Static Analysis-based Repair of Memory Errors in C Programs

Hakjoo Oh
Korea University

2/25/2025@IFIP WG 2.4 Meeting 70 (Singapore)

PL/SE Research @Korea Univ.

- Members: ~15 graduate students
- Research area: intersection of programming languages (PL) and software engineering (SE)
  - program analysis and testing
  - program synthesis and repair

- Publication: PL, SE, and Security
  - PL: POPL('22),PLDI('12,'14,'20,'24),OOPSLA('15,'17a,'17b,'18a,'18b,'19,'20,'23,'24a,'24b,25)
  - SE: ICSE('17,'18,'19,'20,'21'22a,'22b,'23a,'23b,'23c), FSE('18,'19,'20,'21,'22,'23), ASE('18,'24a,'24b)
  - Security: IEEE S&P('17,'20), USENIX Security('21,'23)

http://kupl.github.io

SEOUL

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Line 3
Line 4
Line 5
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Line 7
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Suin Bundang Line
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Sillim LRT Line
Railway
Transfer Station
Train Station

Museum/Gallery
Performance Hall
Shopping
Casino
Sightseeing
Local Hot Spot
Multi-purpose Cultural Space
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Sightseeing

D3 108 Steps
D1 April 19th National Cemetery
C4 63 Square
D2 Gyeonghoegung Palace
C3 Gyeongui Line Forest Park
E2 Gyeongchun Line Forest Trail
D3 Gyeonghuigung Palace
B4 Gocheok Sky Dome
D2 Gwanghwamun
D4 Seoul National Cemetery
C3 National Assembly Building
D2 Gilsangsa Temple
D2 Naksan Park
D3 Namsangol Hanok Village
D3 Namsan Baekbeom Square
D3 Namsan Seoul Tower
D3 Namsan Botanical Garden
D3 Deoksugung Palace
C3 Dongnimmun Gate
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F4 Lotte World Tower
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D3 Bosingak Belfry
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E2 Dream Forest
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D2 Bugak Palgakjeong
D2 Bukchon Hanok Village
B2 Sangam DMC
A3 Seoseoulhosu Park
D1 Seoul Hiking Tourism Center
D3 Seoullo 7017
E3 Seoul Forest
A3 Seoul Botanic Park
F3 Seoul Amsa-dong Historic Site
B3 Seoul World Cup Stadium
B3 Seoul Battleship Park
C5 Hoamsanseong Fortress, Seoul
E4 Seokchon Lake
B3 Seonyudo Park
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D3 Sungnyemun
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D2 Changdeokgung Palace
D2 Changgyeonggung Gate
D2 Cheonggwadae
D2 Pungnaptoseong Earthen Fortification
F1 Taereung · Gangneung Royal Tomb
E1 K-Star Road
A4 Hangdong Railroad Trail
D2 Pureun Arboretum
E5 Heonilleung Royal Tomb
C5 Hoapsa Temple
C3 Hyochang Park
D3 Heunginjimun Gate

Local Hot Spot

D4 Garosu-gil·Seosu-gil
D4 Gangnam Station Street
E3 Kondae Rodeo Street
D3 Gyeongnidan-gil
D2 Daehangno Street
B3 Mangridan Road
D3 Myeong-dong
B4 Mullae Art Village
C2 Buam-dong
D2 Samcheong-dong
C3 Sangsu Cafe Street
C4 Syarosu-gil
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E4 Yangjaecheon Cafe Street
C3 Yeonnam-dong Café District
C3 Yeonhui Multi-Culture Street
D3 Usadan-gil
D3 Itaewon Street
D2 Ikseon-dong Hanok Village
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C3 Hapjeong Cafe Street
D3 Haebangchon Village
C3 Hongdae Street

Museum/Gallery

C2 Hongjie Yuyeon
C3 SeMA Bunker
D2 Kansong Art Museum
A3 Gyeomjae Jeongseon Art Museum
D3 National Theater of Korea
C3 National Meteorological Museum of Korea
C2 National Memorial of the Korea Provisional Government
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A3 Nationanl Aviation Museum of Korea
D3 MMCA Deoksugung
D2 MMCA Seoul
E1 Dooly Museum
D5 Nam Seoul Annex Building of Seoul Museum of Art
D3 Seoul Museum of History
C2 Seoul Museum
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B2 Korean Film Museum
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D2 Seoul City Wall Museum
A3 Heojun Museum
D2 Whanki Art Museum

