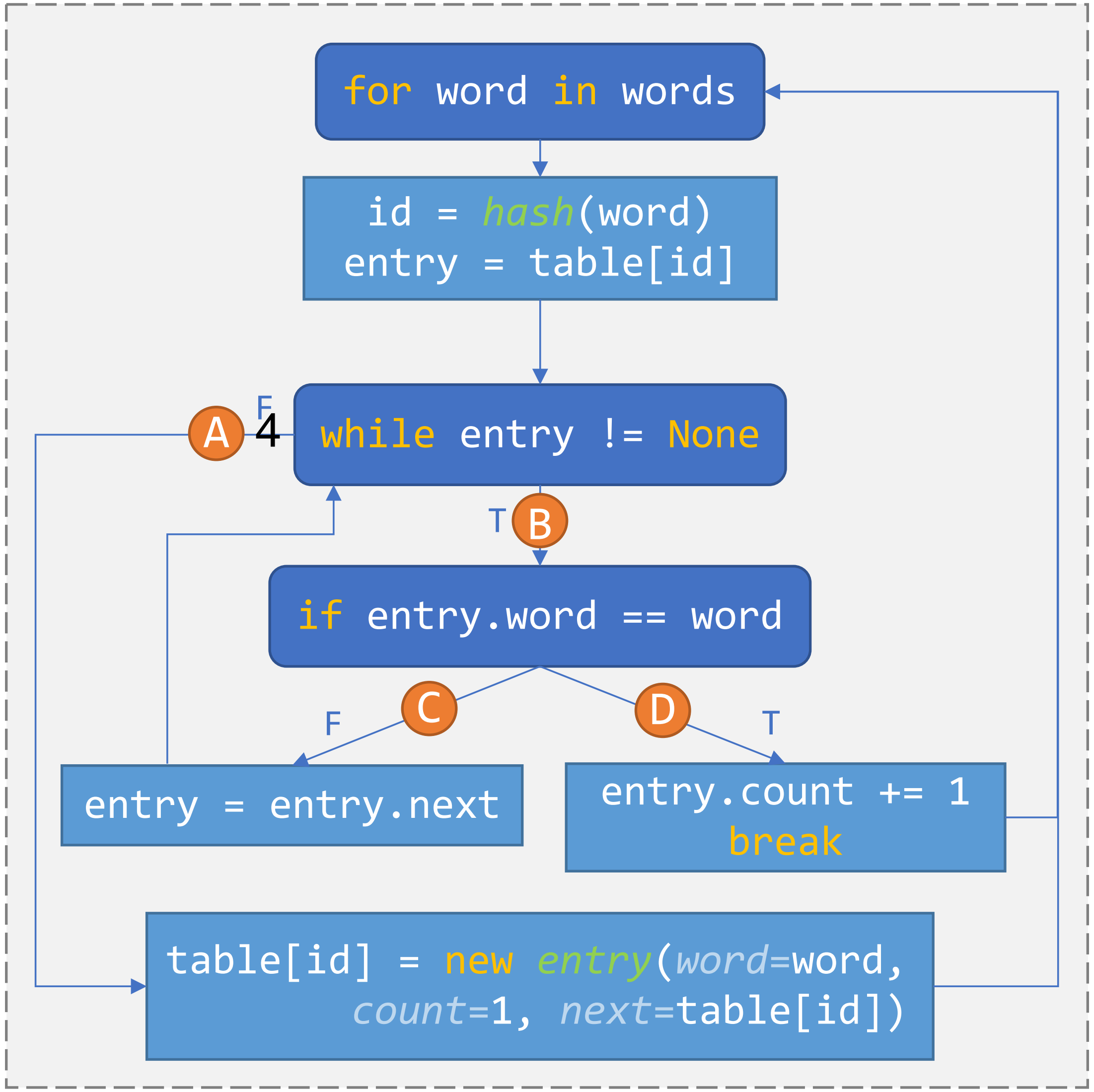
```

wf Performance Response

- Usual case:

```
the quick brown the dog
```

Edge	# Hits
A	4
B	
C	
D	

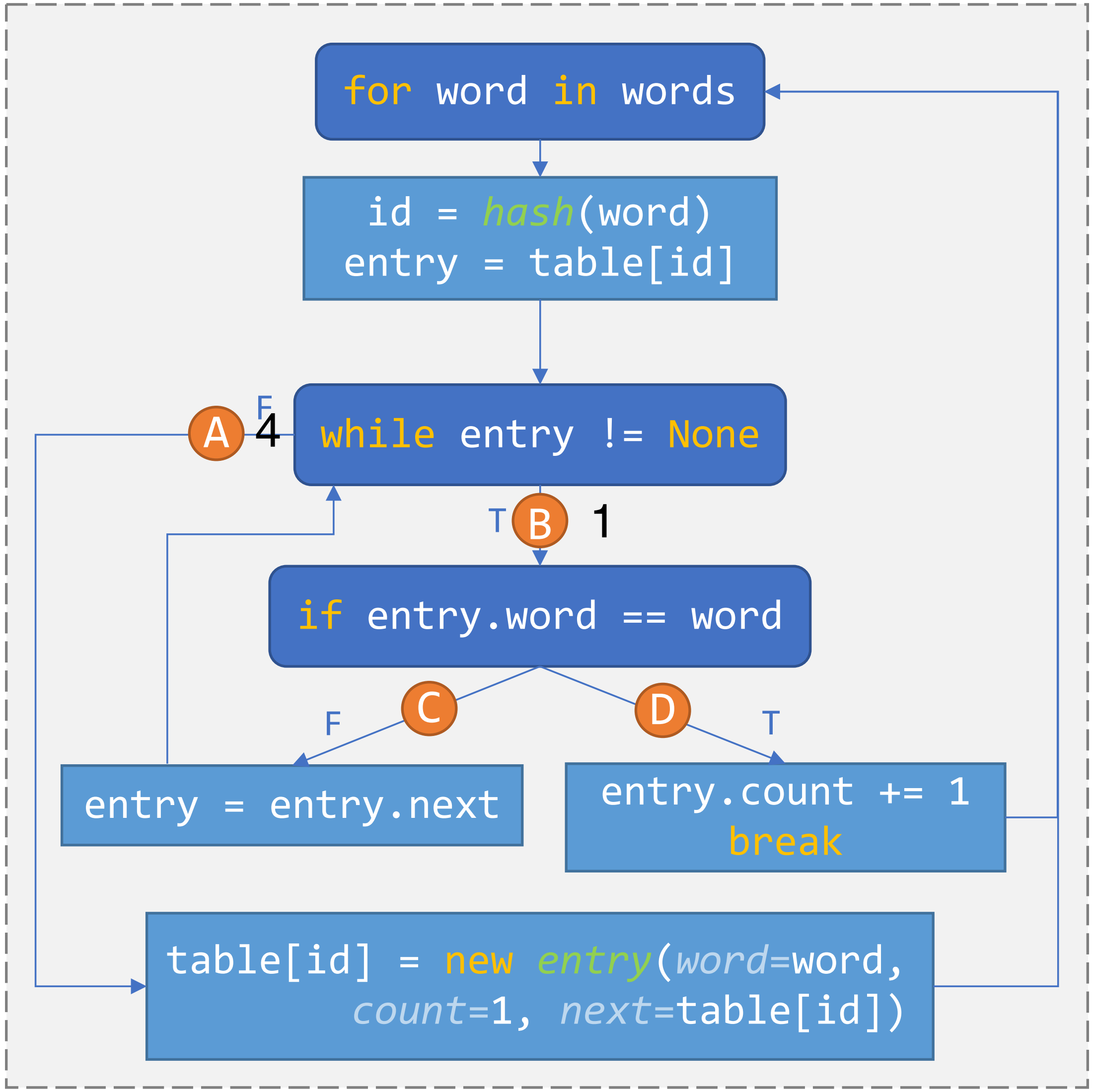


wf Performance Response

- Usual case:

```
the quick brown the dog
```

Edge	# Hits
A	4
B	1
C	
D	



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```

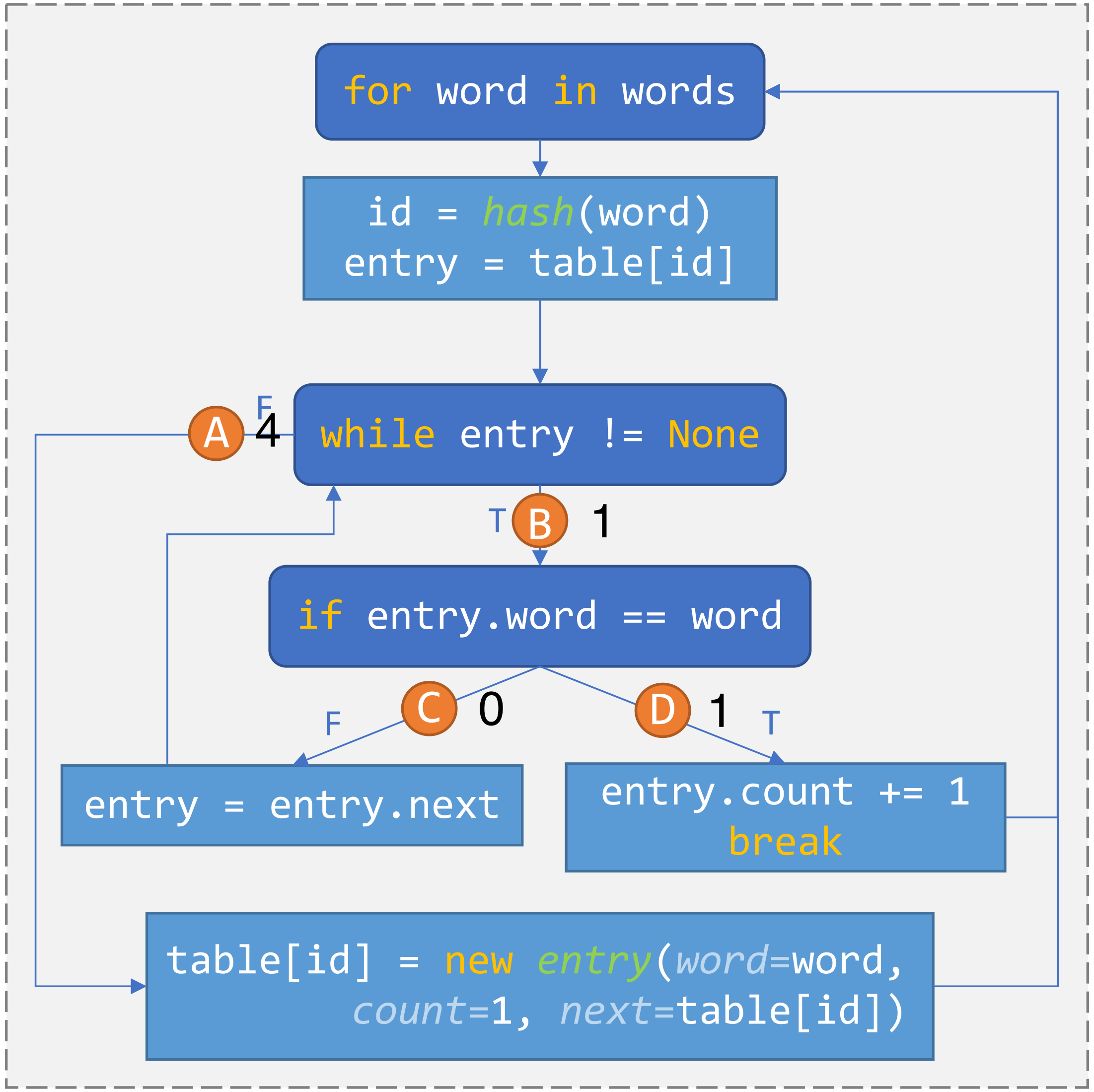
```
table[id] = new entry(word=word,
                 count=1, next=table[id])
```

wf Performance Response

- Usual case:

```
the quick brown the dog
```

Edge	# Hits
A	4
B	1
C	0
D	1



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while entry != None

if entry.word == word

entry = entry.next

entry.count += 1
break

table[id] = new entry(word=word,
count=1, next=table[id])

wf Performance Response

- Usual case:

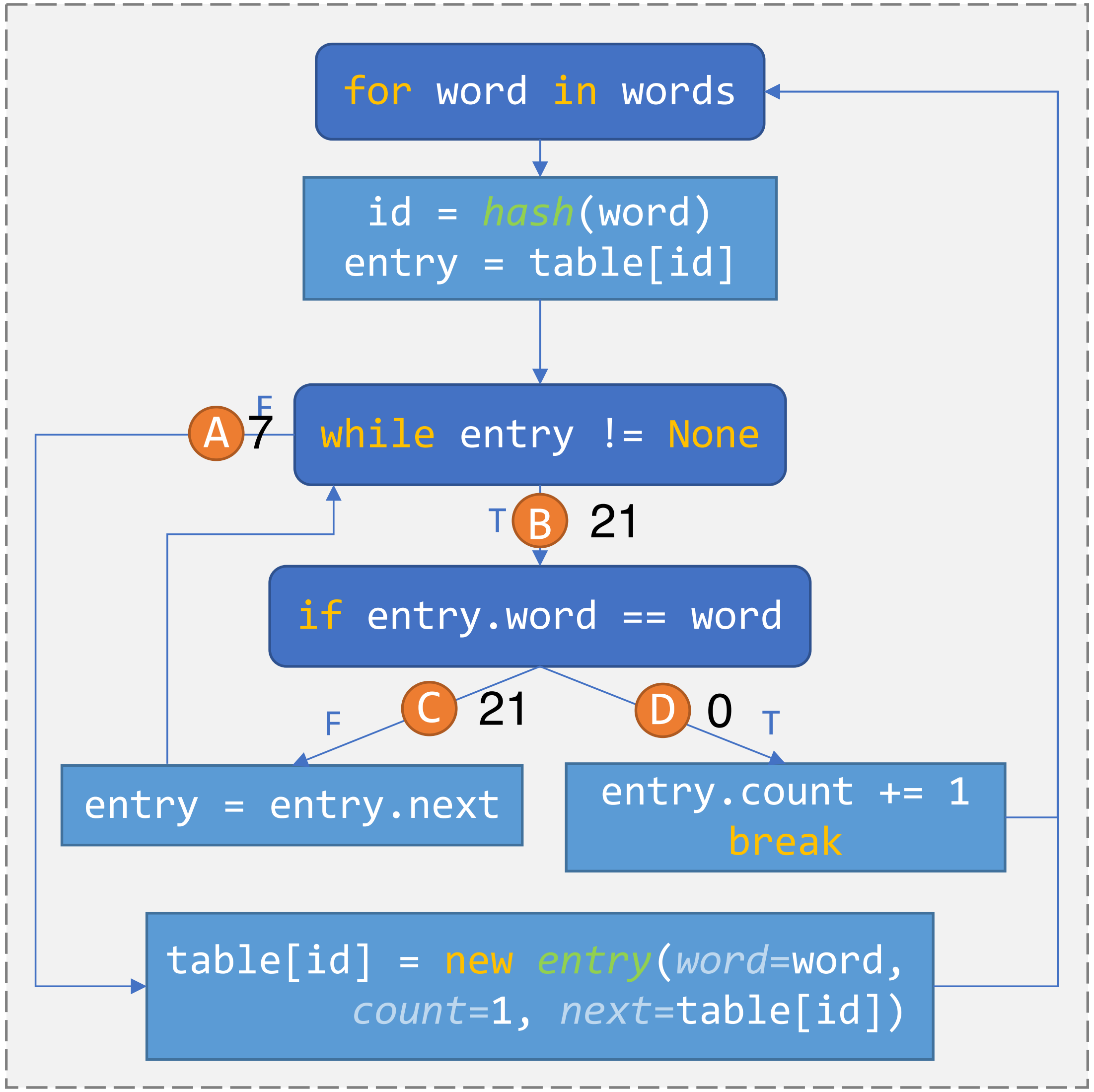
```
the quick brown the dog
```

Edge	# Hits
A	4
B	1
C	0
D	1

- Hash collisions:

```
t ?t xt at$ #a ))t Qwaa
```

Edge	# Hits
A	7
B	21
C	21
D	0



wf Performance Response

- Usual case:

```
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```

Edge	# Hits
A	4
B	1
C	0
D	1

- Hash collisions:

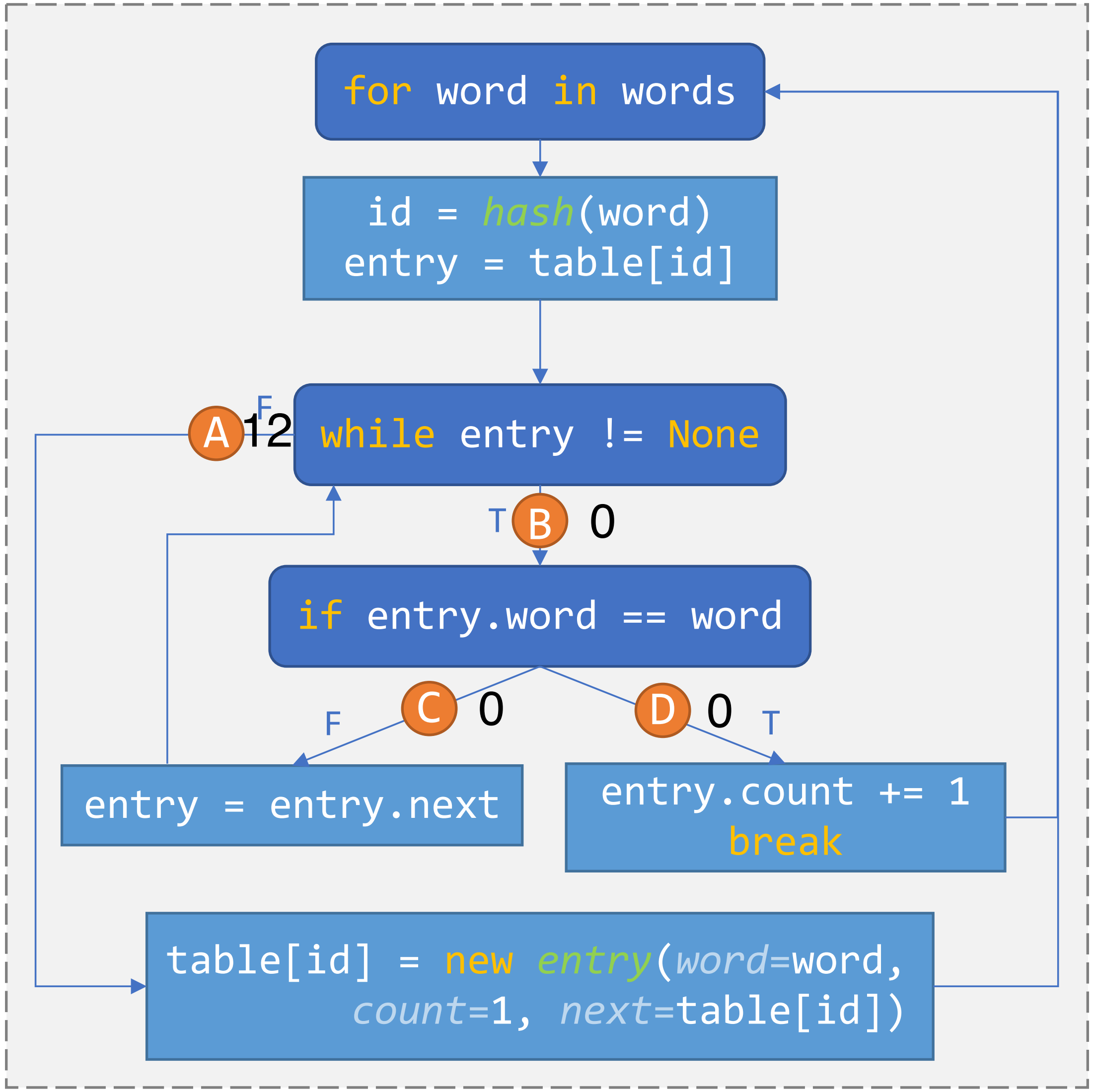
```
t ?t xt at$ #a ))t Qwaa
```

Edge	# Hits
A	7
B	21
C	21
D	0

- Small words:

```
t h e q u i c k b r o w
```

Edge	# Hits
A	12
B	0
C	0
D	0



wf Performance Response

- Usual case:

```
the quick brown the dog
```

Edge	# Hits
A	4
B	1
C	0
D	1

- Hash collisions:

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```

Edge	# Hits
A	7
B	21
C	21
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- Small words:

```
t h e q u i c k b r o w
```

Edge	# Hits
A	12
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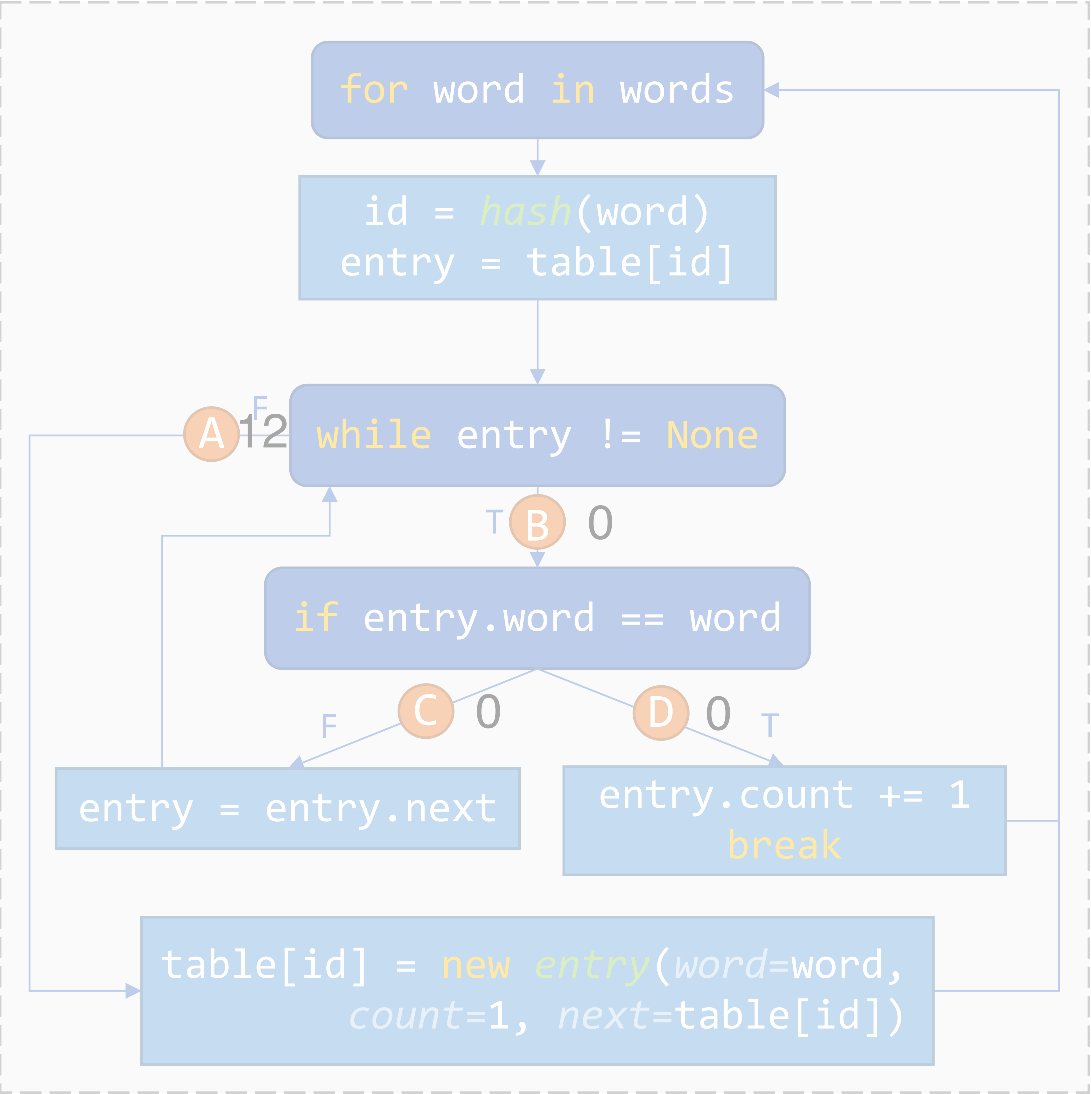
C	0
D	0



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wf Performance Response

- Usual case:

```
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```

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A	4
B	1
C	0
D	1

- Hash collisions:

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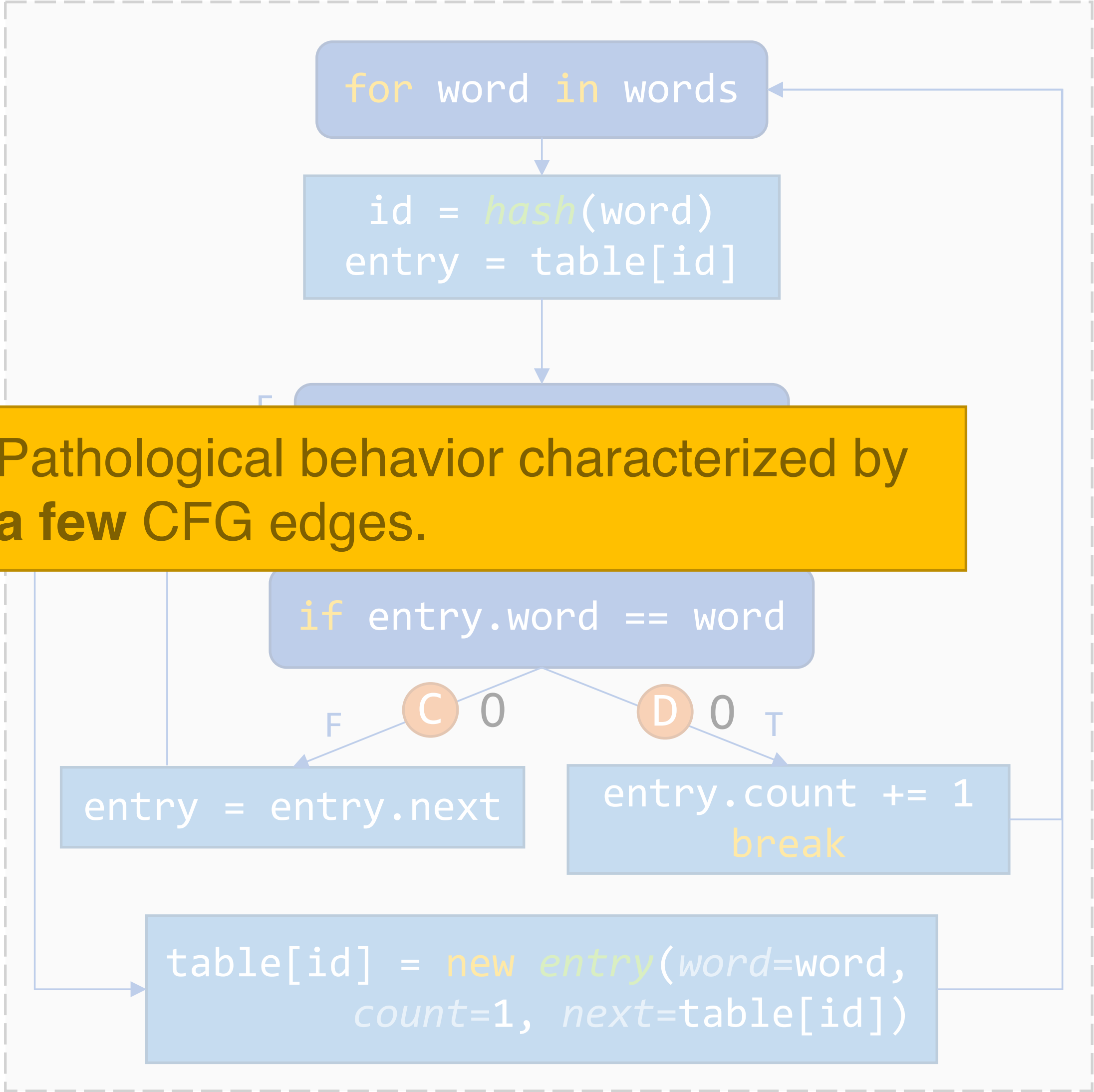

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```

→ Pathological behavior characterized by **a few** CFG edges.

wf Performance Response

- Usual case:

```
the quick brown the dog
```

Edge	# Hits
A	4
B	1
C	0
D	1

- Hash collisions:

```
t ?t xt at$ #a ))t Qwaa
```

Edge	# Hits
A	7
B	21
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- Small words:

```
t h e q u i c k b r o w
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Edge	# Hits
A	12
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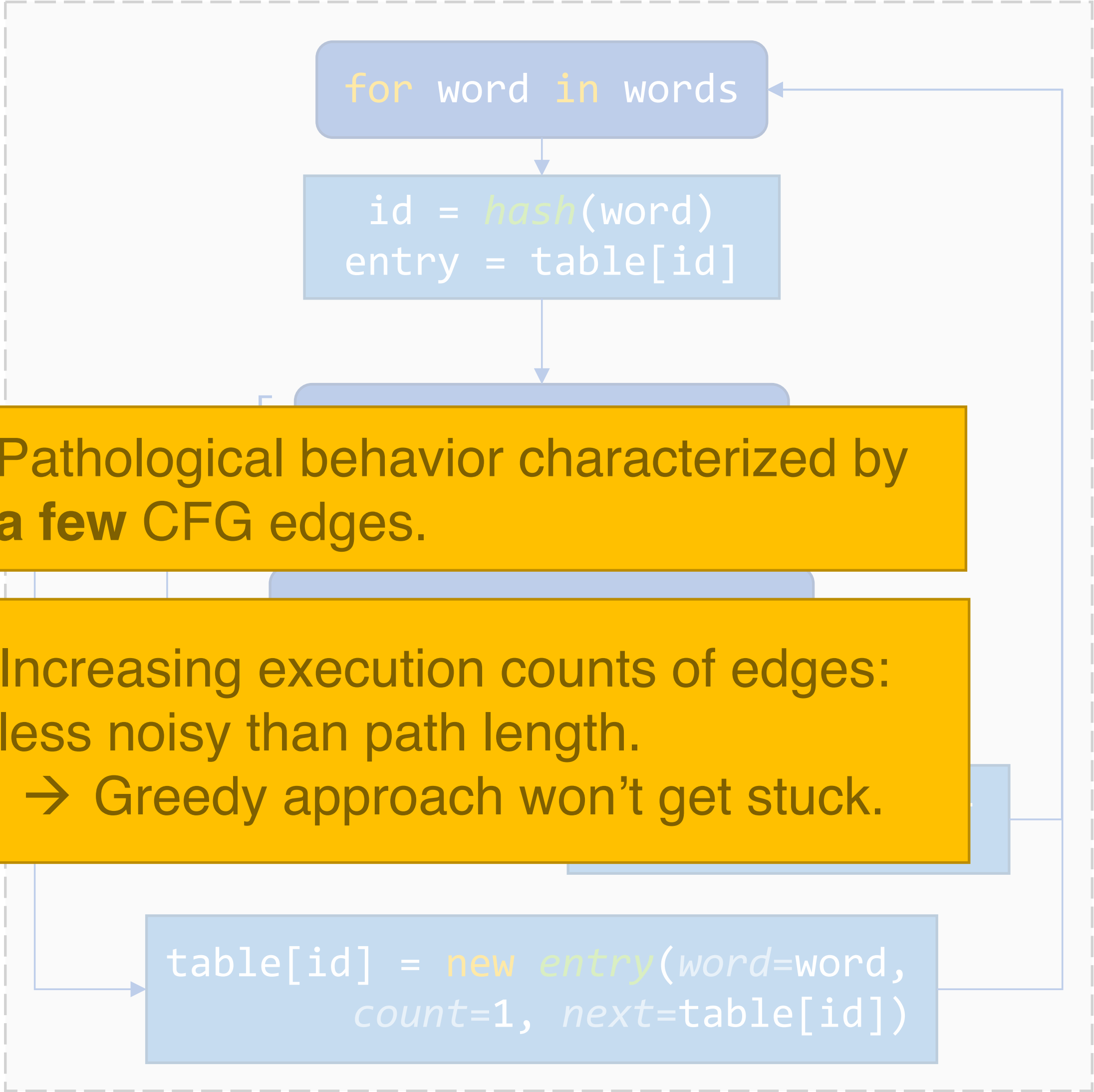

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→ Pathological behavior characterized by **a few** CFG edges.

→ Increasing execution counts of edges: less noisy than path length.
  → Greedy approach won't get stuck.

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input

mutation engine

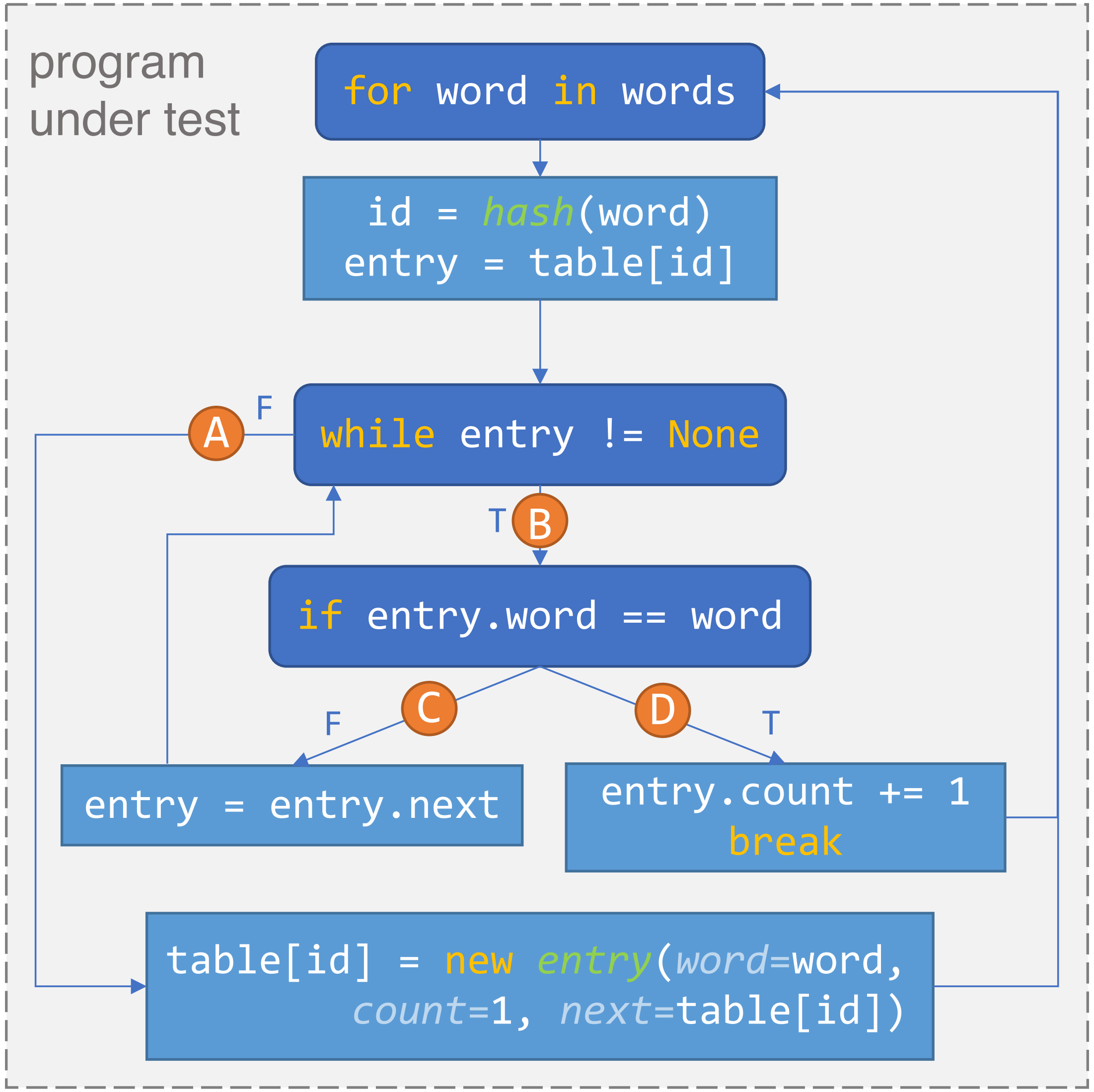
Parent to Mutate

input running, feedback analysis

Current Input

Edge	# Hits

program under test



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for word in words
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while entry != None
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if entry.word == word
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entry = entry.next
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entry.count += 1
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table[id] = new entry(word=word,
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PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input

mutation engine

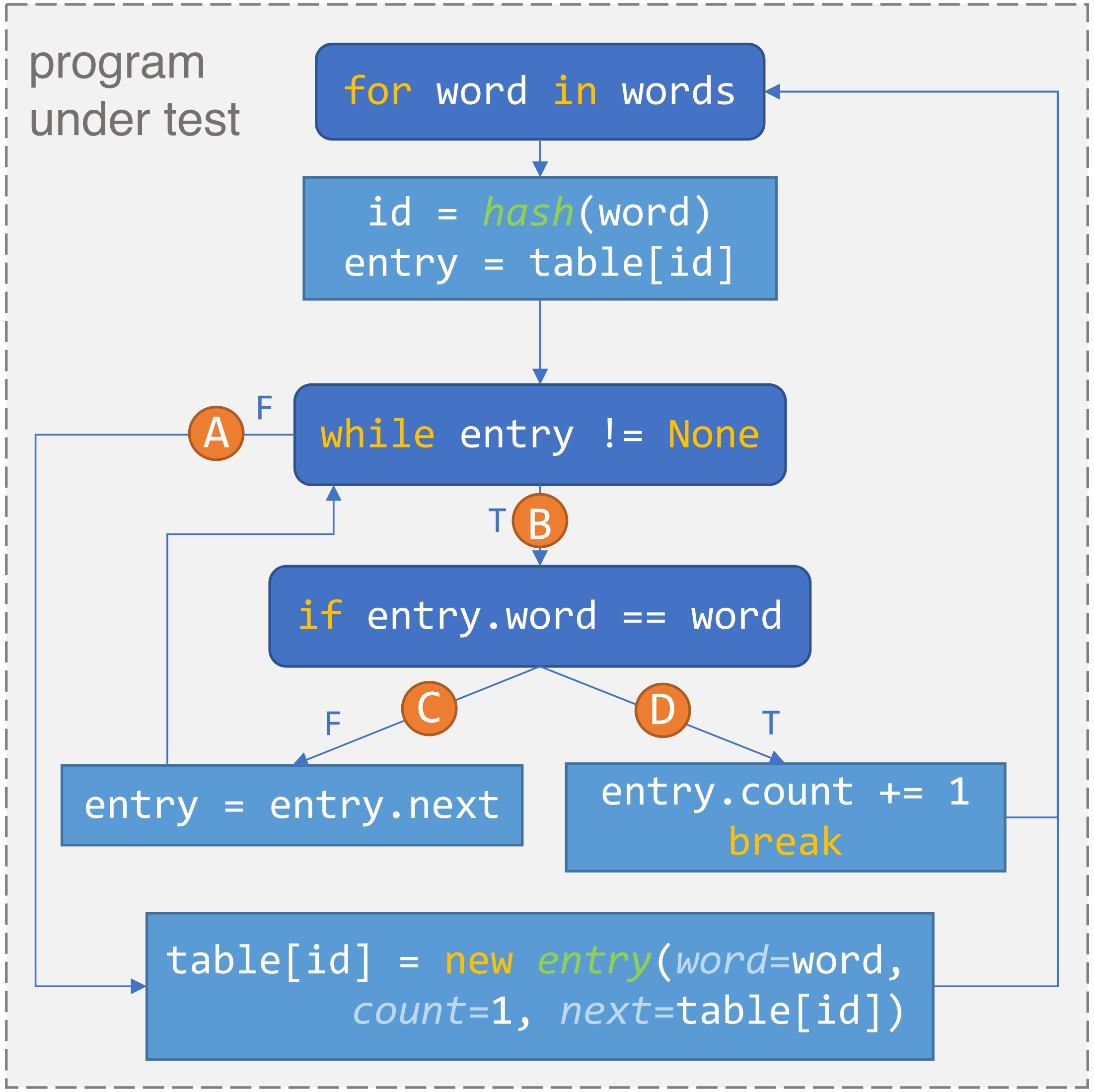
Parent to Mutate

input running, feedback analysis

seed input

Current Input
the quick brown the dog

Edge	# Hits



program under test

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PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input

mutation engine

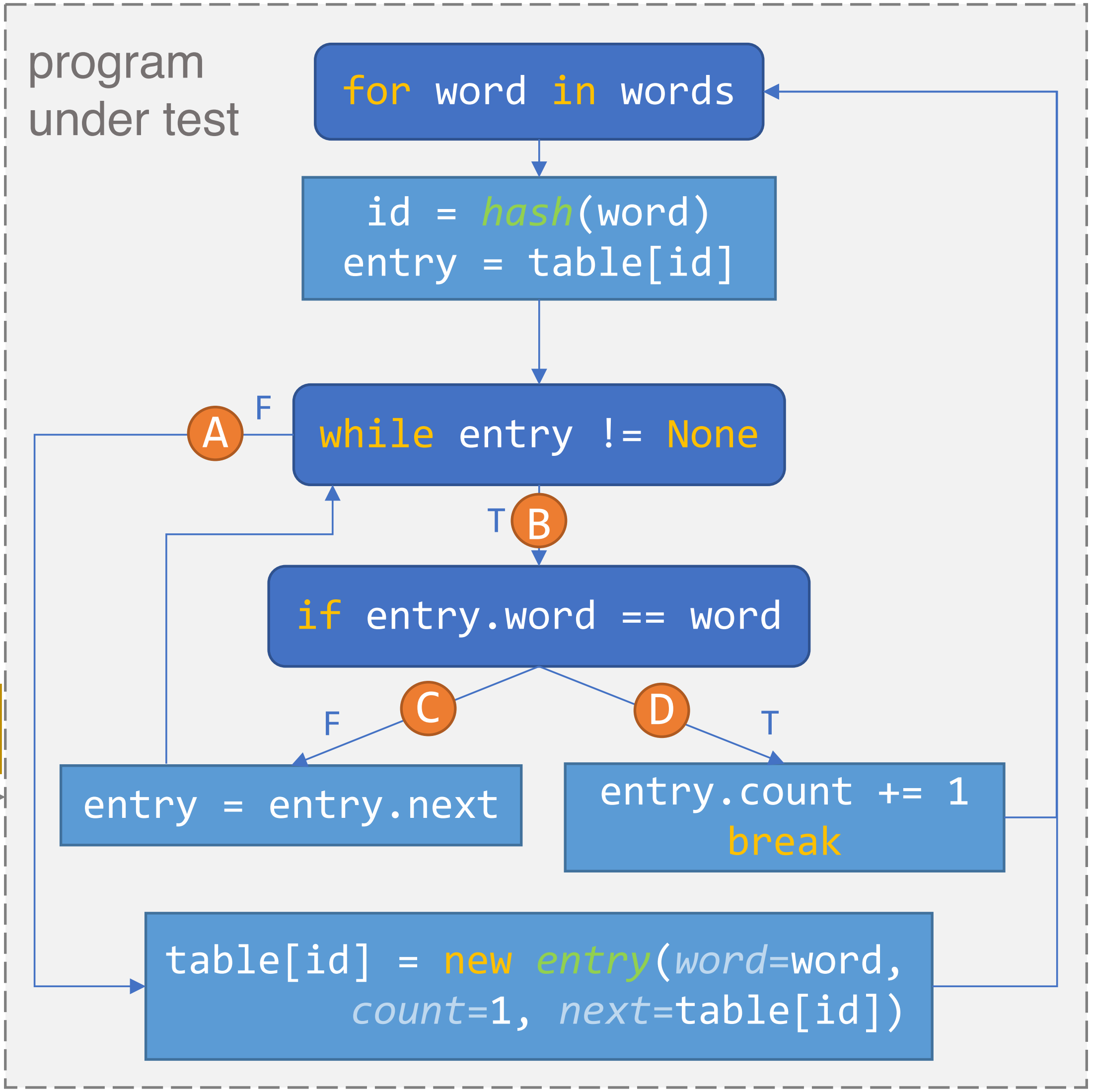
Parent to Mutate

input running, feedback analysis

Current Input
`the quick brown the dog`

Edge	# Hits

input



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PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input

mutation engine

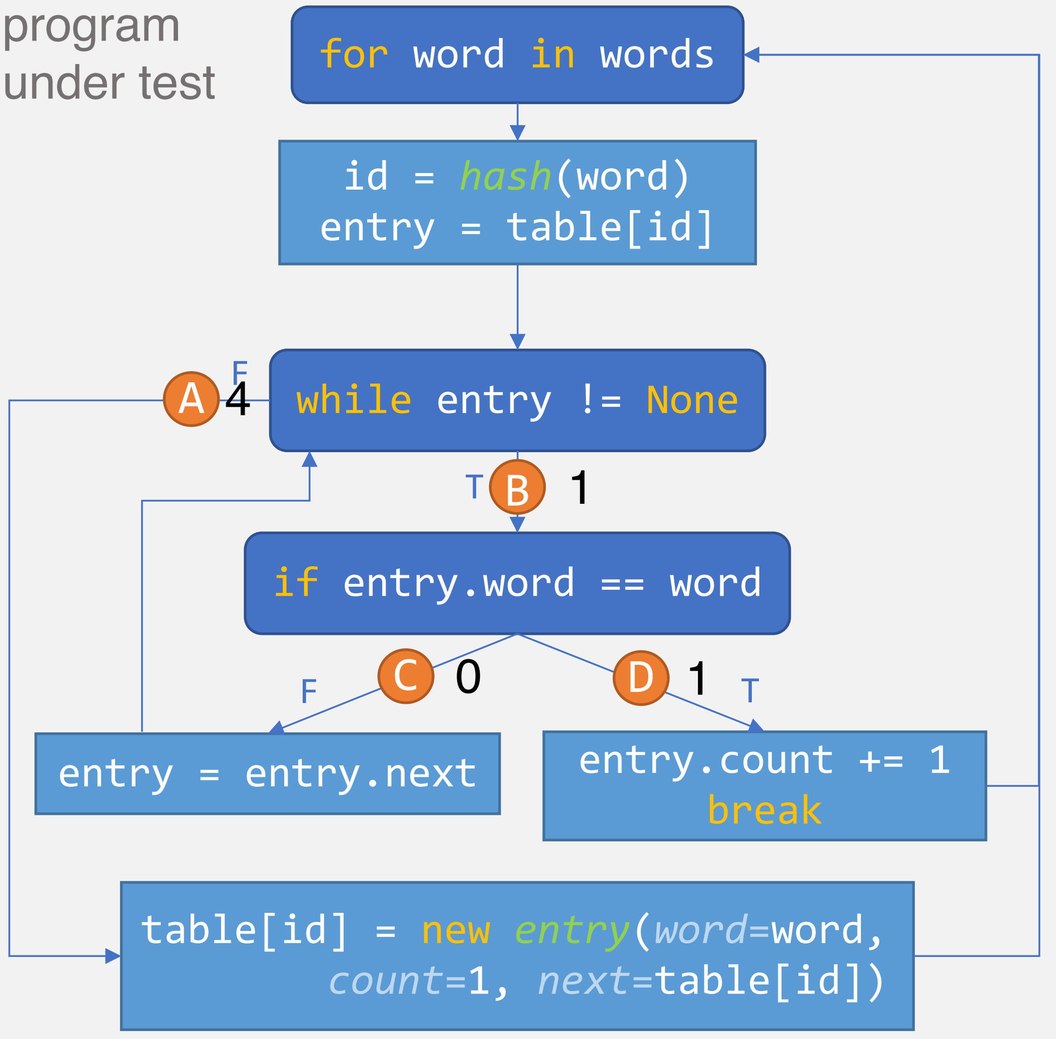
Parent to Mutate

input running, feedback analysis

Current Input
`the quick brown the dog`

Edge	# Hits

program under test



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```
table[id] = new entry(word=word,
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```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input

mutation engine

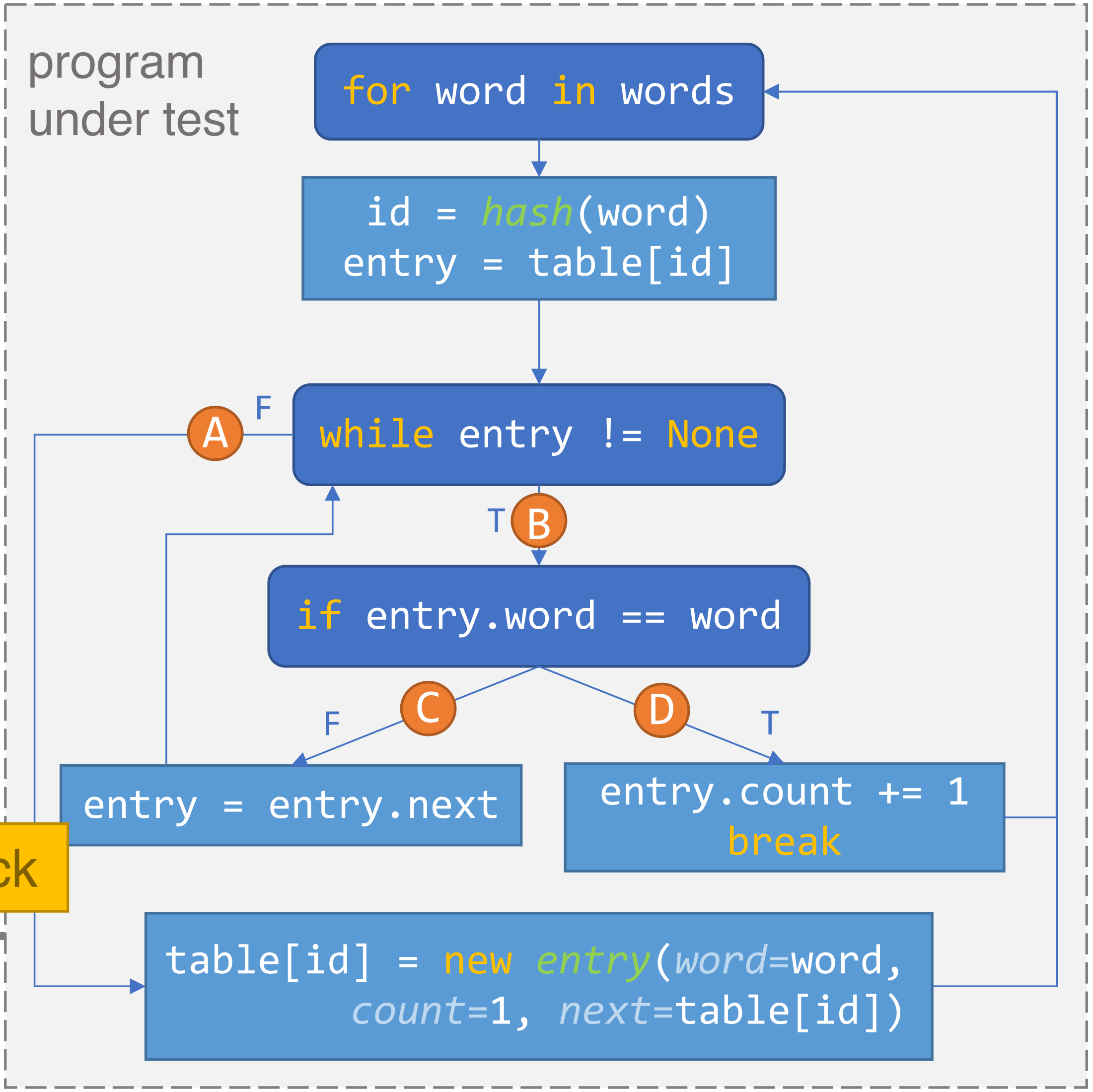
Parent to Mutate

input running, feedback analysis

Current Input
`the quick brown the dog`

Edge	# Hits
A	4
B	1
D	1

feedback



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break
table[id] = new entry(word=word,
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```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	the quick brown the dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

Parent to Mutate

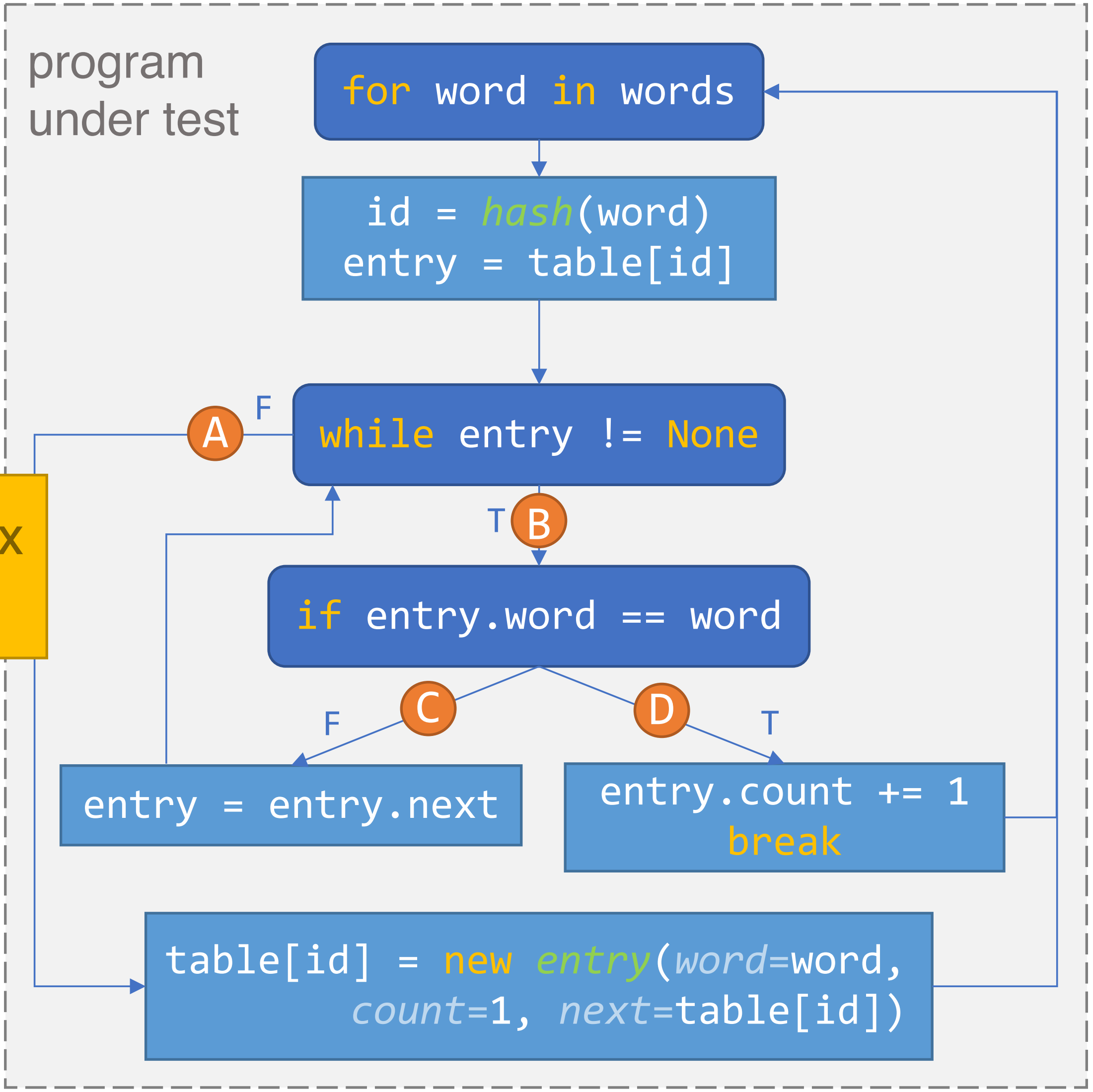
save new max for A, B, D

input running, feedback analysis

Current Input
the quick brown the dog

Edge	# Hits
A	4
B	1
D	1

program under test



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```
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```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	`the quick brown the dog`
B	1	`the quick brown the dog`
D	1	`the quick brown the dog`