Shopping

C3 IFC Mall
F4 Garak Market
E4 Gangnam Station Underground Shopping Center
E3 Galleria Department Store Luxury Hall
D4 Goto Mall
D3 Gwangjang Market
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D3 12 Mondrian Seoul Itaewon
F3 13 Vista Walkerhill Seoul
C2 14 Swiss Grand Hotel Seoul
F4 15 Signiel Seoul
E3 16 Andaz Seoul Gangnam
D3 17 The Westin Chosun Seoul
E4 18 InterContinental Seoul COEX
E4 19 Josun Palace Seoul Gangnam
C3 20 Conrad Seoul
E4 21 Park Hyatt Seoul
C3 22 Fairmont Ambassador Seoul
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D3 24 The Shilla Seoul
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D4 26 JW Marriott Hotel Seoul

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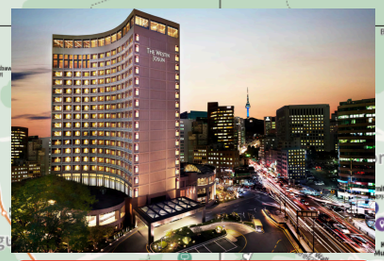

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- Meeting 67, York Harbor (April 23-27, 2023)
- Meeting 69, Lugano (May 12-16, 2024)

Data-Driven Static Analysis

Hakjoo Oh

25 April 2023 @IFIP WG 2.4 Meeting 67, York Harbor

PL4XGL: A Programming Language Approach to Explainable Graph Learning

Hakjoo Oh
Korea University

(co-work with Minseok Jeon and Jihyeok Park)

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Today: automated program repair (APR)

APR Research @Korea Univ.

- Automatic Diagnosis and Correction of Logical Errors for Functional Programming Assignments. OOPSLA 2018
- Context-Aware and Data-Driven Feedback Generation for Programming Assignments. ESEC/FSE 2021
- MemFix: Static Analysis-Based Repair of Memory Deallocation Errors for C. ESEC/FSE 2018
- SAVER: Scalable, Precise, and Safe Memory-Error Repair. ICSE 2020 (deployed in industry)
- NPEX: Repairing Java Null Pointer Exceptions without Tests. ICSE 2022
- PyTER: Effective Program Repair for Python Type Errors. ESEC/FSE 2022
- SmartFix: Fixing Vulnerable Smart Contracts by Accelerating Generate-and-Verify Repair using Statistical Models. ESEC/FSE 2023
- Reducing the Cost of LLM-based APR via Execution-Guided Static Analysis. In progress
- Accurate Detection of Overfitting Patches in Automated Program Repair through Semantic Anti-Patterns. In progress

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Our approach: Static analysis-based program repair

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Memory Errors in C Programs

- Memory-leak (**ML**), use-after-free (**UAF**), and double-free (**DF**) are prevalent in real-world C programs

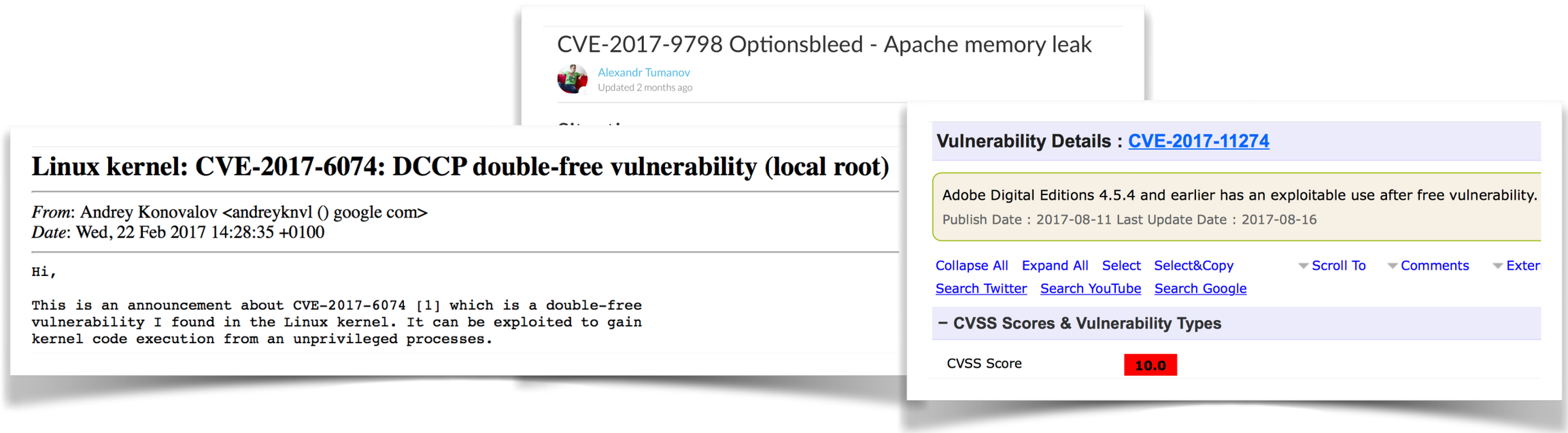
Repository	#commits	ML	DF	UAF	Total	*-overflow
linux	721,119	3,740	821	1,986	**6,363**	5,092
openssl	21,009	220	36	12	**264**	61
numpy	17,008	58	2	2	**59**	53
php	105,613	1,129	148	197	**1,449**	649
git	49,475	350	19	95	**442**	258