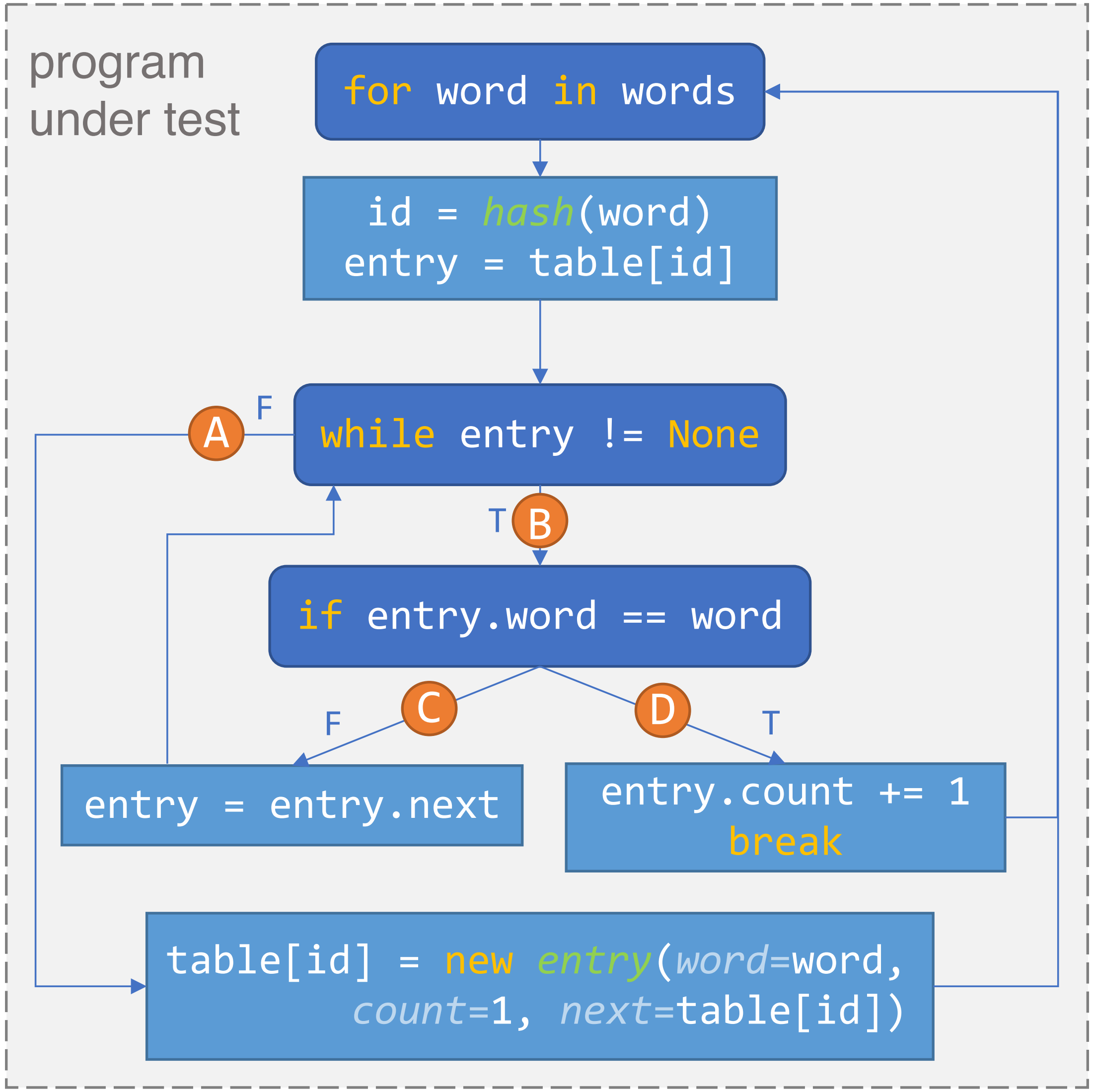
mutation engine

Parent to Mutate

input running, feedback analysis

Current Input

Edge	# Hits



program under test

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break
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```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	the quick brown the dog
B	1	the quick brown the dog
D	1	the quick brown the dog

choose parent

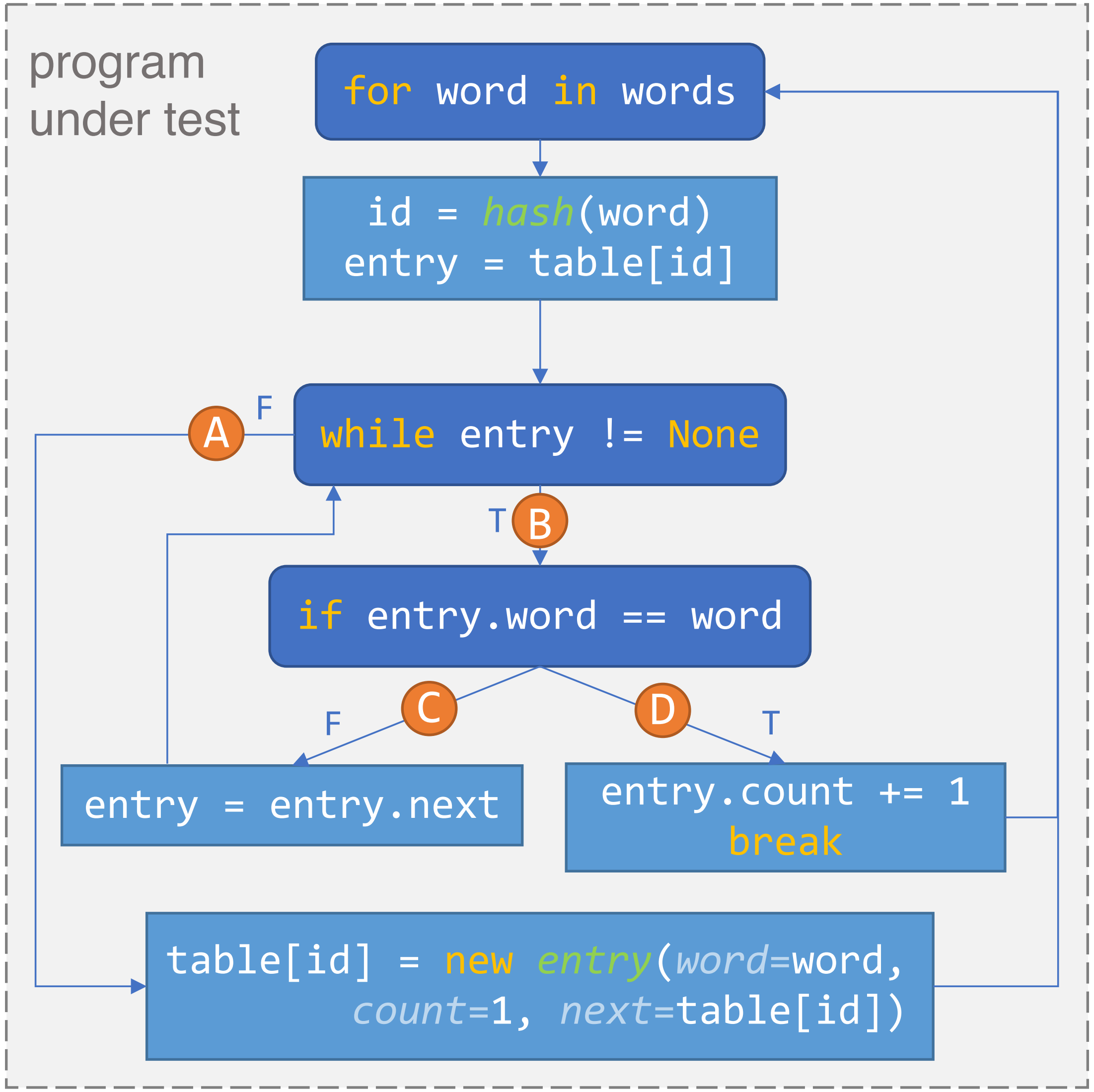
mutation engine

Parent to Mutate
the quick brown the dog

input running, feedback analysis

Current Input

Edge	# Hits



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PerfFuzz Algorithm

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Edge	Max # Hits	Maximizing Input
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mutation engine

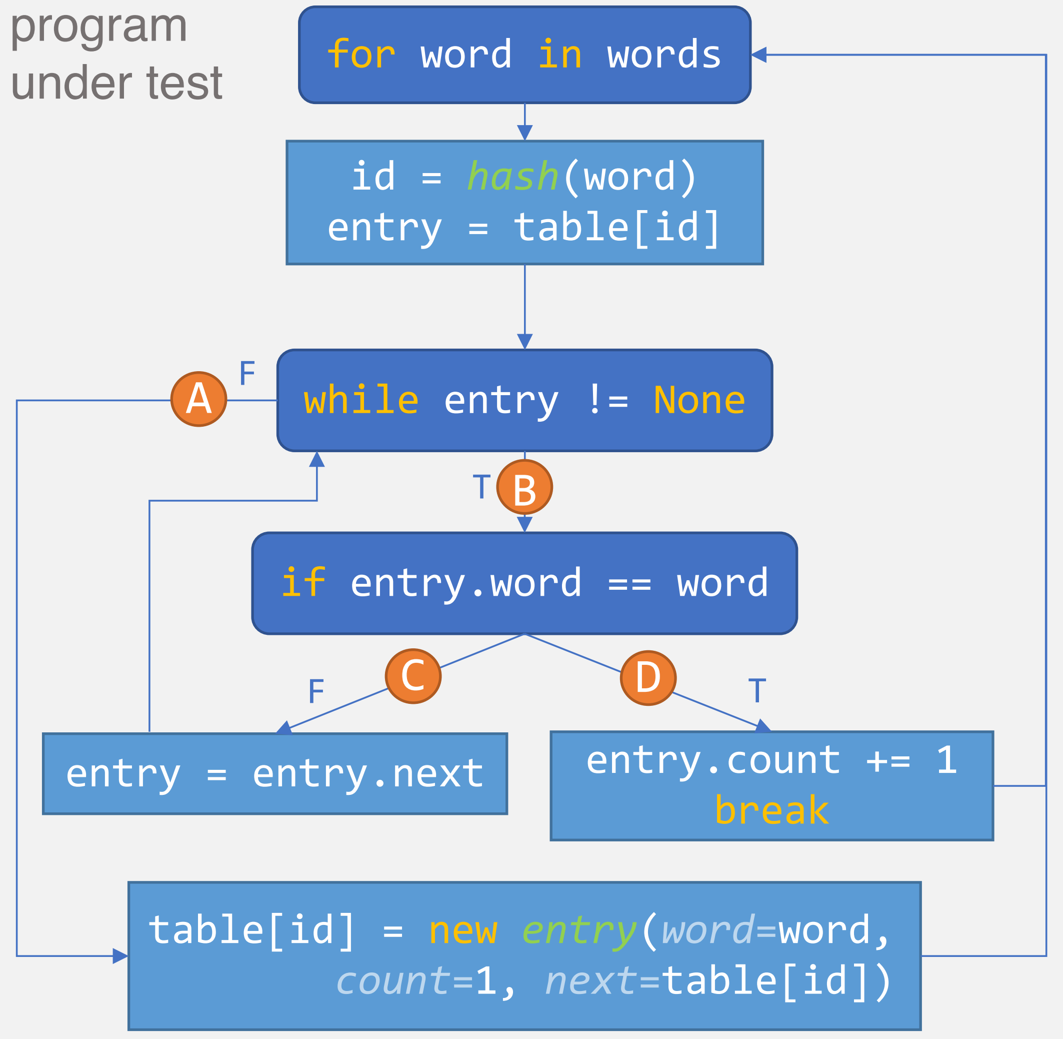
Parent to Mutate
the quick brown the dog

input running, feedback analysis

Current Input

Edge	# Hits

program under test



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PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
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B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

Parent to Mutate
the quick brown the dog

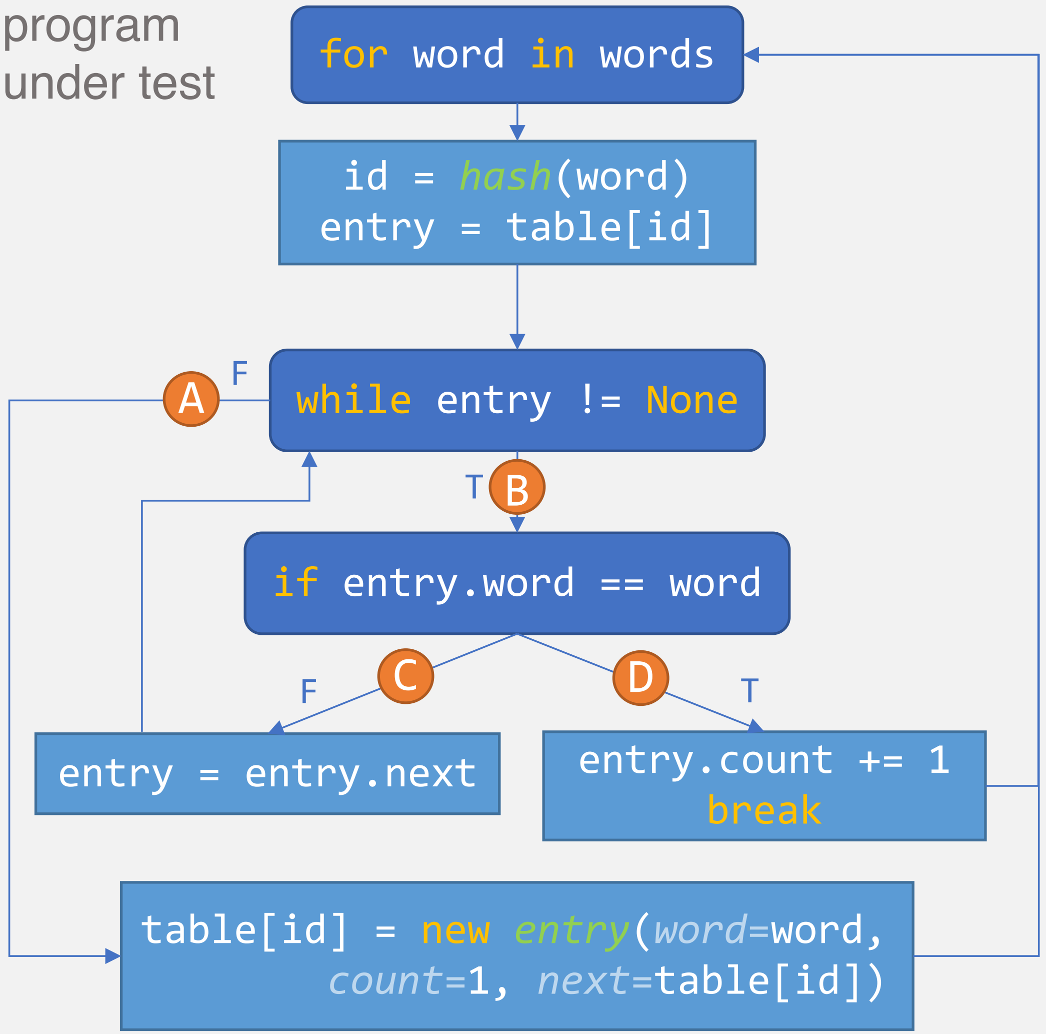
let's mutate this many times

input running, feedback analysis

Current Input

Edge	# Hits

program under test



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entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
        count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	the quick brown the dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

Parent to Mutate
the quick brown the dog

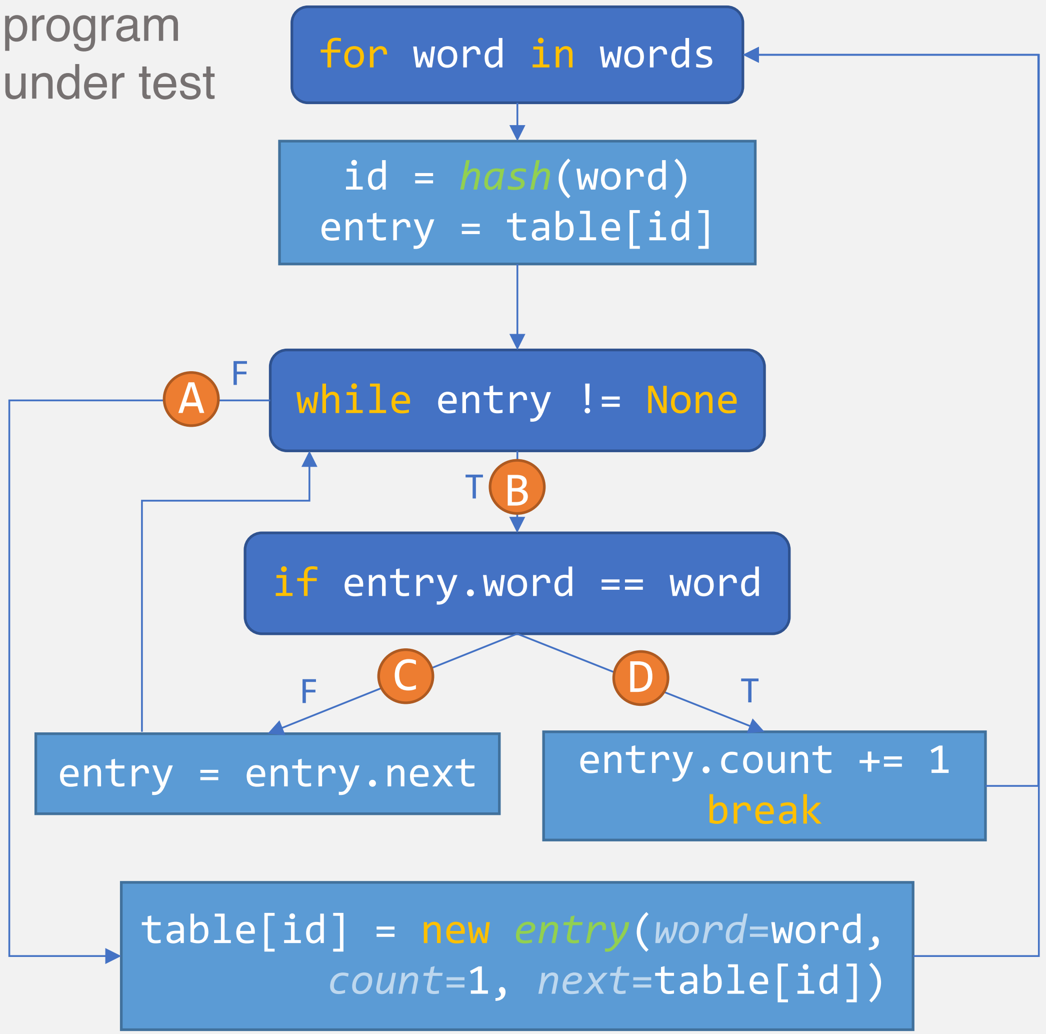
input running, feedback analysis

new mutant

Current Input
the quack brown the dog

Edge	# Hits

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
    count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	the quick brown the dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

Parent to Mutate
the quick brown the dog

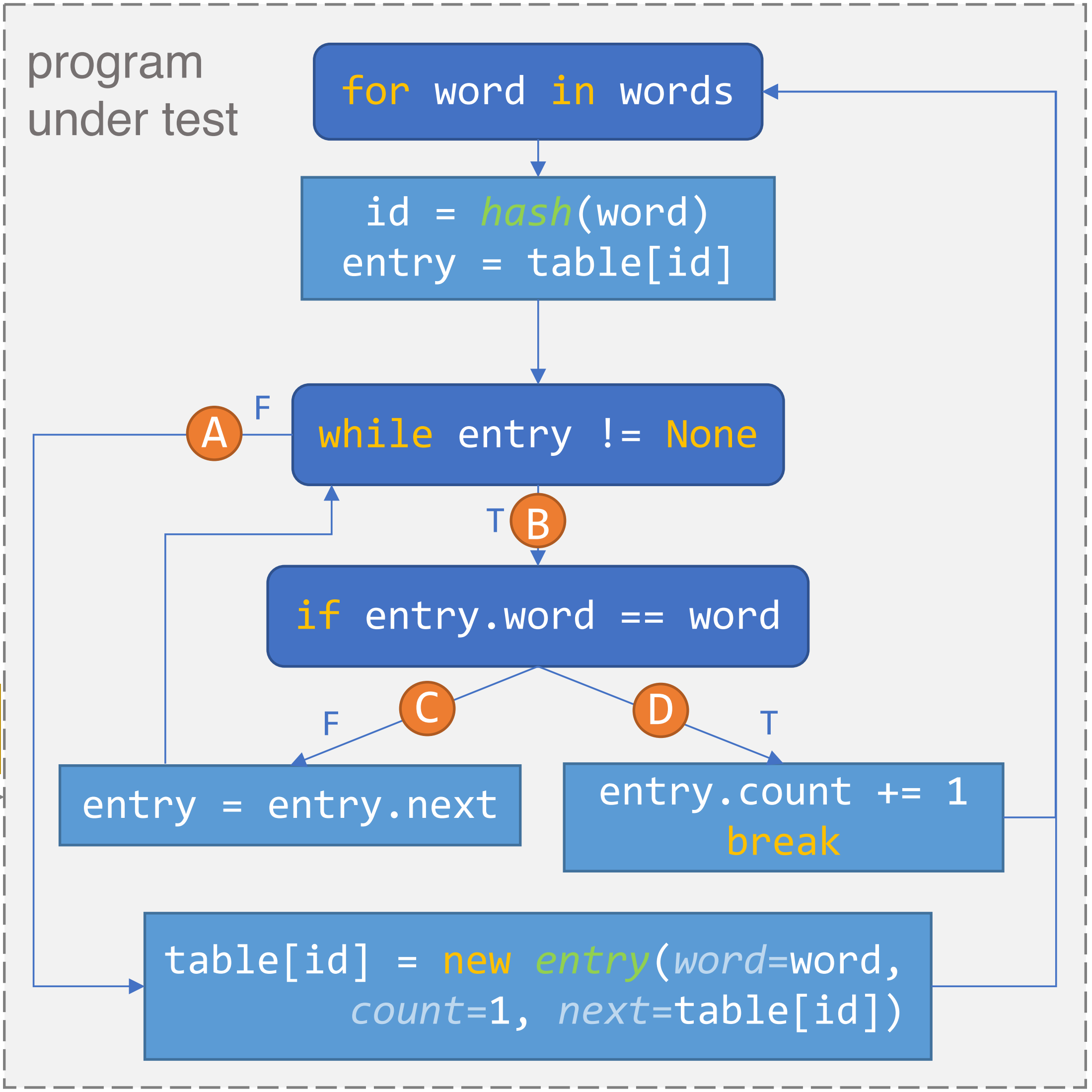
input running, feedback analysis

Current Input
the quack brown the dog

Edge	# Hits

input

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
    count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	the quick brown the dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

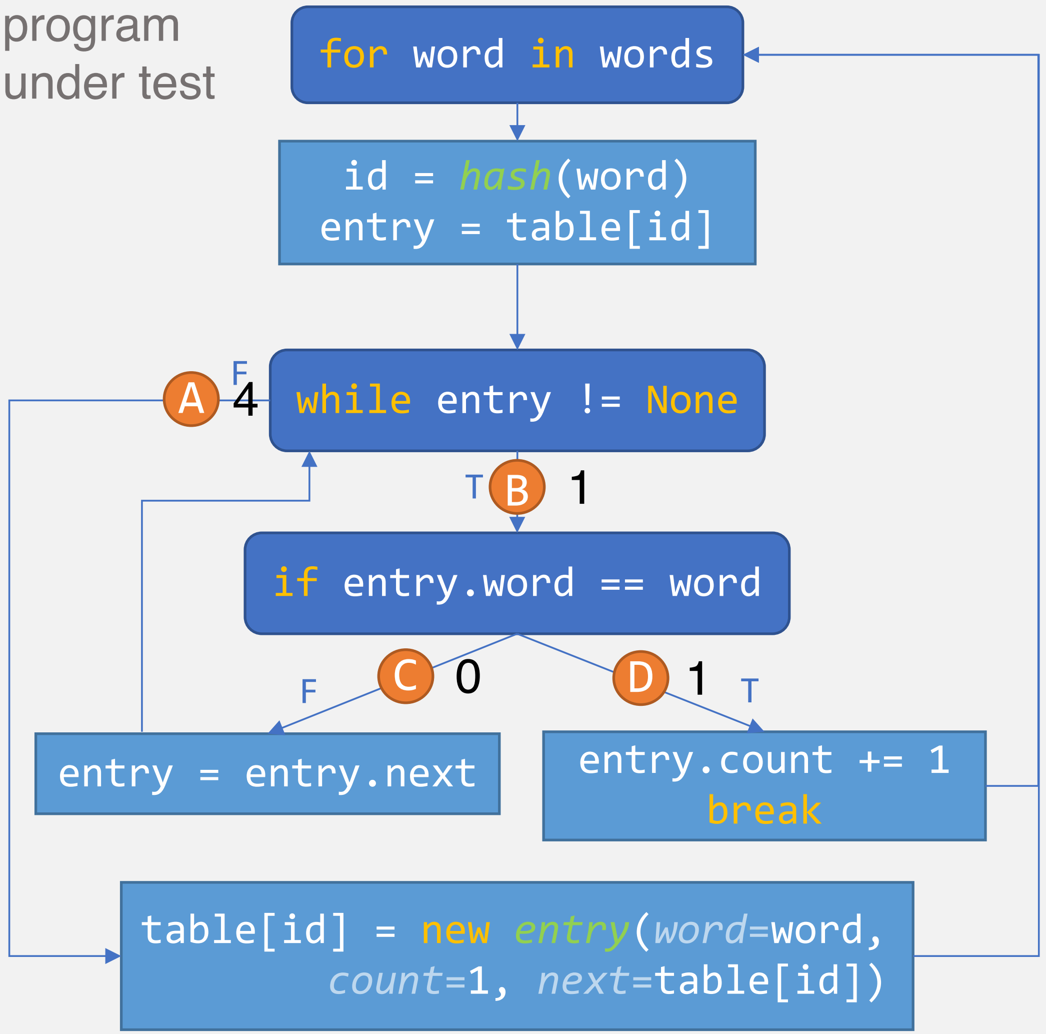
Parent to Mutate
the quick brown the dog

input running, feedback analysis

Current Input
the quack brown the dog

Edge	# Hits

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
    count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	the quick brown the dog
B	1	the quick brown the dog
D	1	the quick brown the dog

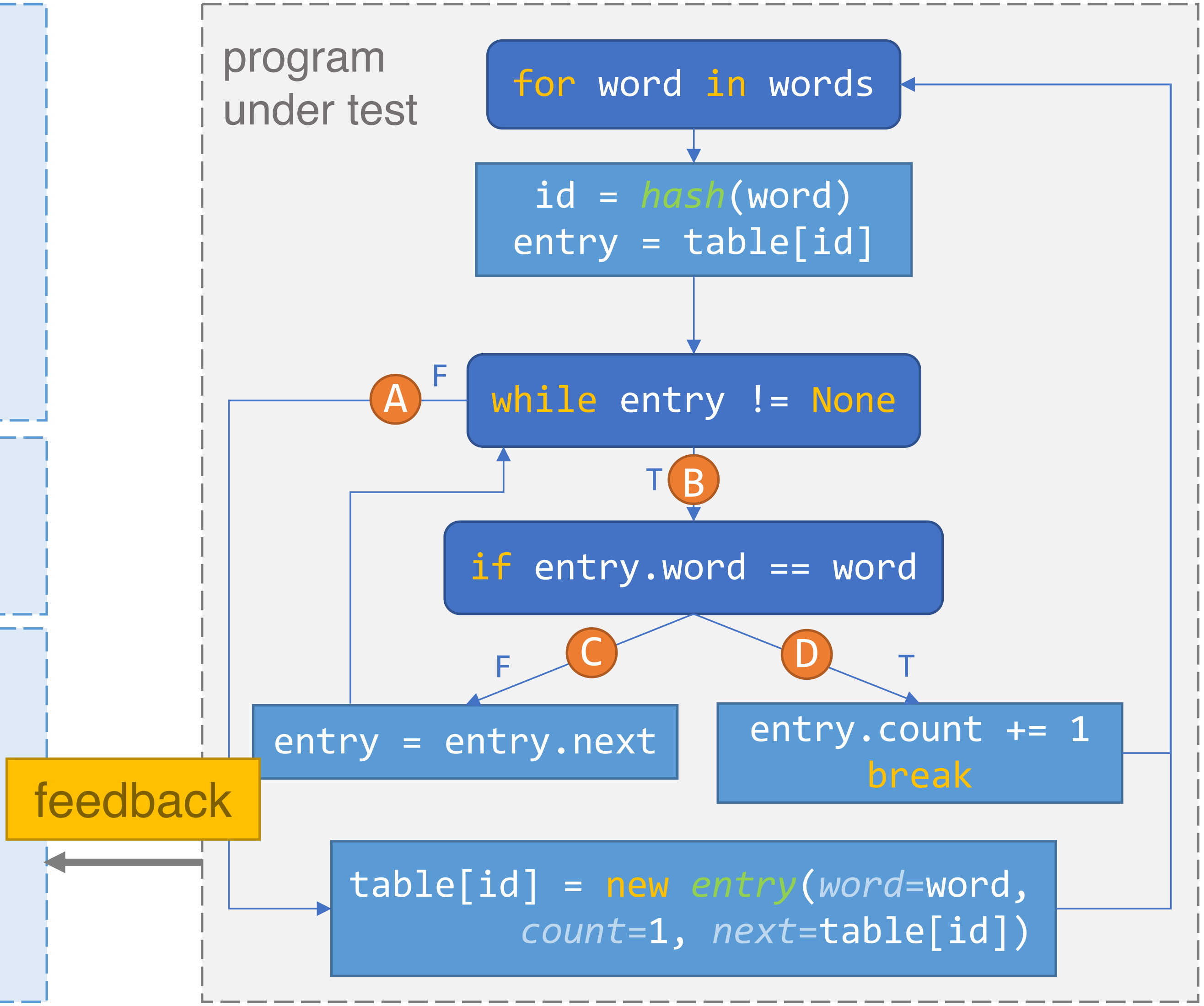
mutation engine

Parent to Mutate
the quick brown the dog

input running, feedback analysis

Current Input
the quack brown the dog

Edge	# Hits
A	4
B	1
D	1



program under test

```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
    count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	the quick brown the dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

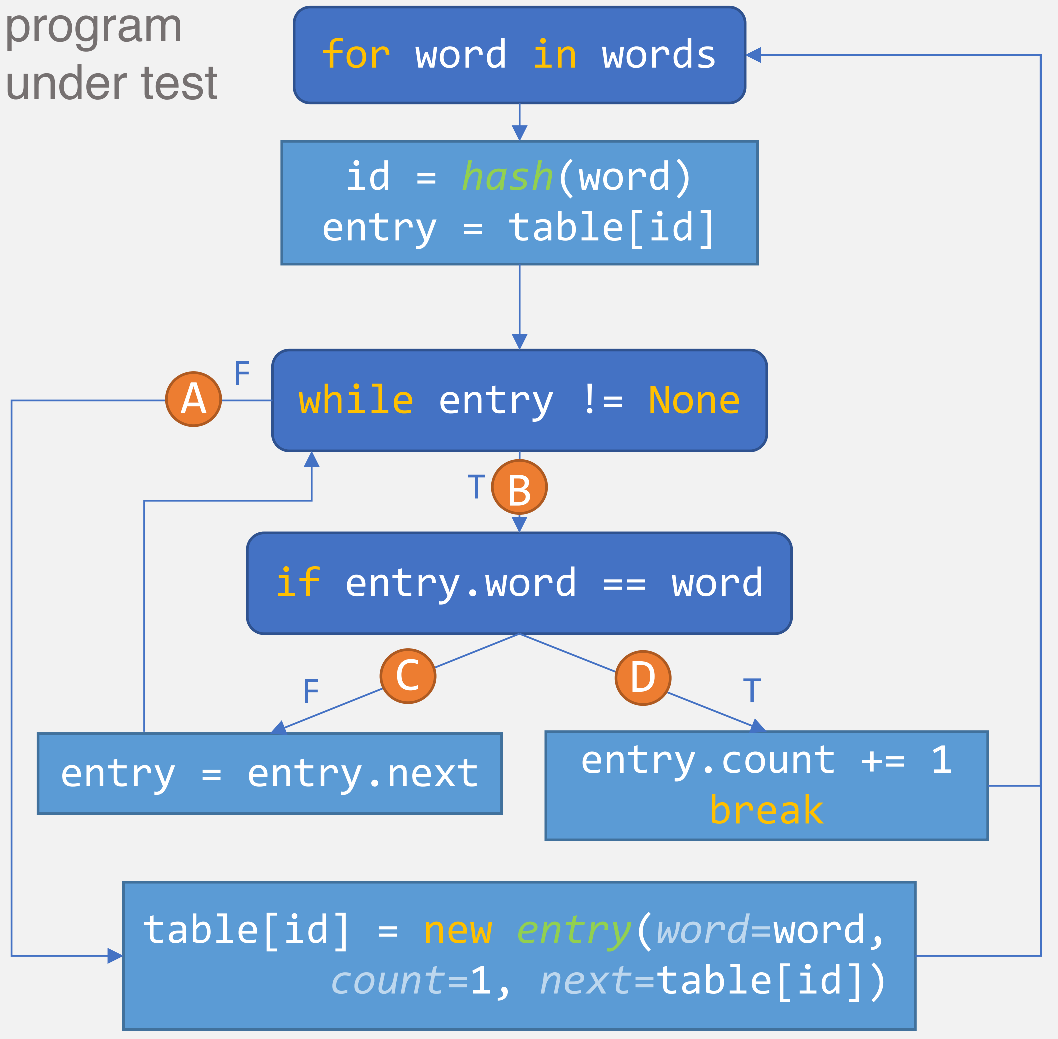
Parent to Mutate
the quick brown the dog

input running, feedback analysis

Current Input
the quack brown the dog

Edge	# Hits
A	4
B	1
D	1

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
                      count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	the quick brown the dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

Parent to Mutate
the quick brown the dog

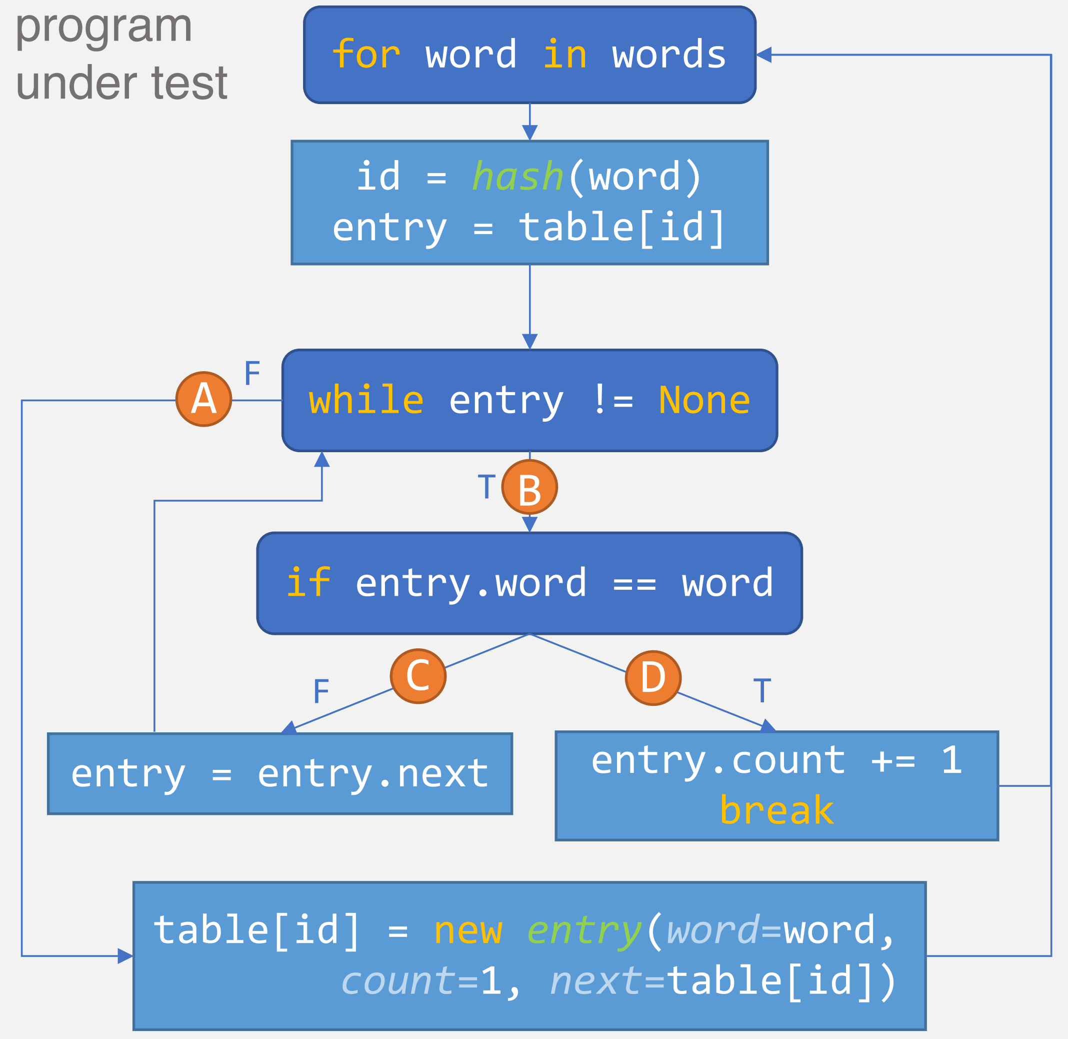
input running, feedback analysis

Current Input
the quack brown the dog

Edge	# Hits
A	4
B	1
D	1

no new max

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
        count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	the quick brown the dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

Parent to Mutate
the quick brown the dog

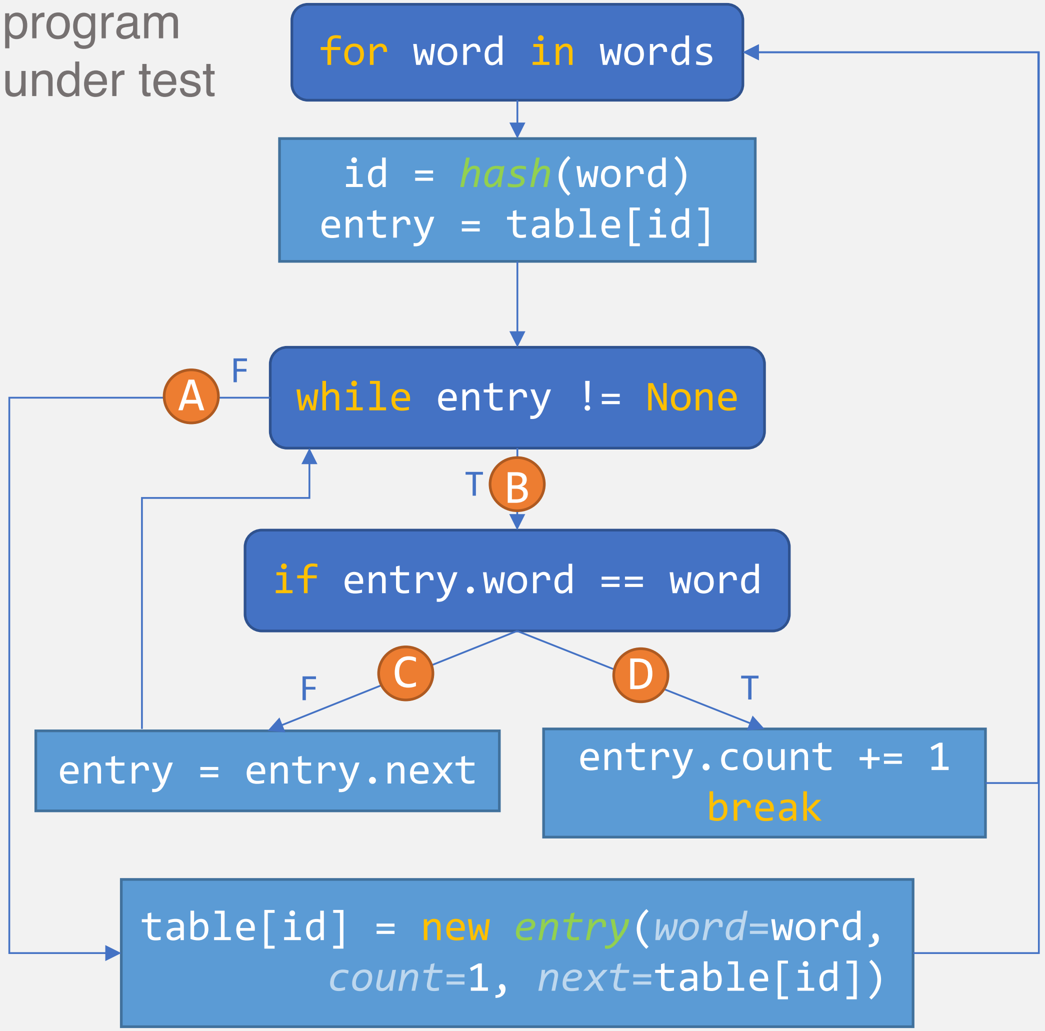
input running, feedback analysis

new mutant

Current Input
the quick brown t▮e dog

Edge	# Hits

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
                      count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	the quick brown the dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

Parent to Mutate
the quick brown the dog

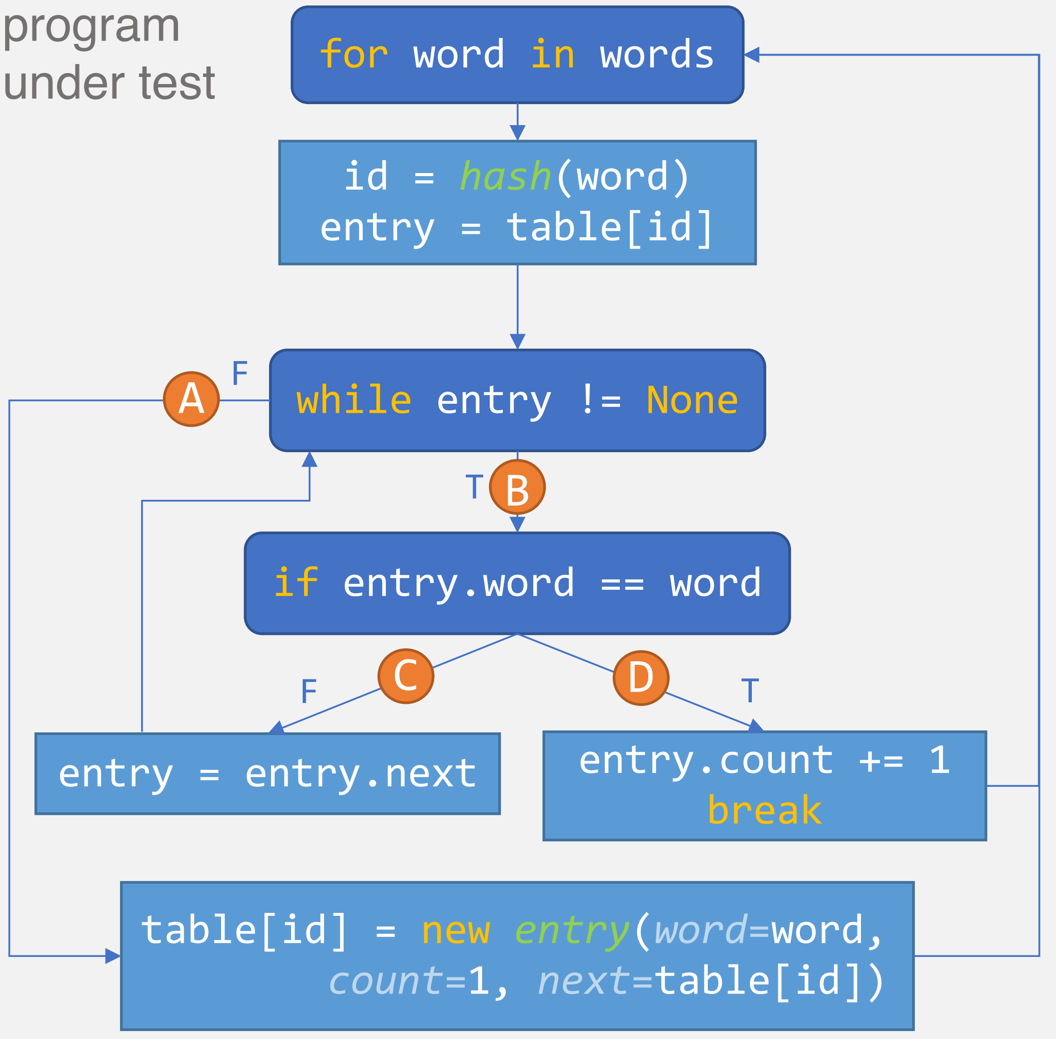
input running, feedback analysis

Current Input
the quick brown t▮e dog

Edge	# Hits

input

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
    count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	the quick brown the dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

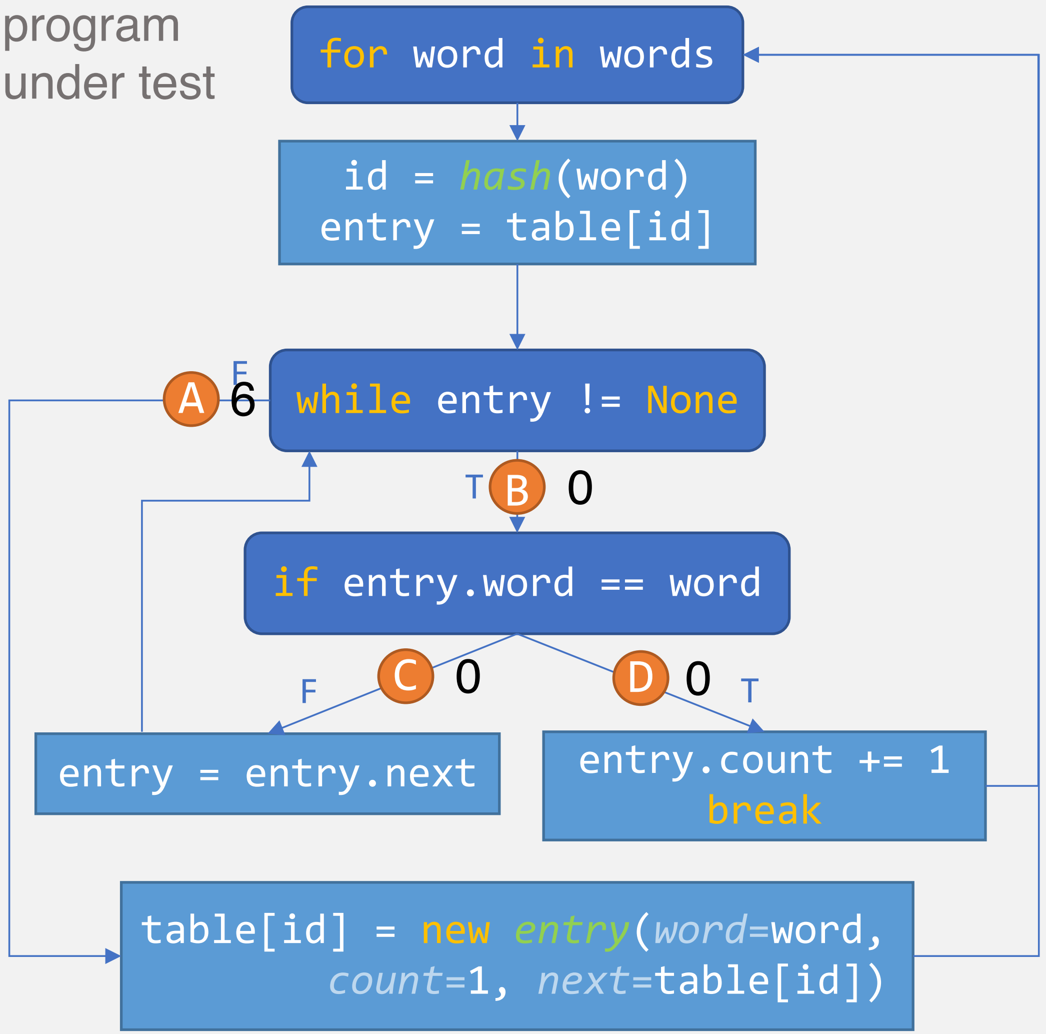
Parent to Mutate
the quick brown the dog

input running, feedback analysis

Current Input
the quick brown t▮e dog

Edge	# Hits

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
                      count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	4	`the quick brown the dog`
B	1	`the quick brown the dog`
D	1	`the quick brown the dog`

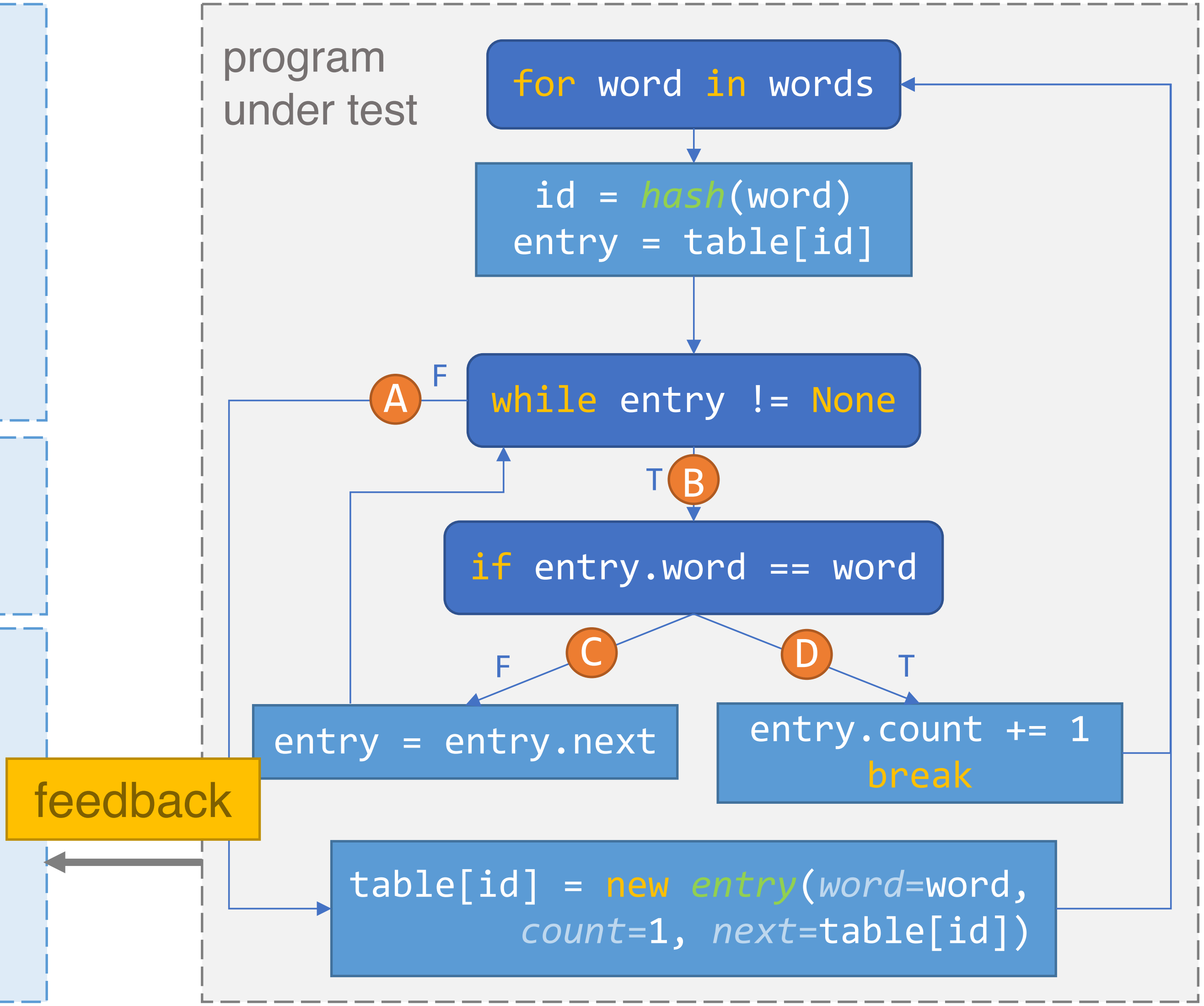
mutation engine

Parent to Mutate
`the quick brown the dog`

input running, feedback analysis

Current Input
`the quick brown t█e dog`

Edge	# Hits
A	6



program under test

```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
                      count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	6	the quick brown t█e dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

Parent to Mutate
the quick brown the dog

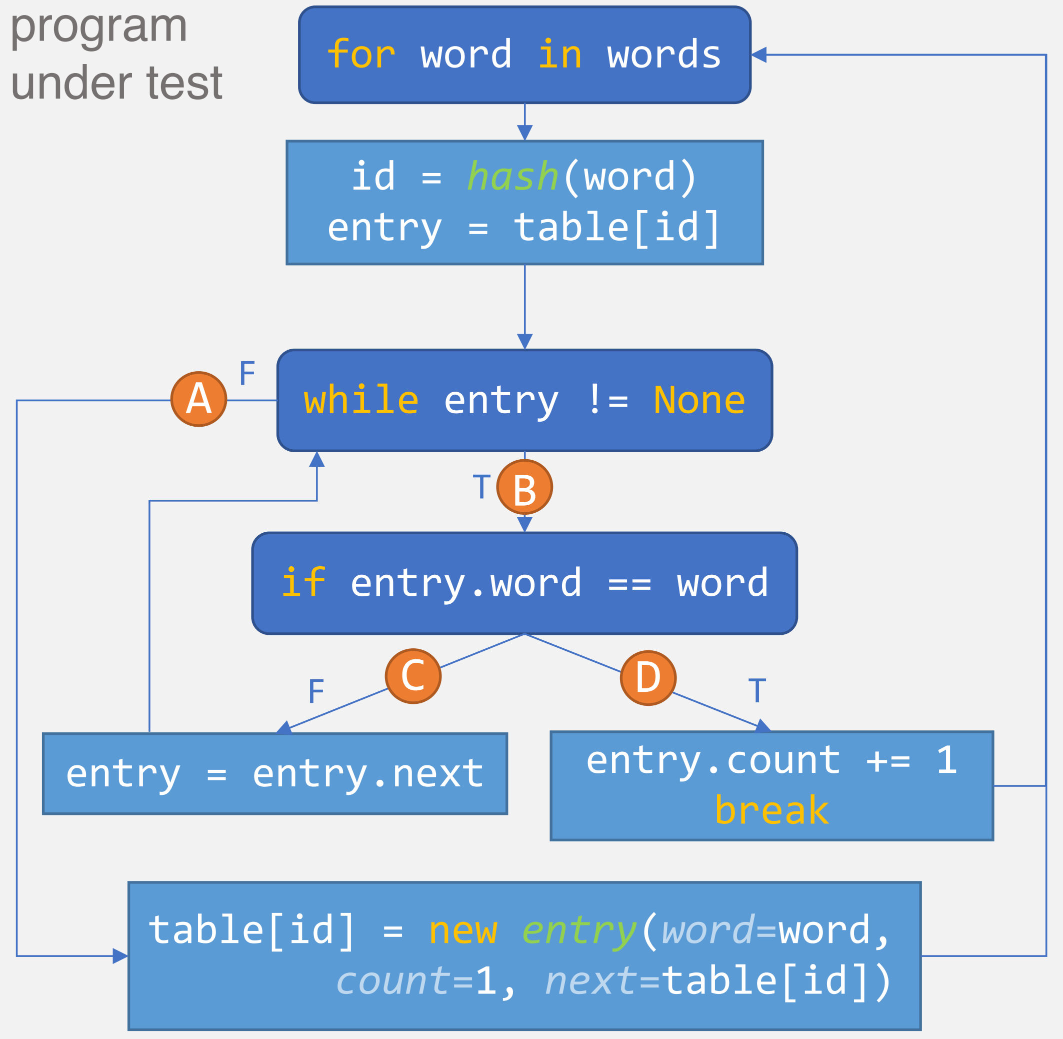
save new max for A

input running, feedback analysis

Current Input
the quick brown t█e dog

Edge	# Hits
A	6

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
    count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	6	the quick brown t█e dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

Parent to Mutate
the quick brown the dog

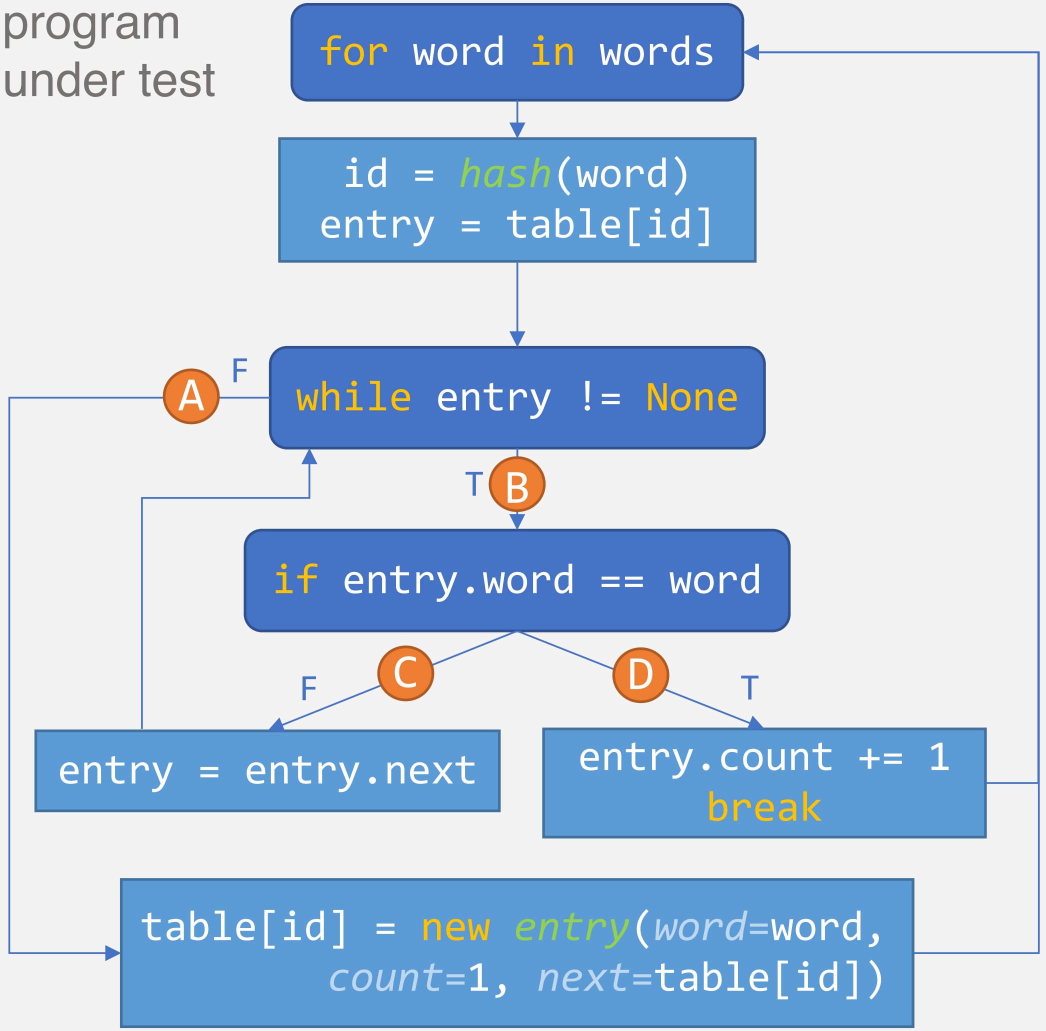
input running, feedback analysis

new mutant

Current Input
the quick_brown the dog

Edge	# Hits

program under test



```
for word in words
```

```
id = hash(word)
entry = table[id]
```

```
while entry != None
```

```
if entry.word == word
```

```
entry = entry.next
```

```
entry.count += 1
break
```

```
table[id] = new entry(word=word,
            count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	6	the quick brown t▮e dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

Parent to Mutate
the quick brown the dog

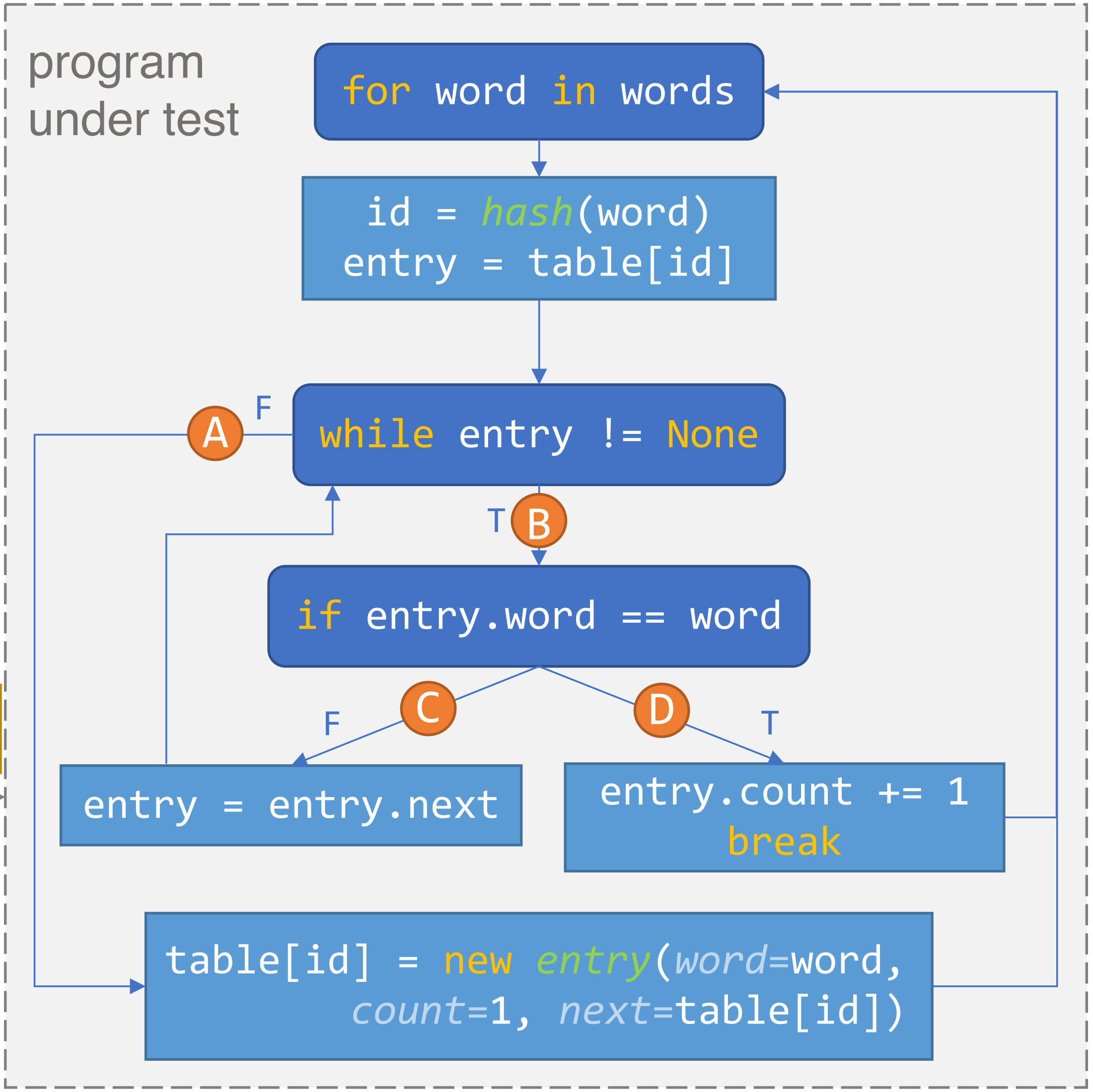
input running, feedback analysis

Current Input
the quick_brown the dog

Edge	# Hits

input

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
                      count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	6	`the quick brown t▮e dog`
B	1	`the quick brown the dog`
D	1	`the quick brown the dog`

mutation engine

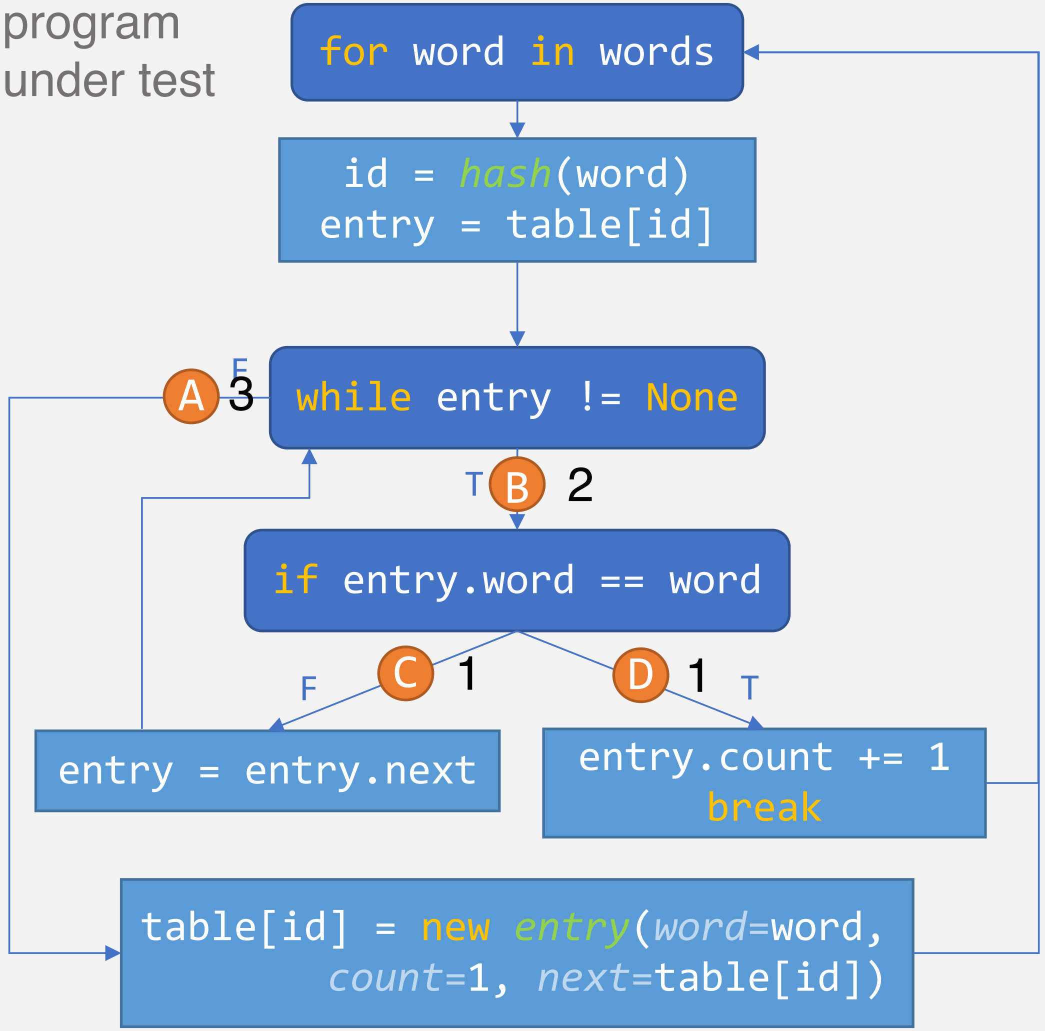
Parent to Mutate
`the quick brown the dog`

input running, feedback analysis

Current Input
`the quick_brown the dog`

Edge	# Hits

program under test



PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	6	the quick brown t▮e dog
B	1	the quick brown the dog
D	1	the quick brown the dog

mutation engine

Parent to Mutate
the quick brown the dog

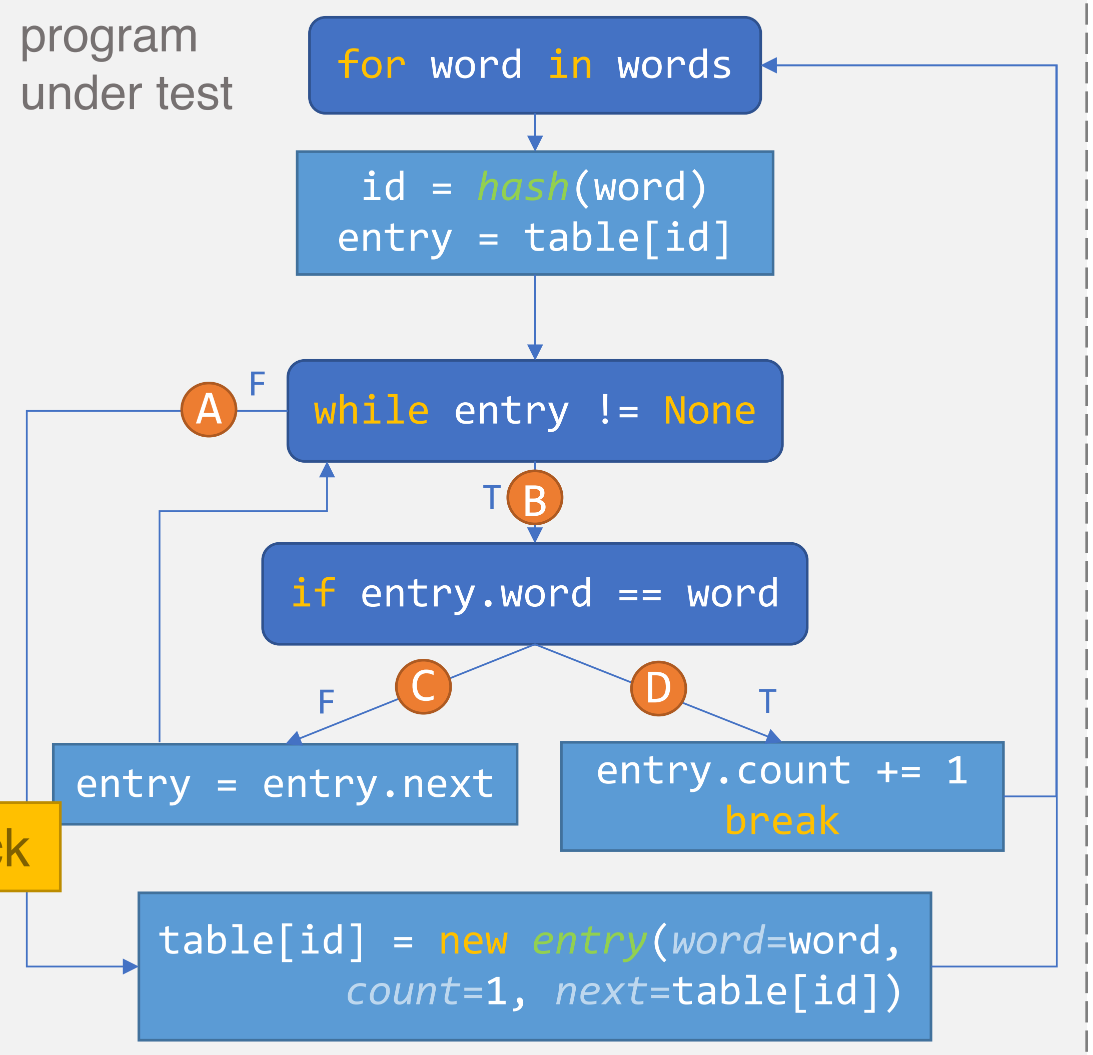
input running, feedback analysis

Current Input
the quick_brown the dog

Edge	# Hits
A	3
B	2
C	1
D	1

feedback

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
        count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	6	`the quick brown t▮e dog`
B	1	`the quick brown the dog`
D	1	`the quick brown the dog`

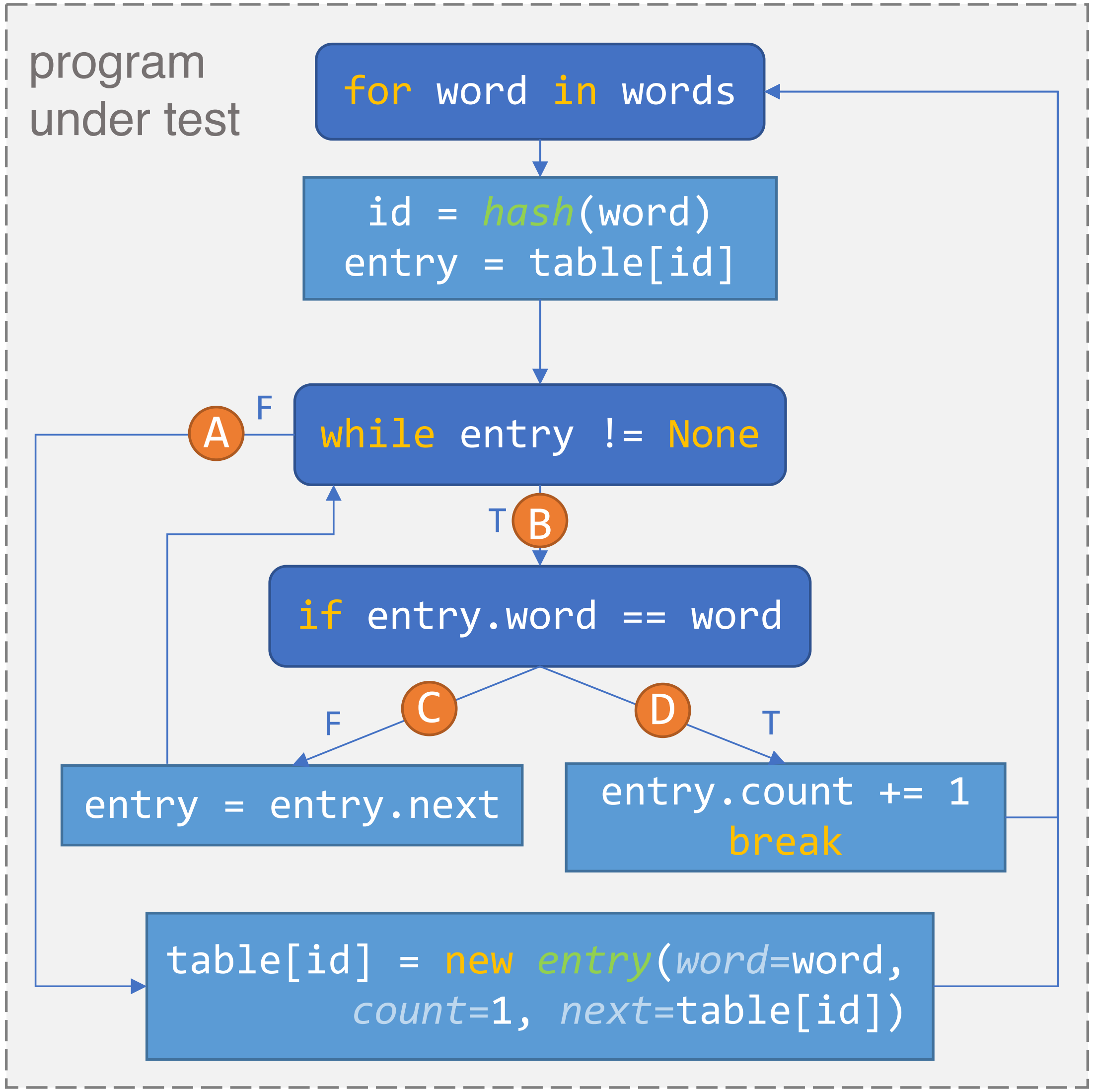
mutation engine

Parent to Mutate
`the quick brown the dog`

input running, feedback analysis

Current Input
`the quick_brown the dog`

Edge	# Hits
A	3
B	2
C	1
D	1



PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	6	the quick brown t█e dog
B	2	the quick_brown the dog
C	1	the quick_brown the dog
D	1	the quick brown the dog

mutation engine

Parent to Mutate
the quick brown the dog

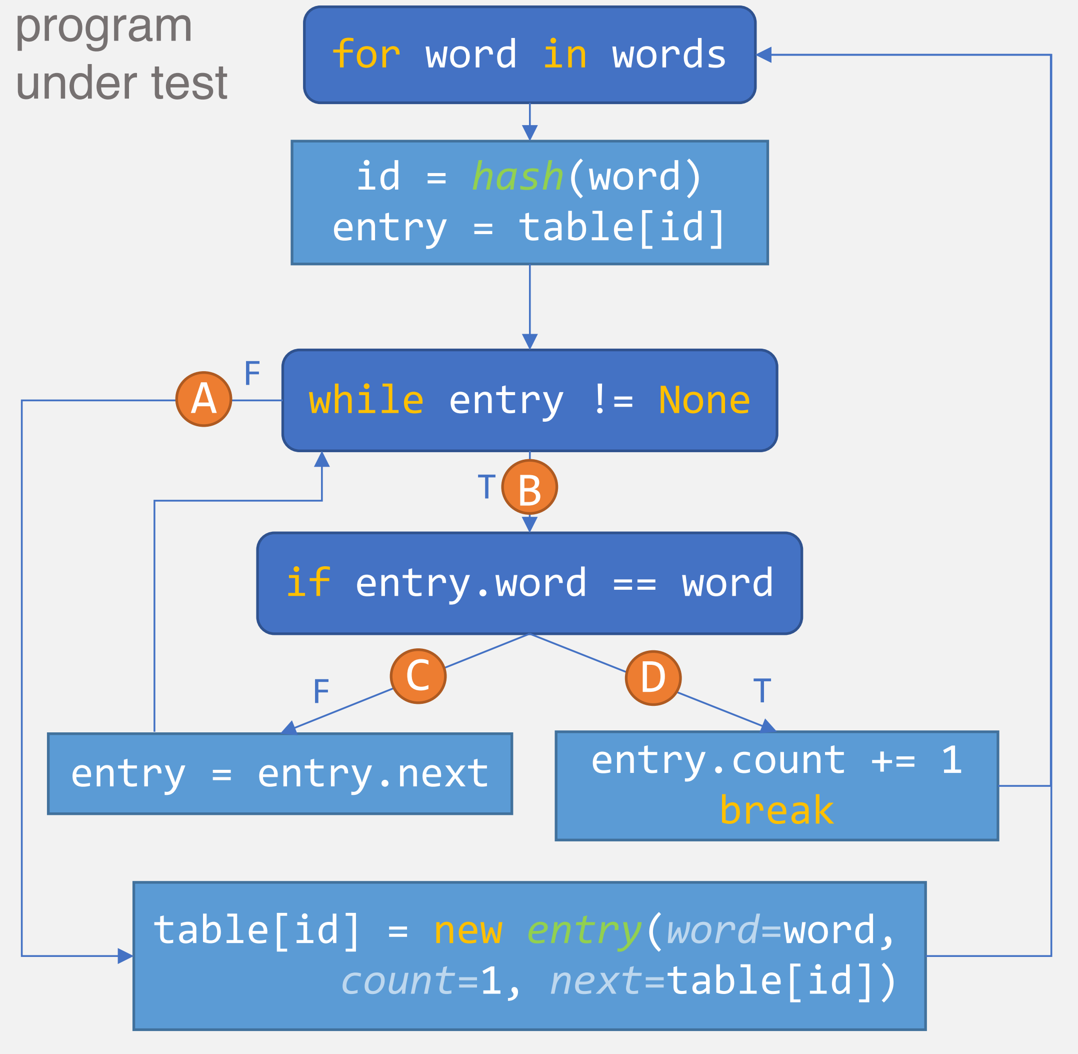
save new max for B,C

input running, feedback analysis

Current Input
the quick_brown the dog

Edge	# Hits
A	3
B	2
C	1
D	1

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
                      count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	6	the quick brown t▮e dog
B	2	the quick_brown the dog
C	1	the quick_brown the dog
D	1	the quick brown the dog

mutation engine

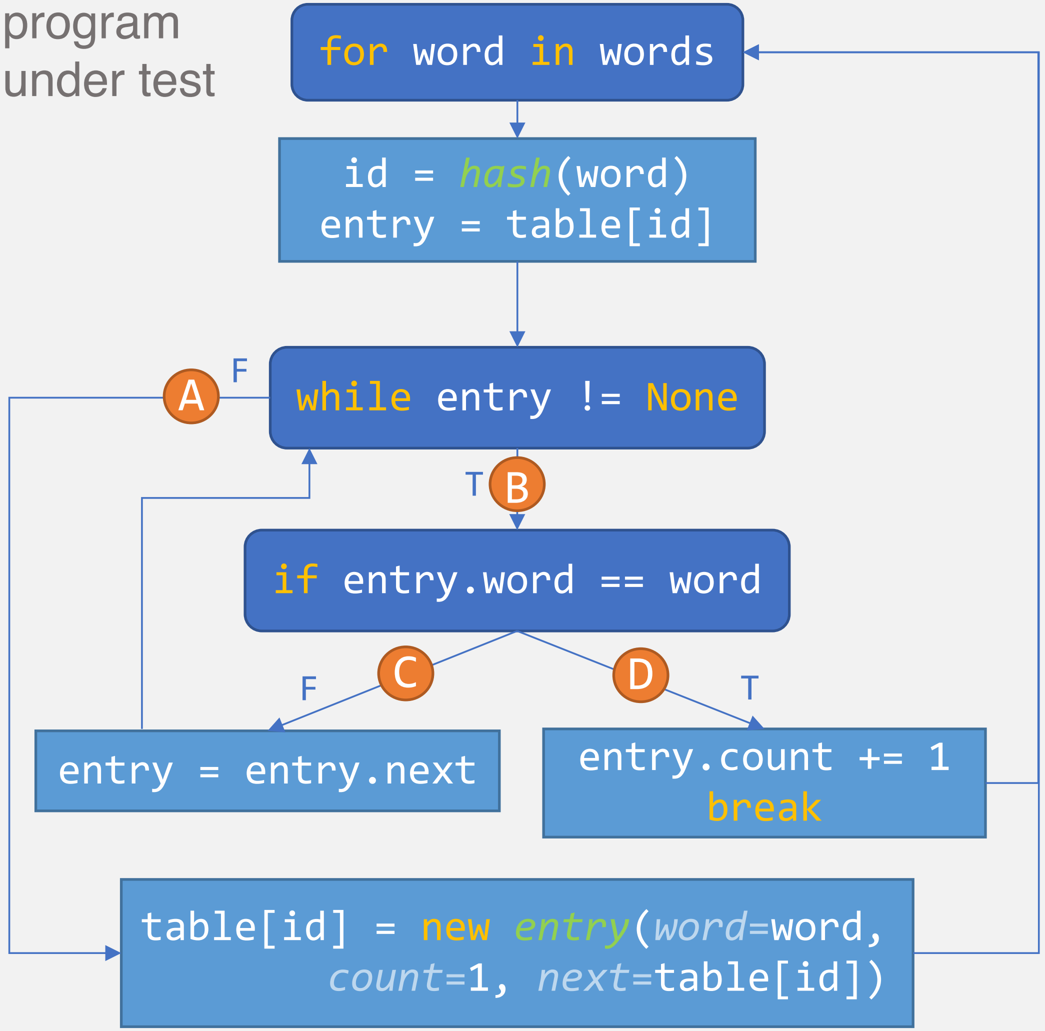
Parent to Mutate
the quick brown the dog

input running, feedback analysis

Current Input

Edge	# Hits

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
    count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	6	`the quick brown t█e dog`
B	2	`the quick_brown the dog`
C	1	`the quick_brown the dog`
D	1	`the quick brown the dog`

choose parent

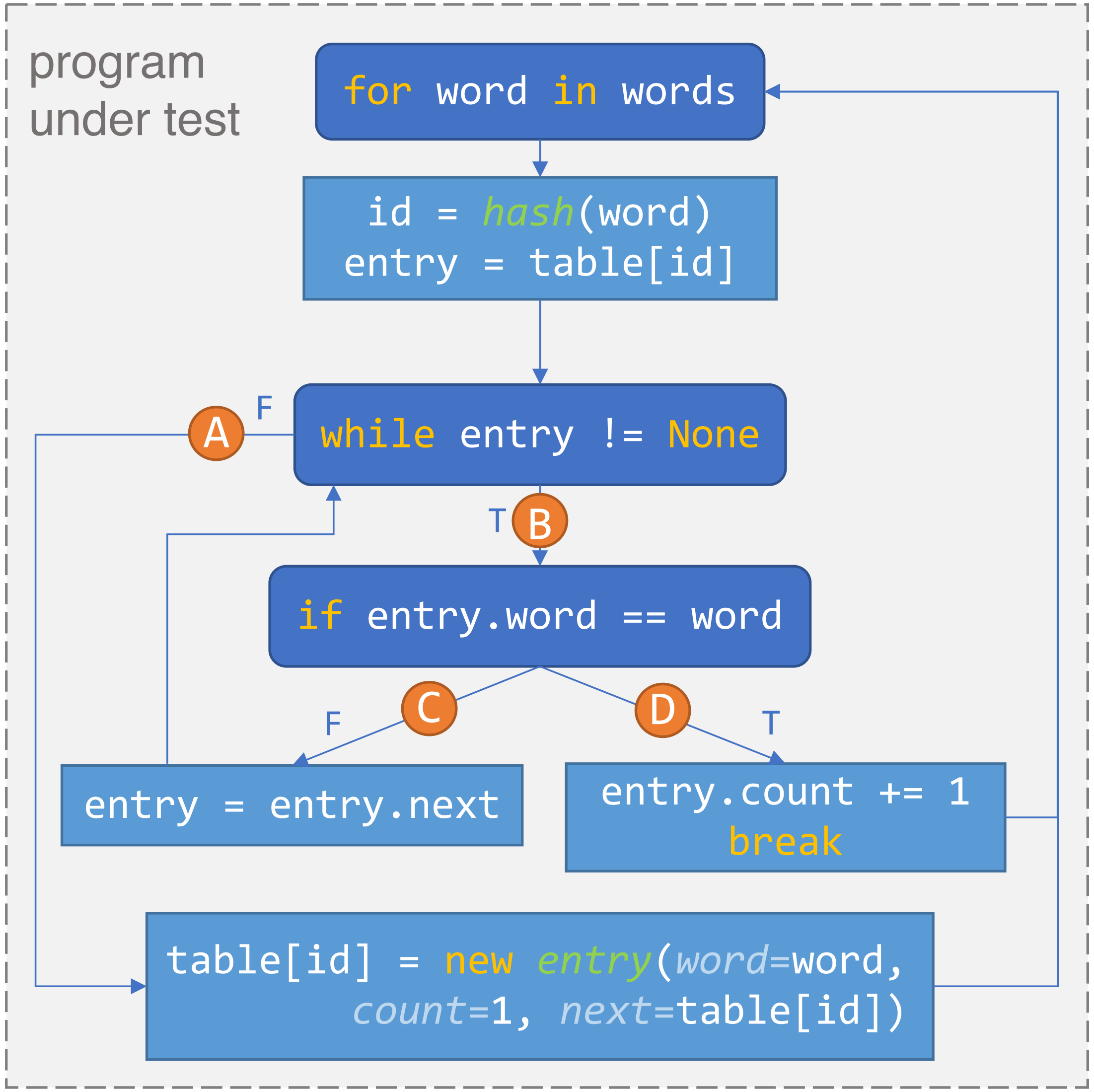
mutation engine

Parent to Mutate
`the quick brown t█e dog`

input running, feedback analysis

Current Input

Edge	# Hits



program under test

```
for word in words
```

```
id = hash(word)
entry = table[id]
```

```
while entry != None
```

```
if entry.word == word
```

```
entry = entry.next
```

```
entry.count += 1
break
```

```
table[id] = new entry(word=word,
                count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	6	the quick brown t█e dog
B	2	the quick_brown the dog
C	1	the quick_brown the dog
D	1	the quick brown the dog

mutation engine

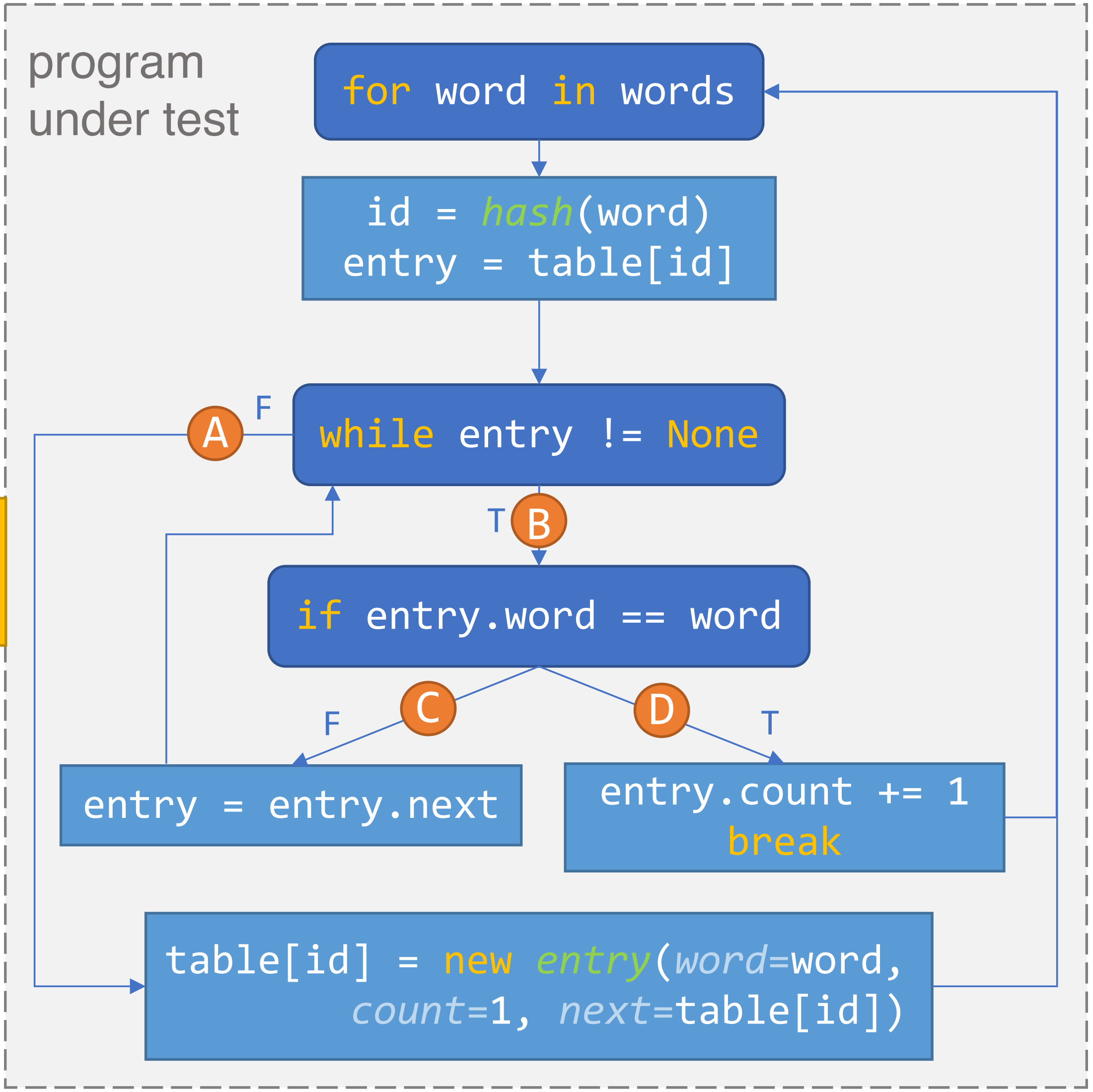
Parent to Mutate
the quick brown t█e dog

let's mutate this many times

input running, feedback analysis

Current Input

Edge	# Hits



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
      count=1, next=table[id])
```

PerfFuzz Algorithm

input corpus

Edge	Max # Hits	Maximizing Input
A	6	`the quick brown t e dog`
B	2	`the quick_brown the dog`
C	1	`the quick_brown the dog`
D	1	`the quick brown the dog`

mutation engine

Parent to Mutat
`the quick brown t`

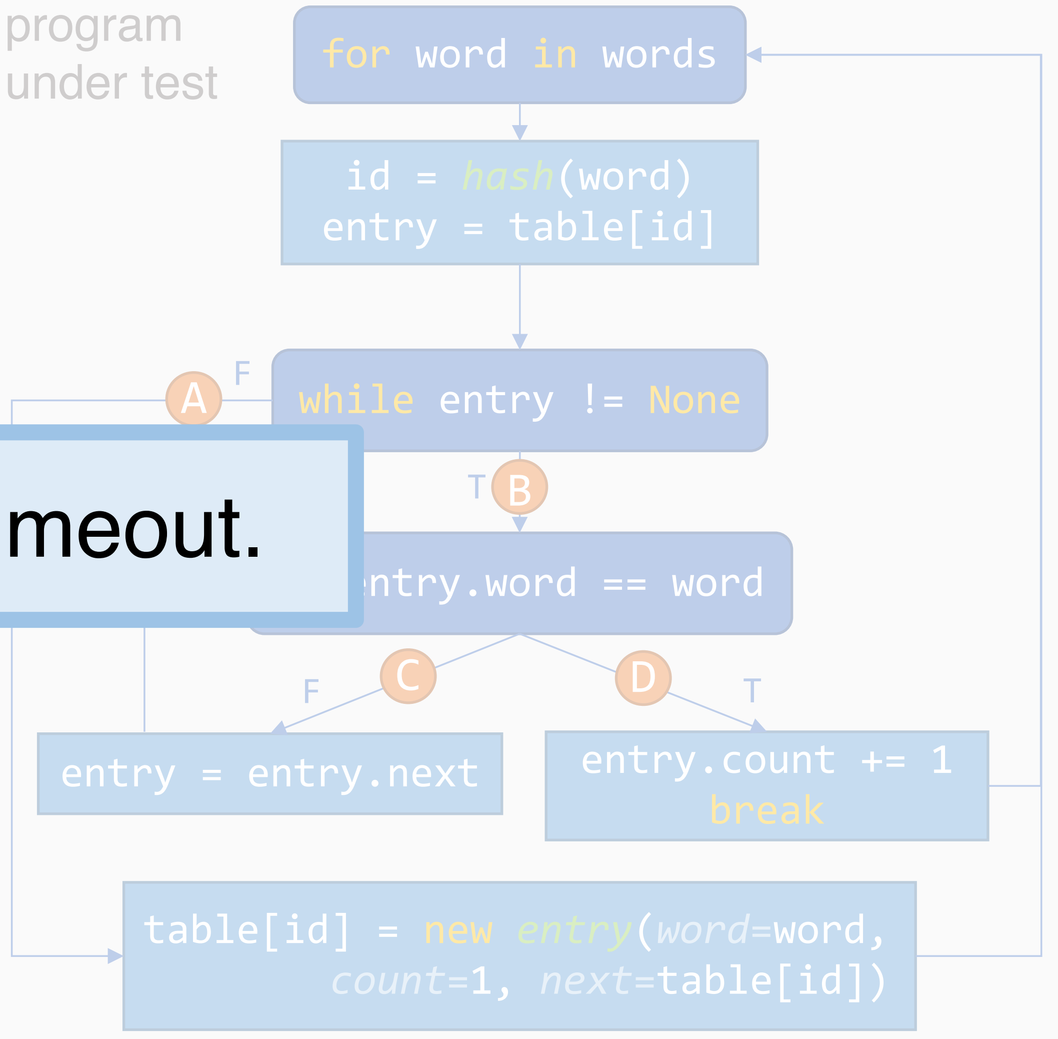
Repeat until timeout.

input running, feedback analysis

Current Input

Edge	# Hits

program under test



```
for word in words
```

```
id = hash(word)
entry = table[id]
```

```
while entry != None
```

```
entry.word == word
```

```
entry = entry.next
```

```
entry.count += 1
break
```

```
table[id] = new entry(word=word,
                      count=1, next=table[id])
```

PerfFuzz Algorithm: Results

input corpus

Edge	Max # Hits	Maximizing Input
A	12	`t h e q u i c k b r o w`
B	21	`t ?t xt at$ #a ))t Qwaa`
C	21	`t ?t xt at$ #a ))t Qwaa`
D	11	`t t t t t t t t t t t t`

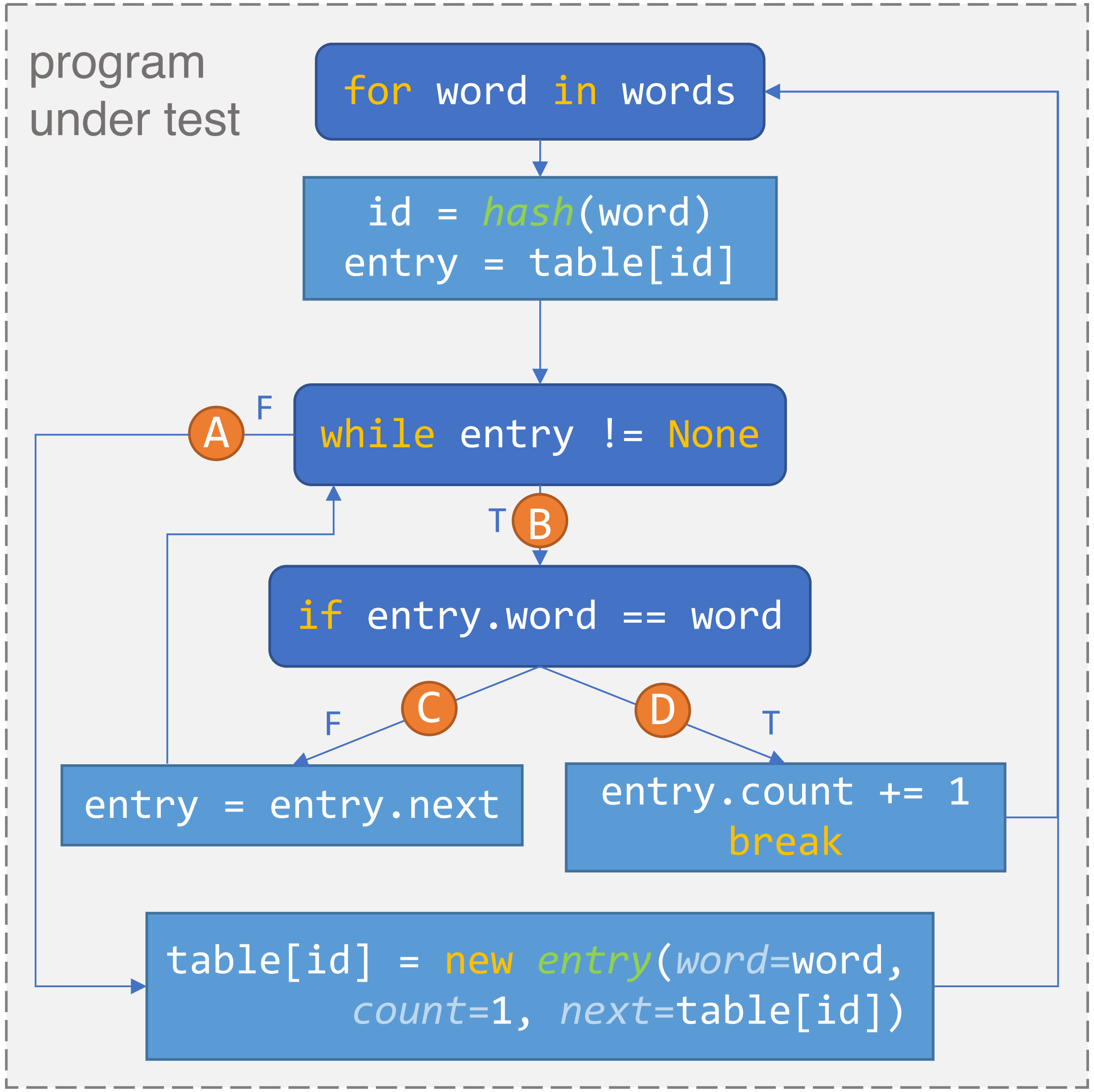
mutation engine

input running, feedback analysis

Current Input

Edge	# Hits

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
        count=1, next=table[id])
```

PerfFuzz Algorithm: Results

input corpus

Edge	Max # Hits	Maximizing Input
A	12	t h e q u i c k b r o w
B	21	t ?t xt at$ #a))t Qwaa
C	21	t ?t xt at$ #a))t Qwaa
D	11	t t t t t t t t t t t t

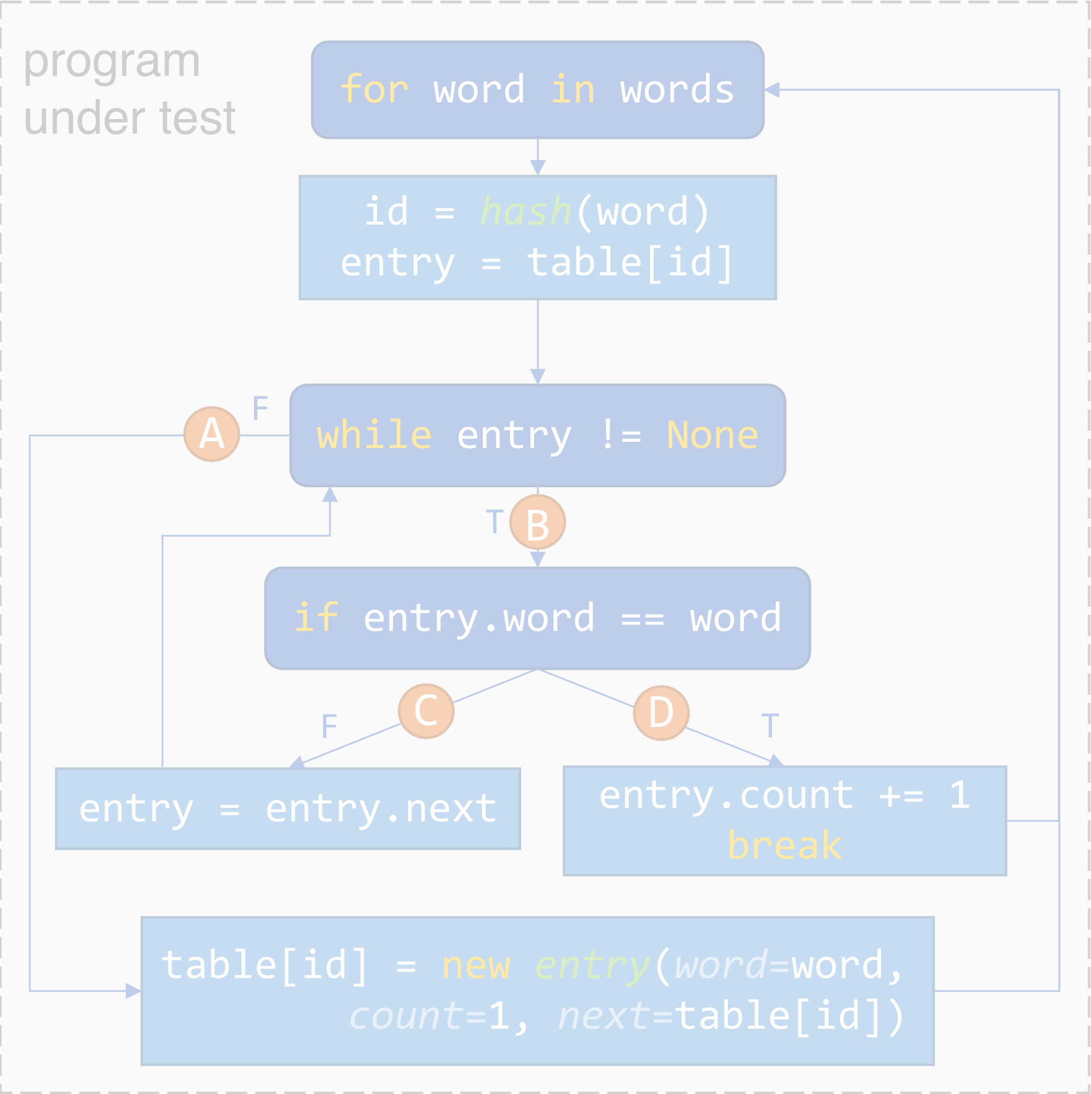
mutation engine

input running, feedback analysis

Current Input

Edge	# Hits

program under test



```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
        count=1, next=table[id])
```

PerfFuzz Algorithm: Results

input corpus

Edge	Max # Hits	Maximizing Input
A	12	`t h e q u i c k b r o w`
B	21	`t ?t xt at$ #a ))t Qwaa`
C	21	`t ?t xt at$ #a ))t Qwaa`
D	11	`t t t t t t t t t t t t`

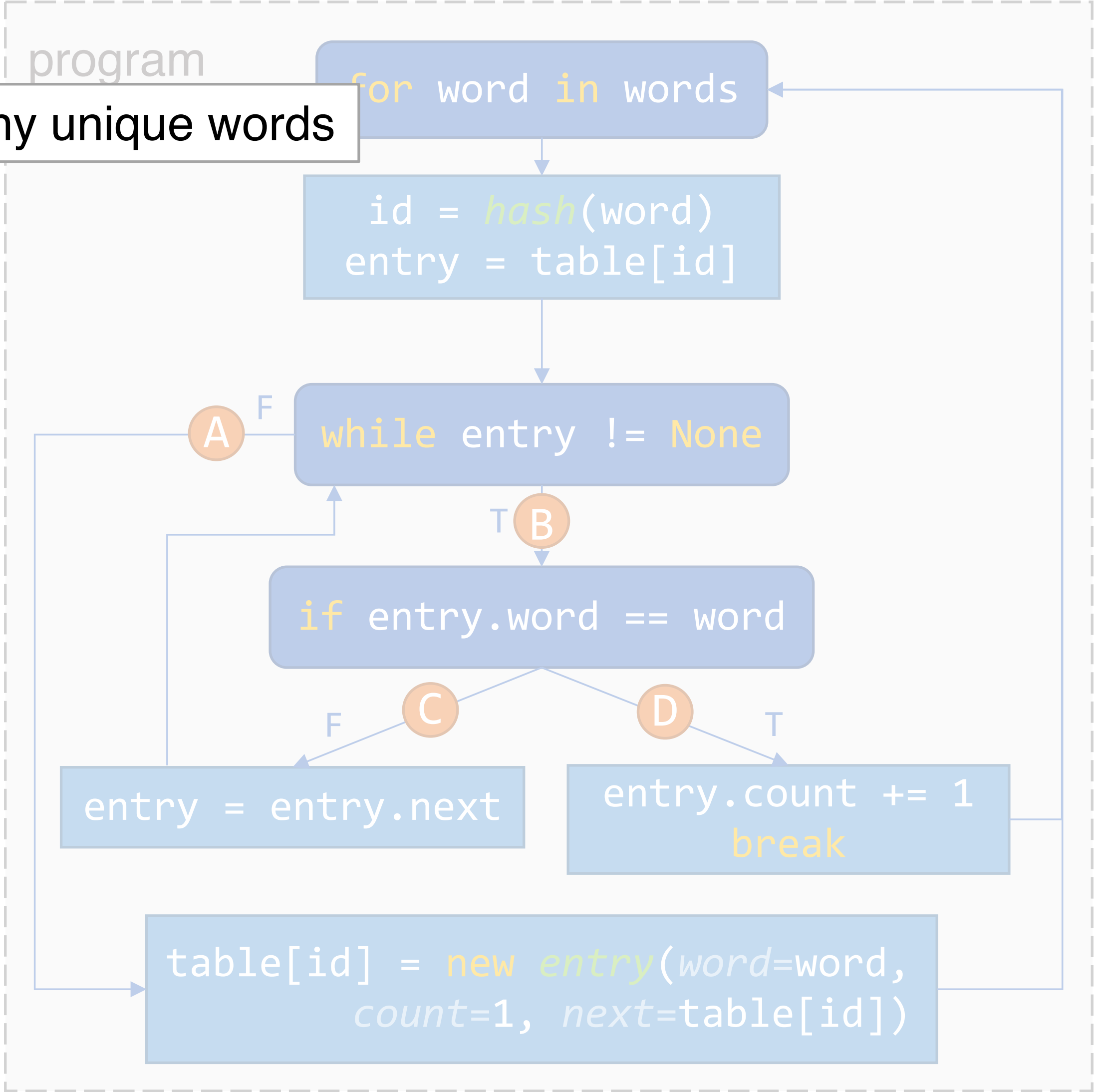
many unique words

mutation engine

input running, feedback analysis

Current Input

Edge	# Hits



program

```
for word in words
id = hash(word)
entry = table[id]
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
    count=1, next=table[id])
```

PerfFuzz Algorithm: Results

input corpus

Edge	Max # Hits	Maximizing Input
A	12	t h e q u i c k b r o w
B	21	t ?t xt at$ #a))t Qwaa
C	21	t ?t xt at$ #a))t Qwaa
D	11	t t t t t t t t t t t t

many unique words

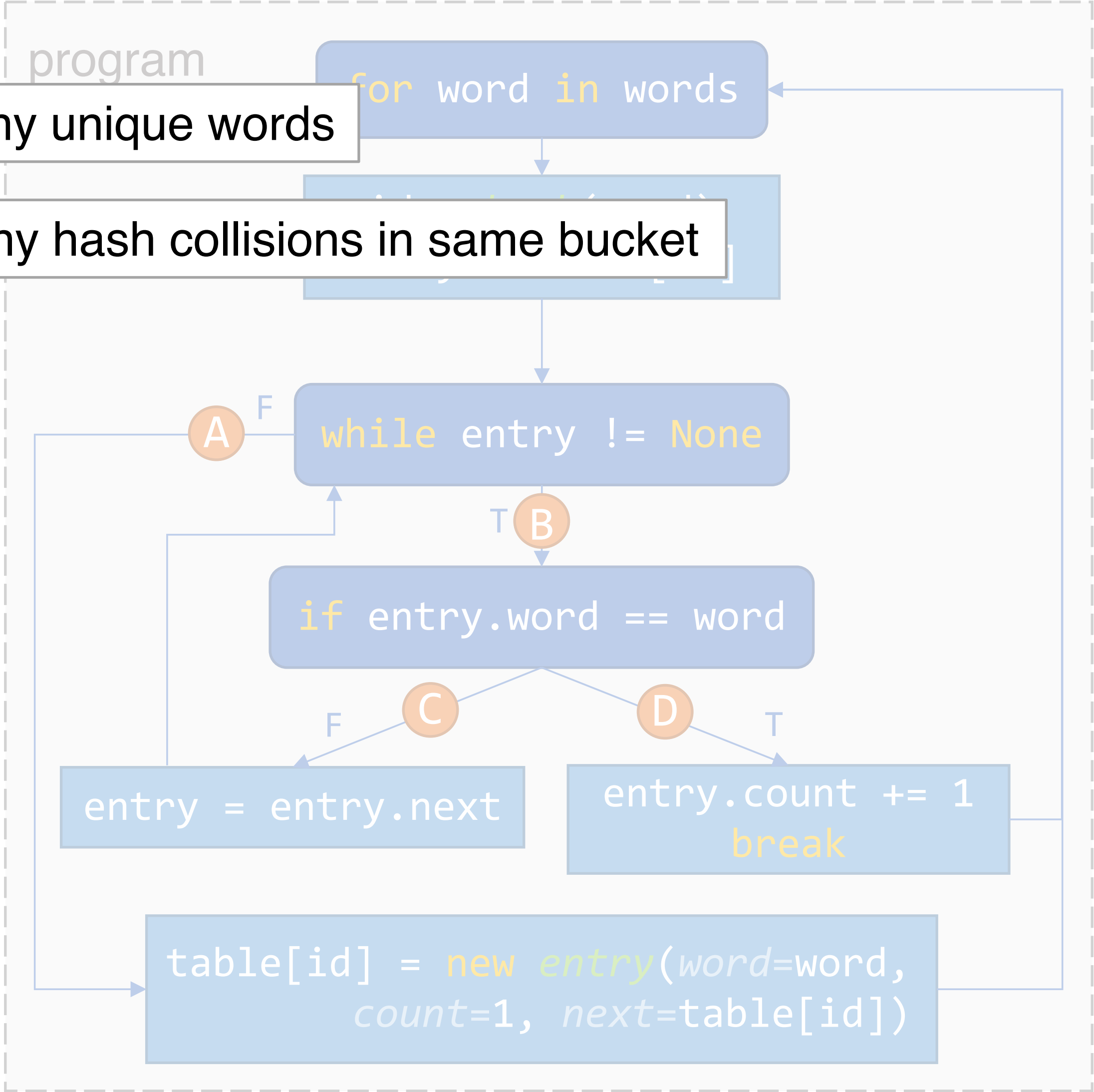
many hash collisions in same bucket

mutation engine

input running, feedback analysis

Current Input

Edge	# Hits



PerfFuzz Algorithm: Results

input corpus

Edge	Max # Hits	Maximizing Input
A	12	`t h e q u i c k b r o w`
B	21	`t ?t xt at$ #a ))t Qwaa`
C	21	`t ?t xt at$ #a ))t Qwaa`
D	11	`t t t t t t t t t t t t`

many unique words

many hash collisions in same bucket

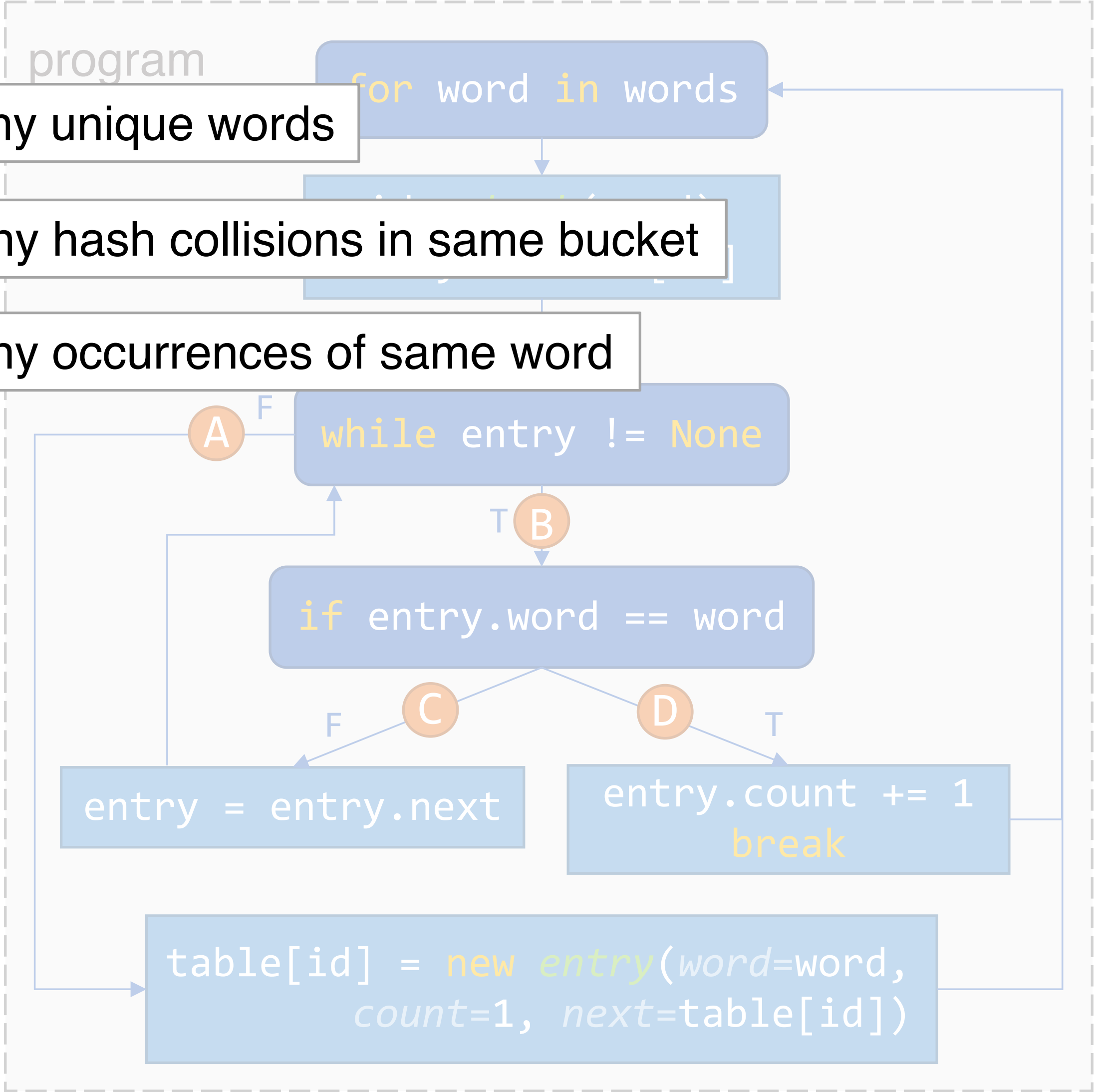
many occurrences of same word

mutation engine

input running, feedback analysis

Edge	# Hits

Current Input



program

```
for word in words
while entry != None
if entry.word == word
entry = entry.next
entry.count += 1
break
table[id] = new entry(word=word,
    count=1, next=table[id])
```

PerfFuzz Algorithm: Results

input corpus

Edge	Max # Hits	Maximizing Input
A	12	`t h e q u i c k b r o w`
B	21	`t ?t xt at$ #a ))t Qwaa`
C	21	`t ?t xt at$ #a ))t Qwaa`
D	11	`t t t t t t t t t t t t`

many unique words

many hash collisions in same bucket

many occurrences of same word

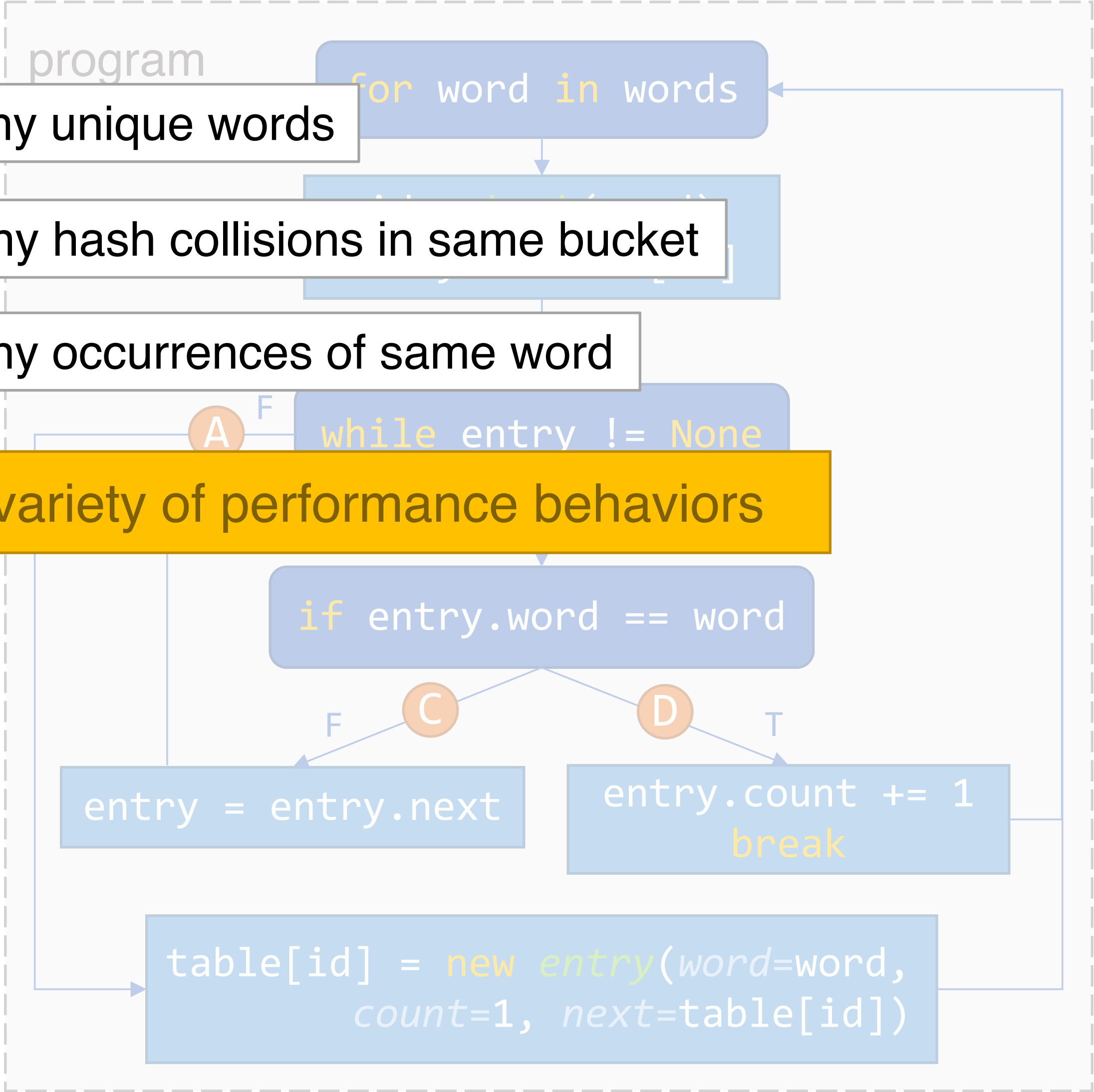
→ variety of performance behaviors

mutation engine

input running, feedback analysis

Current Input

Edge	# Hits



Evaluation Outline

- Compare to SlowFuzz
  - Macro-benchmarks
  - Micro-benchmarks
- Compare to AFL
- Case Studies

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Prior Work

SlowFuzz → Fuzzing to find algorithmic complexity vulnerabilities

- Saves inputs that increase *total* path length
- Randomly chooses parent
- Prioritizes mutations that increase path length
- Faster than PerfFuzz (based on LibFuzzer)

T. Petsios, J. Zhao, A. D. Keromytis, and S. Jana. 2017. SlowFuzz: Automated Domain-Independent Detection of Algorithmic Complexity Vulnerabilities. In Proceedings of CCS '17. DOI: https://doi.org/10.1145/3133956.3134073

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Experimental Setup: Macro-Benchmarks

- Max input size: 500 bytes
- Seeds: AFL default seed for each format
- Run each tool for 6 hours
- Repeat 6-hour runs 20 times

Library	LoC	Function Exercised
`libpng`	30k	PNG read
`libxml2`	70k	XML read
`libjpeg-turbo`	30k	JPEG decompress
`zlib`	9k	GZIP decombress

Macro-Benchmarks: Maximum Path Length

- Path length: total number of hits of CFG edges by an input

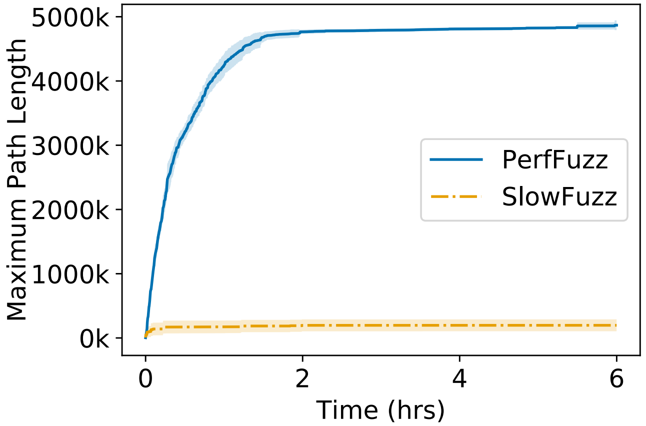
Edge	# Hits
A	1
B	11
C	0
D	11

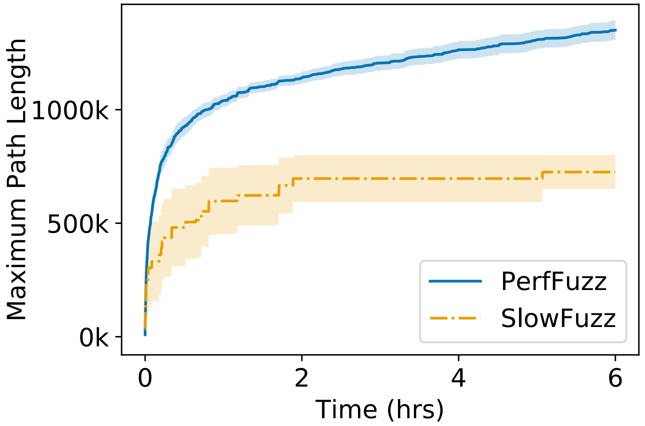
path len: 23

Macro-Benchmarks: Maximum Path Length

- Path length: total number of hits of CFG edges by an input

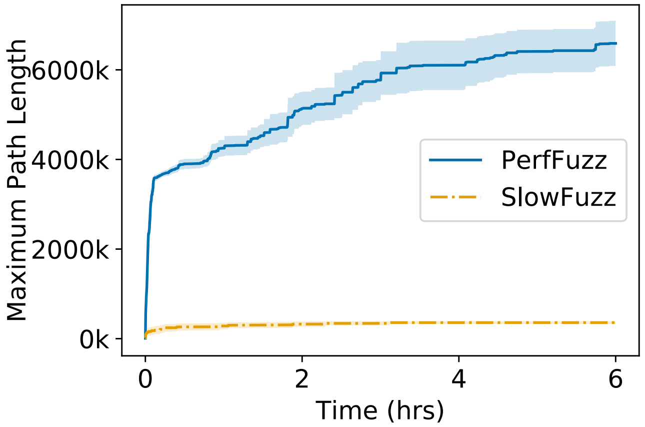
libpng

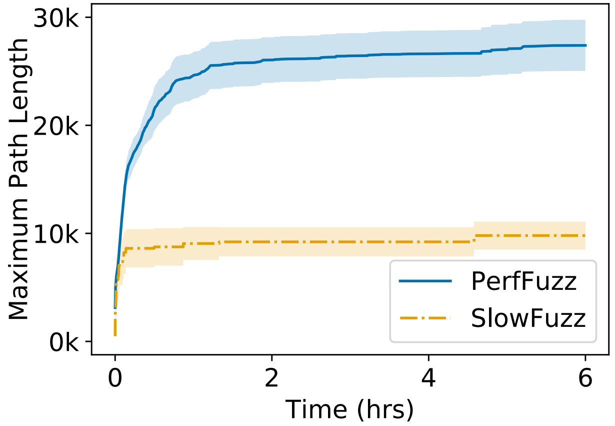




libxml2

libjpeg-turbo



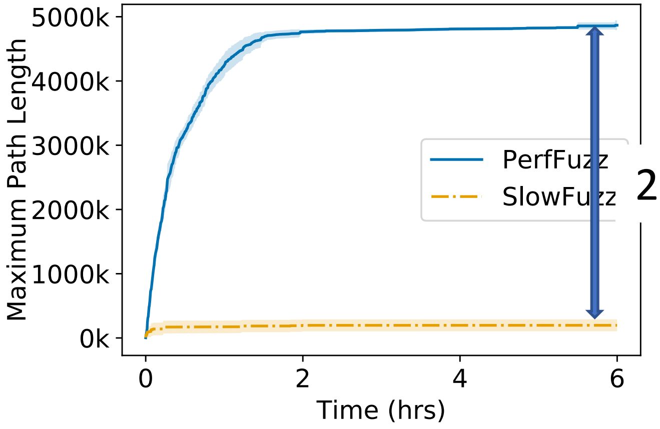


zlib

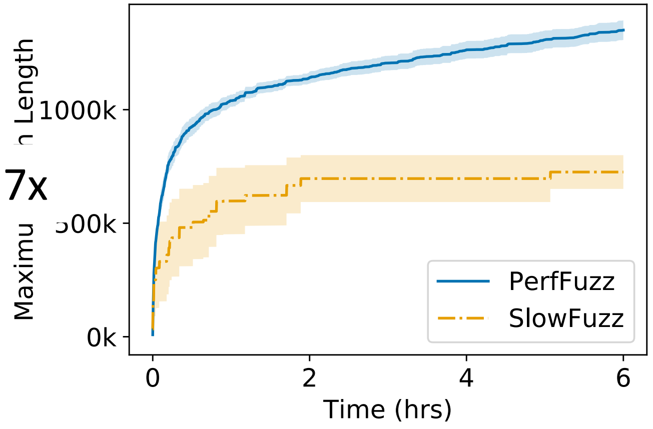
Macro-Benchmarks: Maximum Path Length

- Path length: total number of hits of CFG edges by an input

libpng

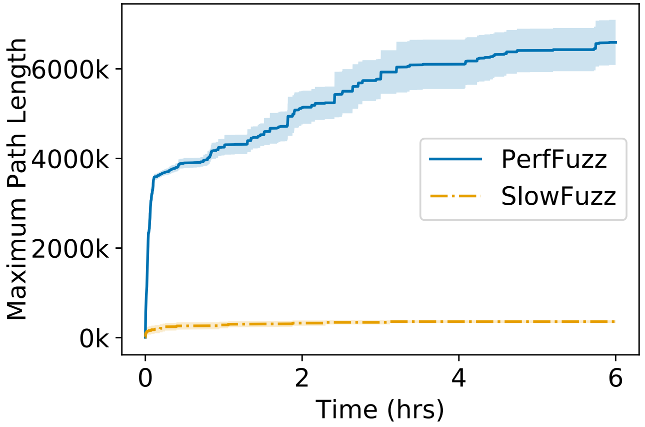


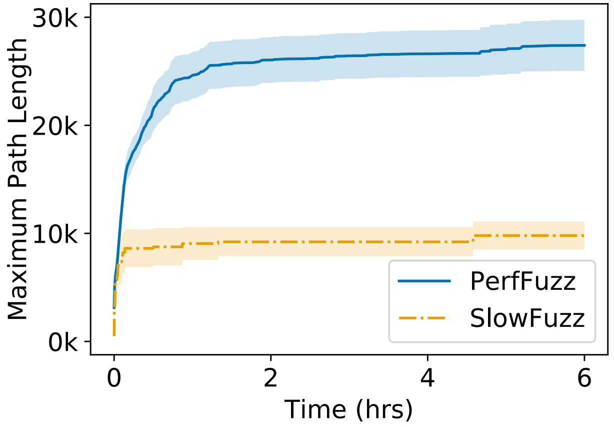
24.7x



libxml2

libjpeg-turbo





zlib

Macro-Benchmarks: Maximum Hot Spot

- Hot spot: maximum # hits of a CFG edge by an input

Edge	# Hits
A	1
B	11
C	0
D	11

hot spot: 11

Macro-Benchmarks: Maximum Hot Spot

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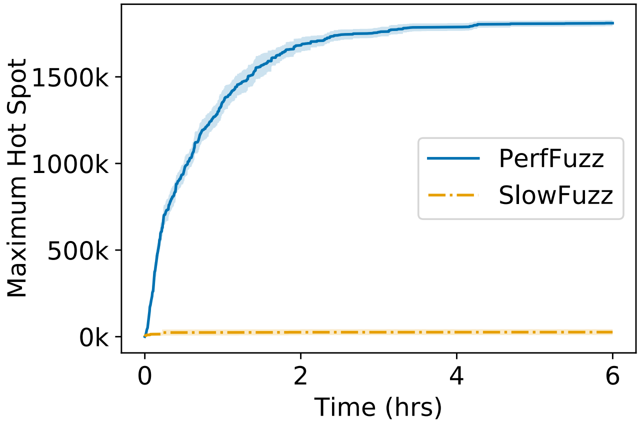
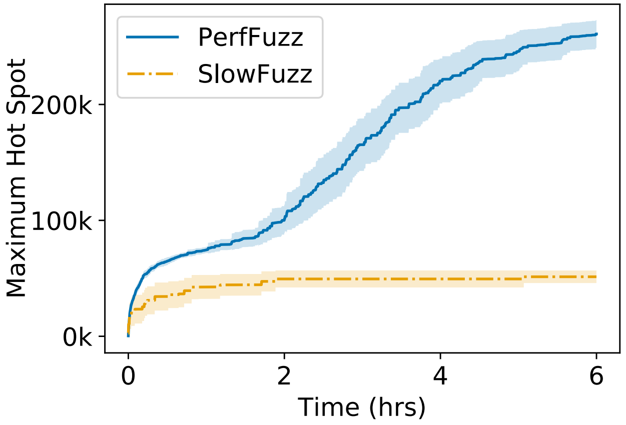
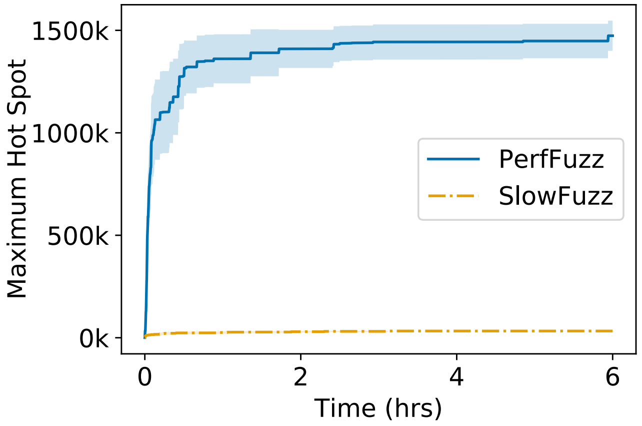
`libpng`

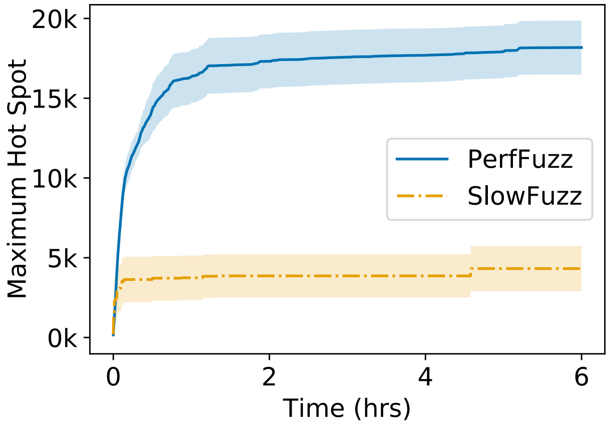




`libxml2`

`libjpeg-turbo`





`zlib`

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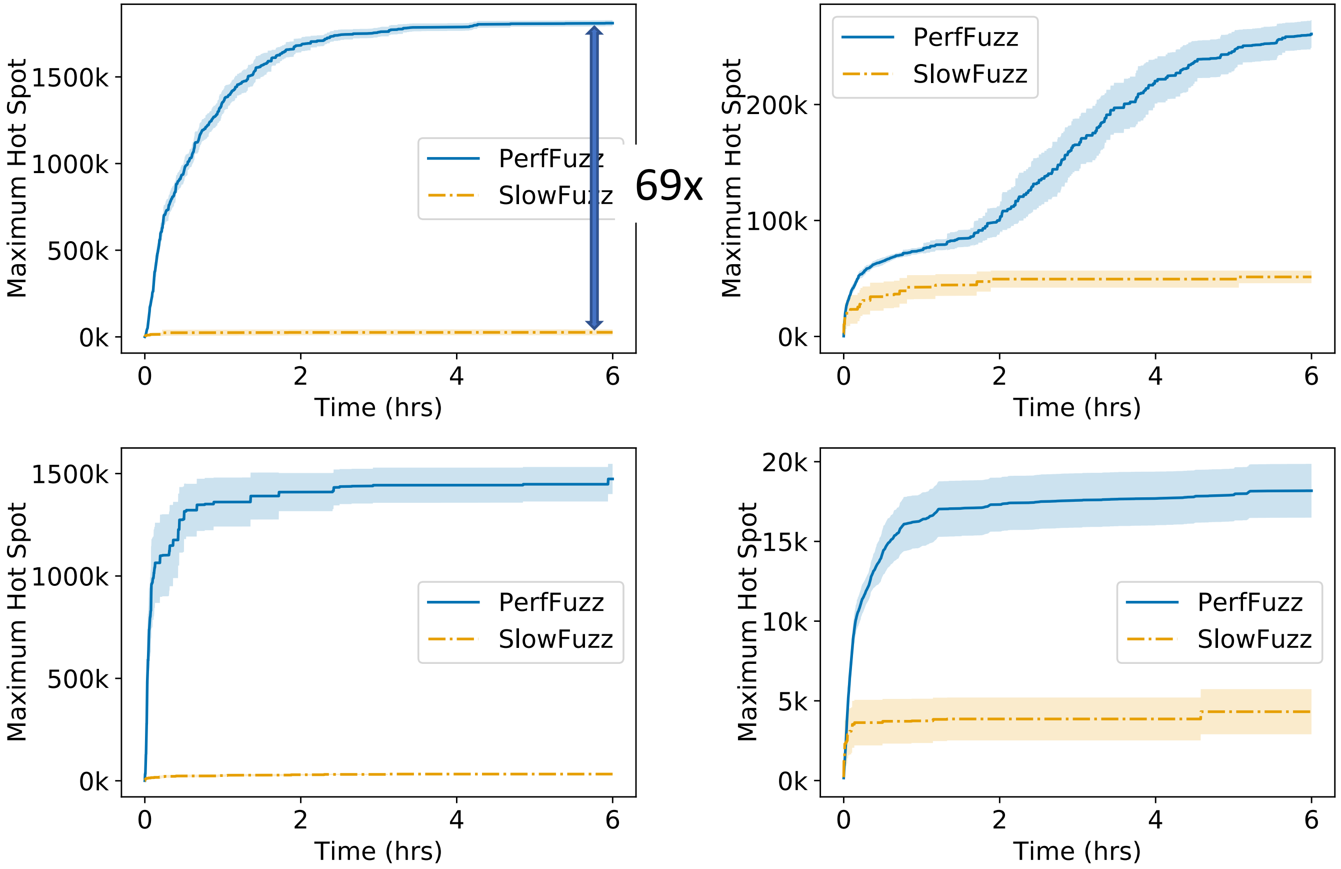
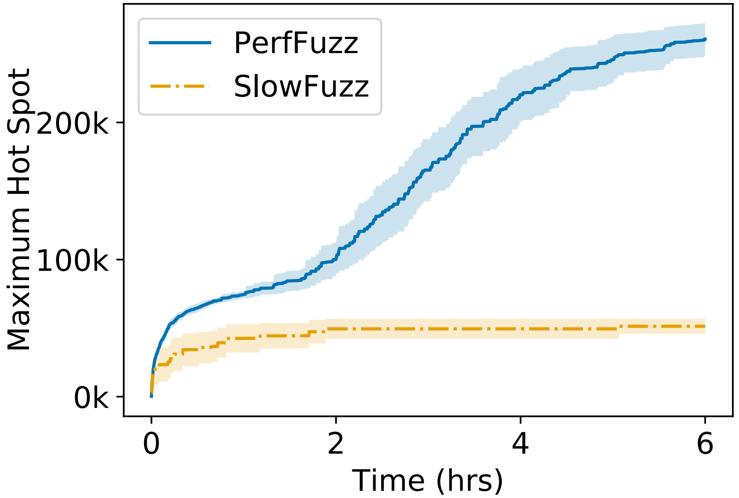


What Does It Mean?

libxml2 case study:



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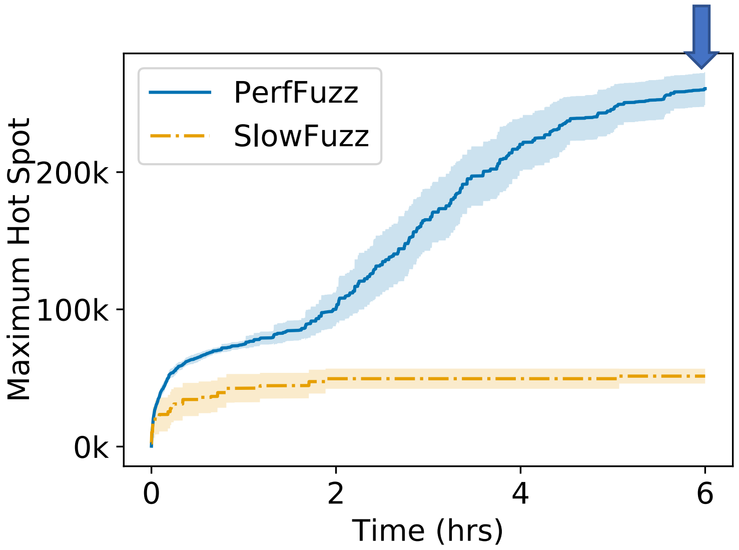
libxml2 case study:

a loop in xml strncpy



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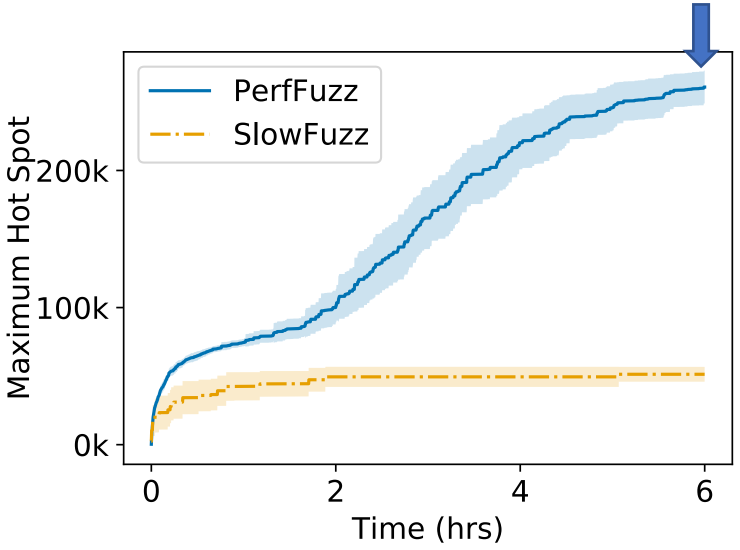

output of read XML on that input:

```
parser error : Double hyphen within comment: <!--3
<a>>>>0>>>#>G<!--3---6-----------------------------4-------------
                  ^
parser error : Double hyphen within comment: <!--3---6
<a>>>>0>>>#>G<!--3---6-----------------------------4-------------
                      ^
parser error : Double hyphen within comment: <!--3---6--
<a>>>>0>>>#>G<!--3---6-----------------------------4-------------
                        ^
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                          ^
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                            ^
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<a>>>>0>>>#>G<!--3---6-----------------------------4-------------
                              ^
parser error : Double hyphen within comment: <!--3---6----------
<a>>>>0>>>#>G<!--3---6-----------------------------4-------------
                                ^
parser error : Double hyphen within comment: <!--3---6------------
<a>>>>0>>>#>G<!--3---6-----------------------------4-------------
                                  ^
```

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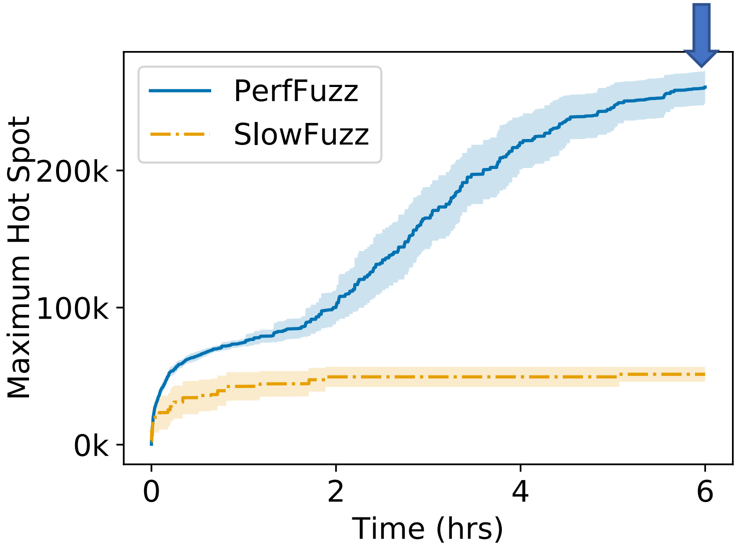

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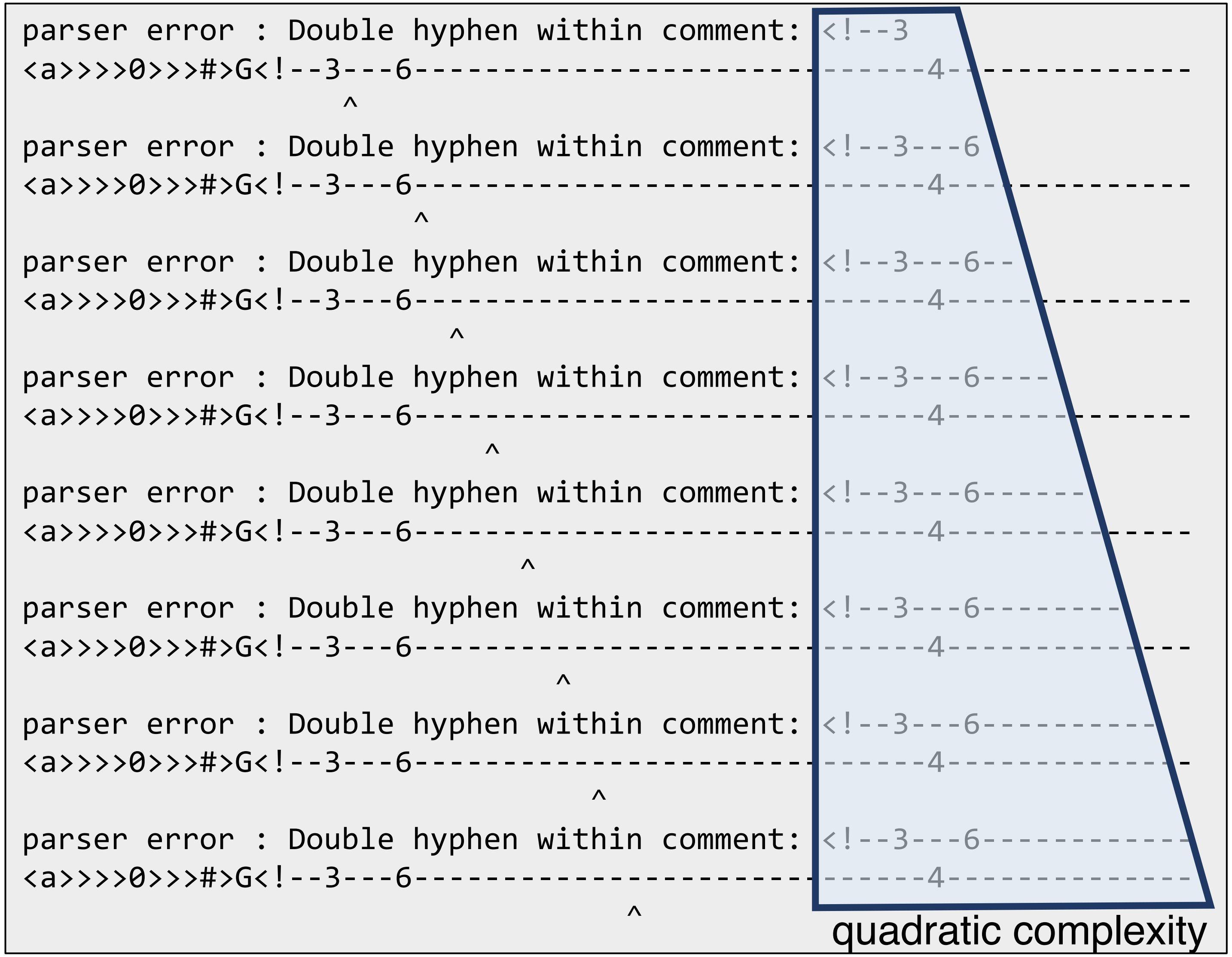

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                              ^
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<a>>>>0>>>#>G<!--3---6-----------------------------4--------------
                                ^
parser error : Double hyphen within comment: <!--3---6------------
<a>>>>0>>>#>G<!--3---6-----------------------------4--------------
                                  ^
```

quadratic complexity

Experimental Setup: Micro-Benchmarks

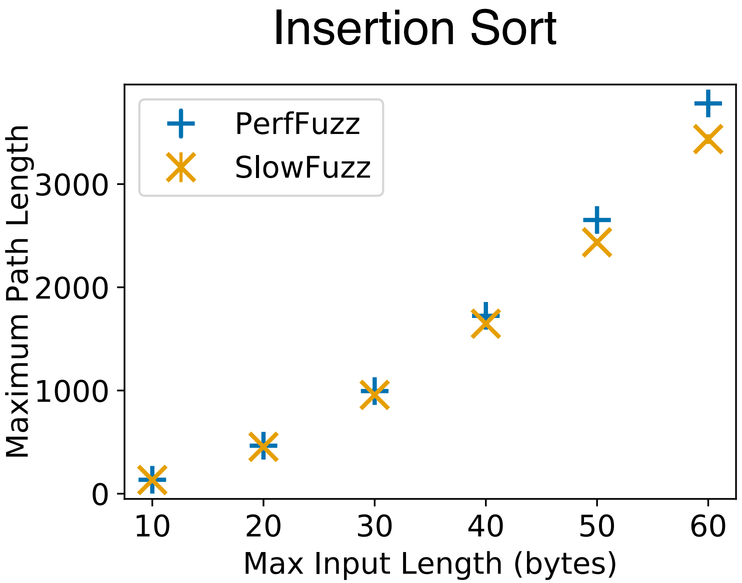
- Choose benchmarks with known worst-case complexity:

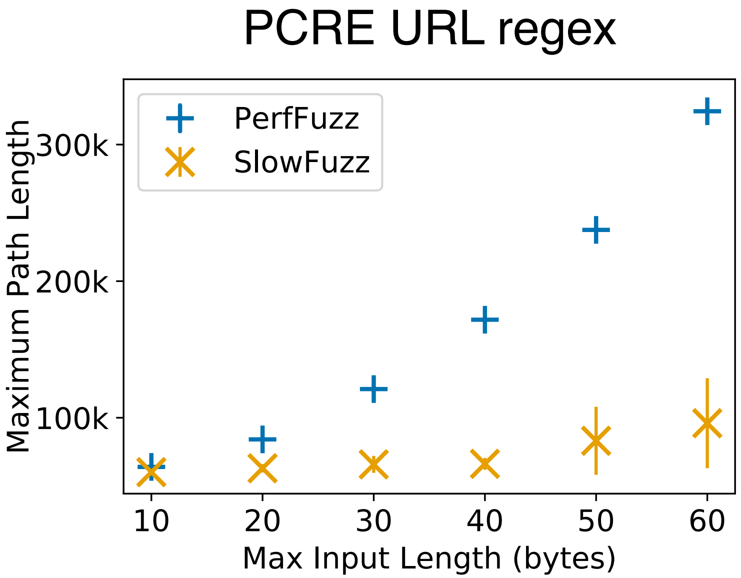
Micro-benchmark	Complexity	Seed	Timeout
Insertion sort (SlowFuzz example)	**n^2** n = input len	List of 0’s	10 min
PCRE regex match (URL regex)	**n^2** n = input len	Null string	60 min
wf-0.41 (Fedora Linux)	**m^2** m = num words	“the quick brown fox jumps over the lazy dog”	60 min

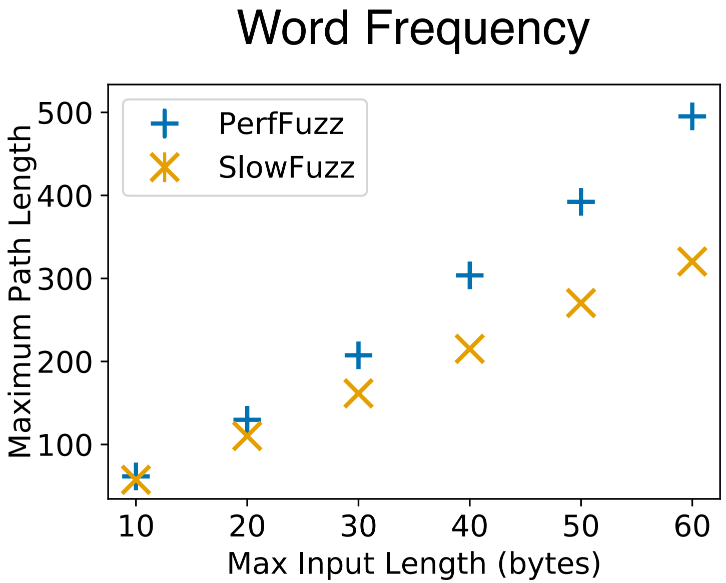
- Repeat 20 runs for each input length: 10, 20, …, 60 bytes.

Micro-Benchmarks: Algorithmic Complexity

- Maximum path length for varying input sizes


Insertion Sort


PCRE URL regex


Word Frequency

Micro-Benchmarks: Algorithmic Complexity

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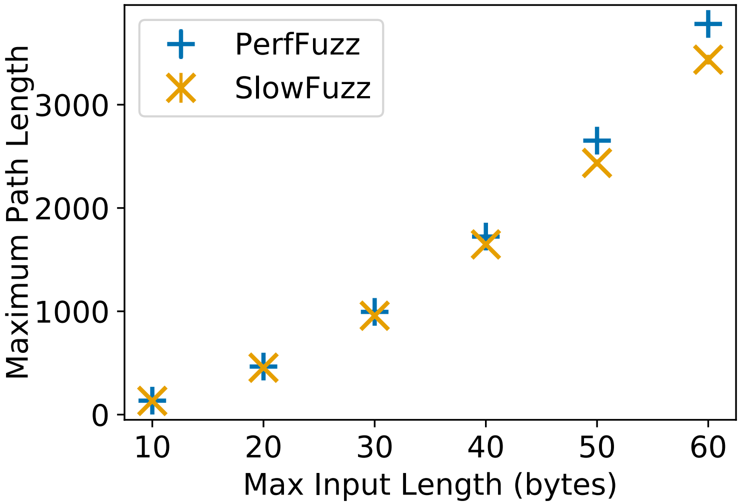
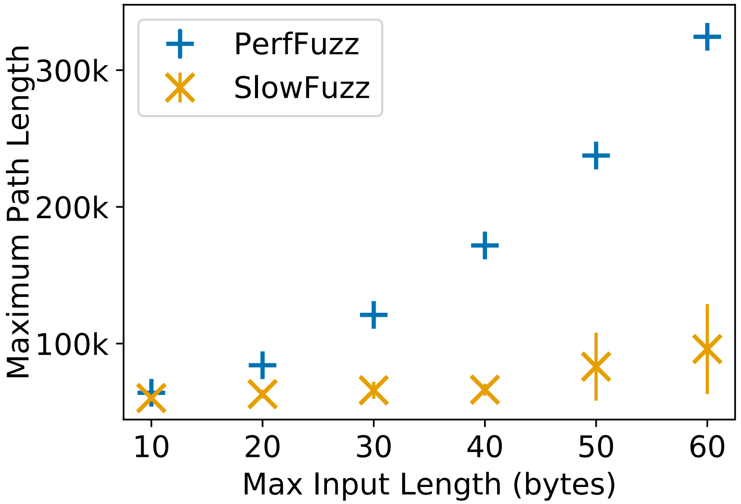
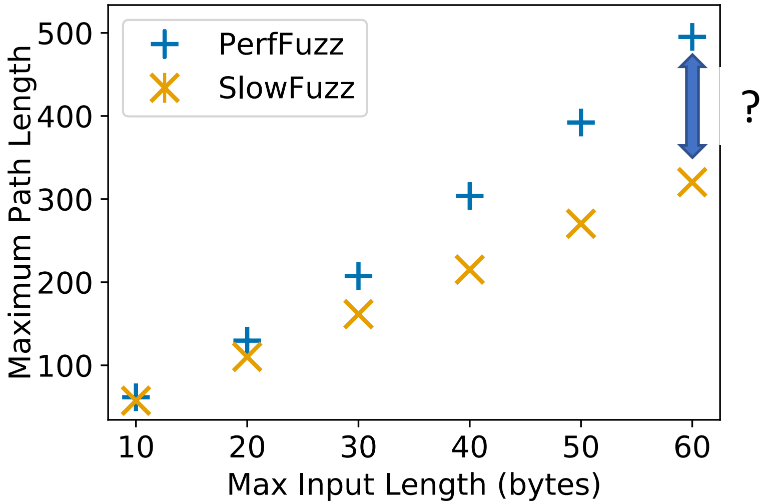
Insertion Sort



PCRE URL regex



Word Frequency



Back to our Motivating Example

- SlowFuzz worst case:

```
t r t t s f o Öe r t s f o r t x x t s f o r t x x
```

- PerfFuzz worst case:

```
t <81>v ^?@t <80>!^?@t <80>!t t^Rn t t t t t t t t t
```

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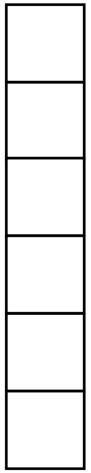

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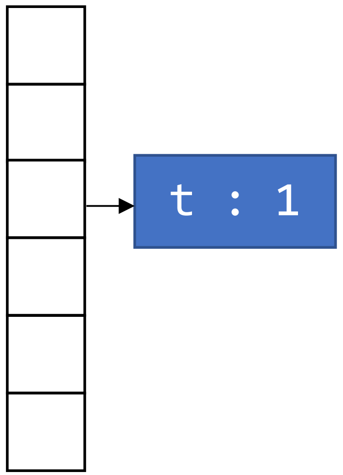

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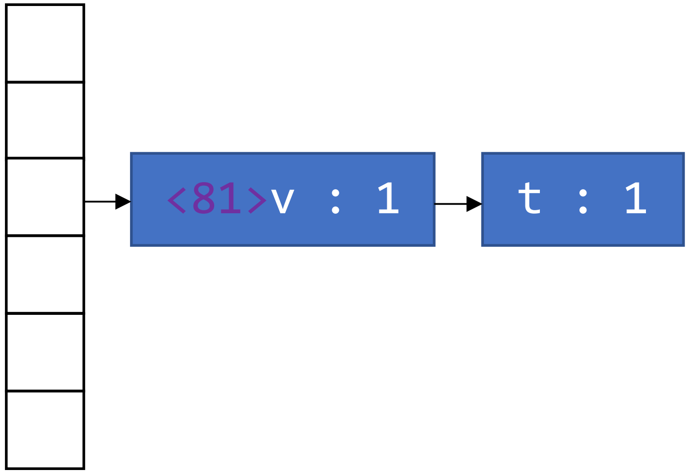
```



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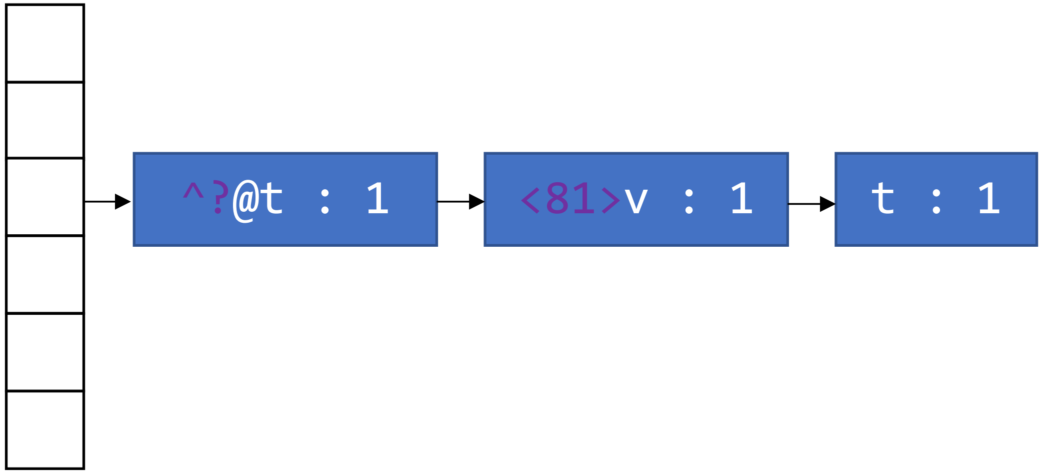

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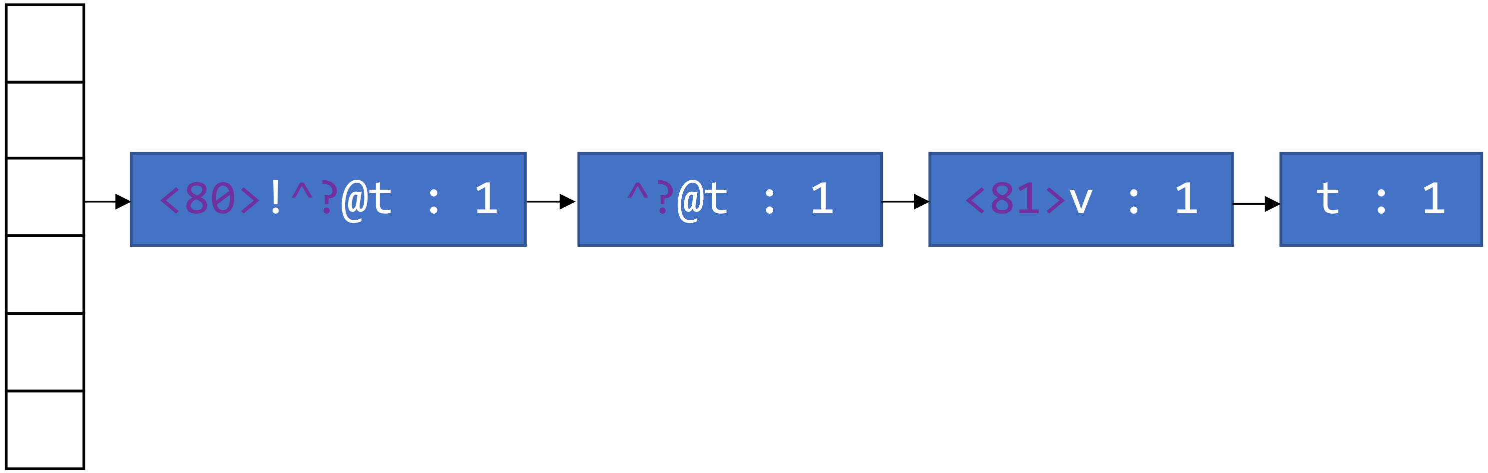

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```
t r t t s f o Öe r t s f o r t x x t s f o r t x x
```

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```
t <81>v ^?@t <80>!^?@t <80>!t t^Rn t t t t t t t t t
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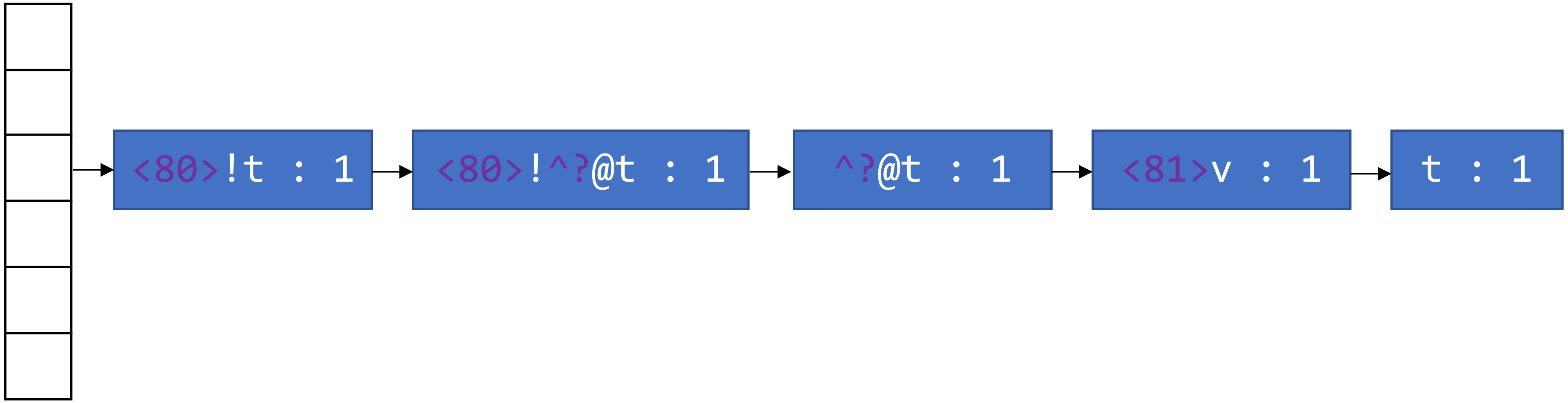

Back to our Motivating Example

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  `t r t t s f o Öe r t s f o r t x x t s f o r t x x`

- PerfFuzz worst case:

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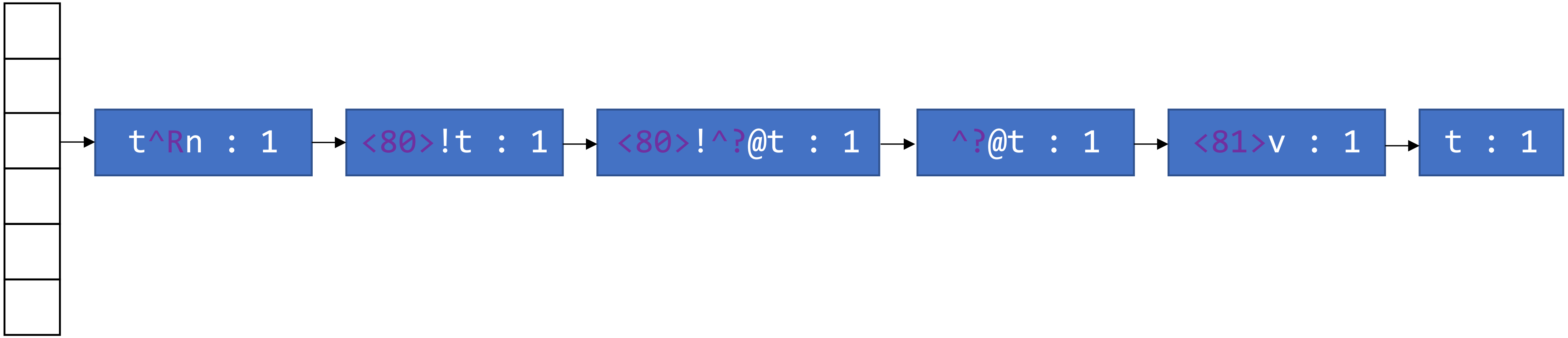

Back to our Motivating Example

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t r t t s f o Öe r t s f o r t x x t s f o r t x x

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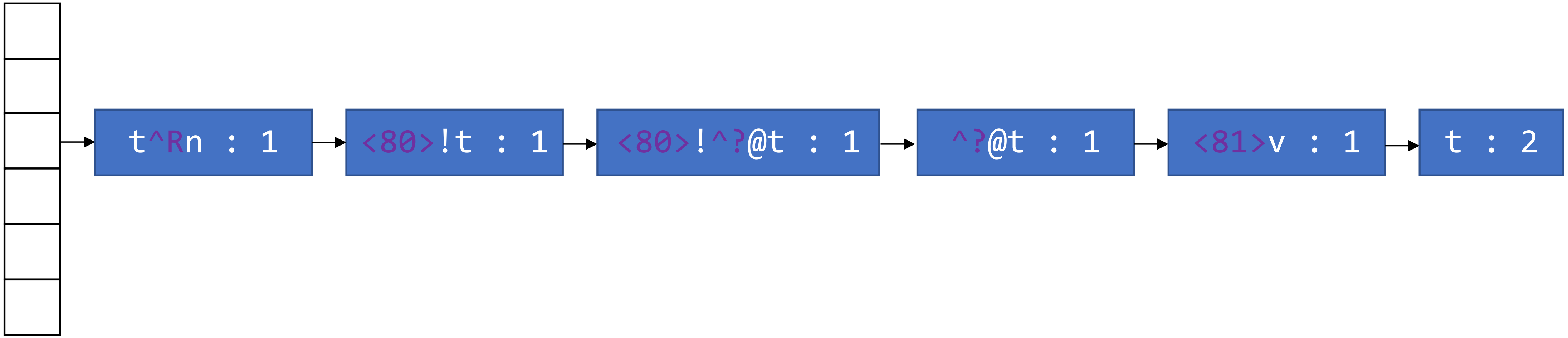

t^Rn : 1

<80>!t : 1

<80>!^?@t : 1

^?@t : 1

<81>v : 1

t : 2

Back to our Motivating Example

- SlowFuzz worst case:

```
t r t t s f o Öe r t s f o r t x x t s f o r t x x
```

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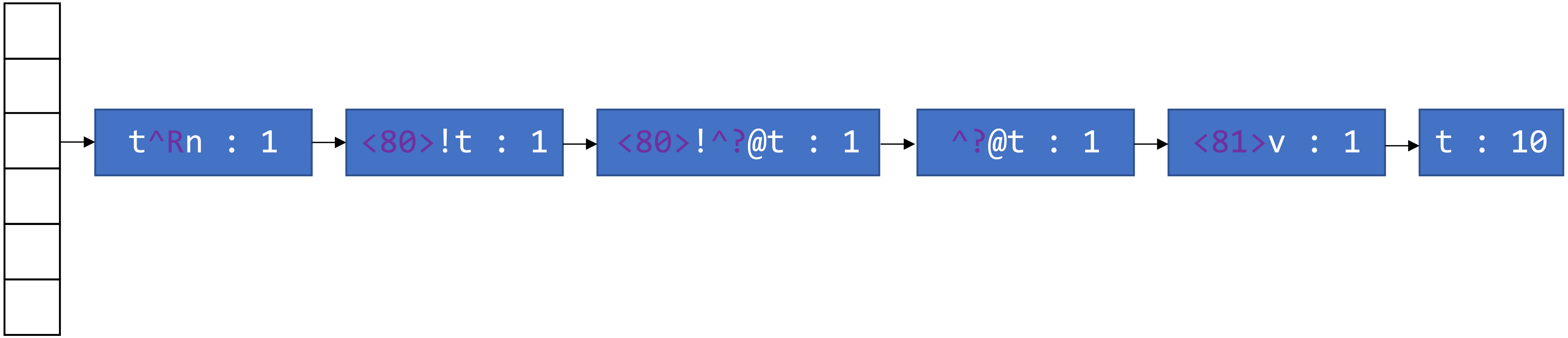
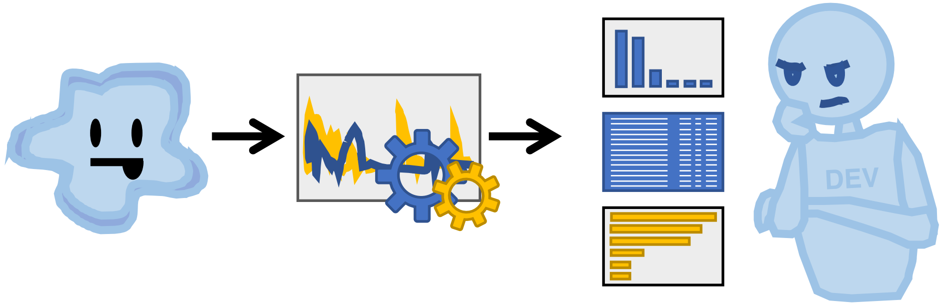
```

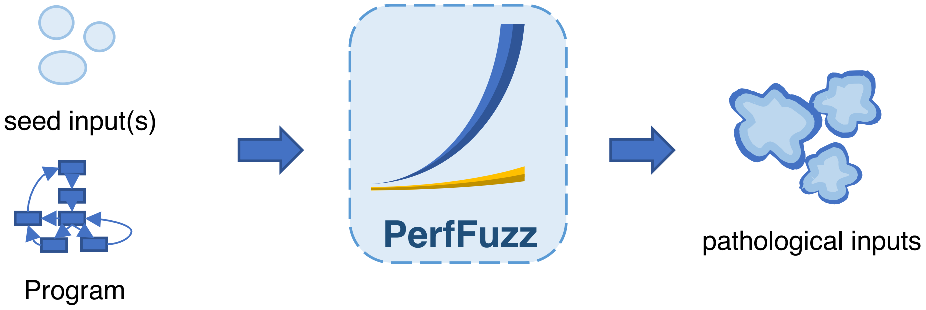


Conclusion

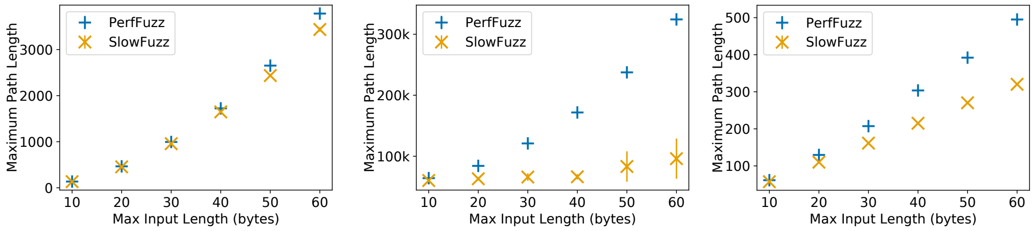
How to find **pathological inputs**?



Use **feedback-directed mutational fuzzing!**



Multi-dimensional feedback more effective.



Where's the code?

https://github.com/carolemieux/perffuzz