Memory Errors in C Programs

- Memory-leak (**ML**), use-after-free (**UAF**), and double-free (**DF**) are prevalent in real-world C programs

Repository	#commits	ML	DF	UAF	Total	*-overflow
linux	721,119	3,740	821	1,986	**6,363**	5,092
openssl	21,009	220	36	12	**264**	61
numpy	17,008	58	2	2	**59**	53
php	105,613	1,129	148	197	**1,449**	649
git	49,475	350	19	95	**442**	258

- Significant sources of security vulnerabilities



Goal

- Long-term goal: Fully automated detection and repair
- This talk: SAVER, a system to automatically fix memory errors

- To be practical, SAVER is designed to be
  - **Scalable**: Capable of handling large, industry programs
  - **Precise**: Effectively fixes diverse bugs with high fix rates
  - **Safe**: Generated patches are safe, not introducing new errors

(1) Double-Free in Linux Kernel

```
in = malloc(1);
out = malloc(1);
... // use in, out
free(out);
free(in);

in = malloc(2);
if (in == NULL) {

  goto err;
}

out = malloc(2);
if (out == NULL) {
  free(in);

  goto err;
}
... // use in, out
err:
  free(in);
  free(out);
  return;
```

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  goto err;
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```

Allocated

```
out = malloc(2);
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Allocated

Freed

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Allocated

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Double Free

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Double Free

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Allocated

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Double Free

Double Free

(1) Double-Free in Linux Kernel

USB: fix double frees in error code paths of ipaq driver

the error code paths can be enter with buffers to freed buffers.
Serial core would do a kfree() on memory already freed.

Signed-off-by: Oliver Neukum <oneukum@suse.de>
Signed-off-by: Greg Kroah-Hartman <gregkh@suse.de>

master v4.15-rc1 ··· v2.6.24-rc1

Oliver Neukum committed with **gregkh** on 18 Sep 2007 1 par

```
in = malloc(1);
out = malloc(1);
... // use in, out
free(out);
free(in);

in = malloc(2);
if (in == NULL) {
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out = malloc(2);
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Oliver Neukum committed with **gregkh** on 18 Sep 2007 1 par

Challenge 1: Difficult to ensure that bugs are fixed correctly

```
in = malloc(1);
out = malloc(1);
... // use in, out
free(out);
free(in);

in = malloc(2);
if (in == NULL) {
  out = NULL;
  goto err;
}

out = malloc(2);
if (out == NULL) {
  free(in);
  in = NULL;
  goto err;
}
... // use in, out
err:
  free(in);
  free(out);
  return;
```

(1) Double-Free in Linux Kernel

Second attempt (9 months later)

```
in = malloc(1);
out = malloc(1);
... // use in, out
free(out);
free(in);

in = malloc(2);
if (in == NULL) {
  out = NULL;
  goto err;
}
free(out);
out = malloc(2);
if (out == NULL) {
  free(in);
  in = NULL;
  goto err;
}
... // use in, out
err:
  free(in);
  free(out);
  return;
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(1) Double-Free in Linux Kernel

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free(in);

in = malloc(2);
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  out = NULL;
  goto err;
}
free(out);
out = malloc(2);
if (out == NULL) {
  free(in);
  in = NULL;
  goto err;
}
... // use in, out
err:
  free(in);
  free(out);
  return;
```

memory leak

Challenge 2: Patches may introduce new errors

USB: fix double kfree in ipaq in error case

in the error case the ipaq driver leaves a dangling pointer to already freed memory that will be freed again.

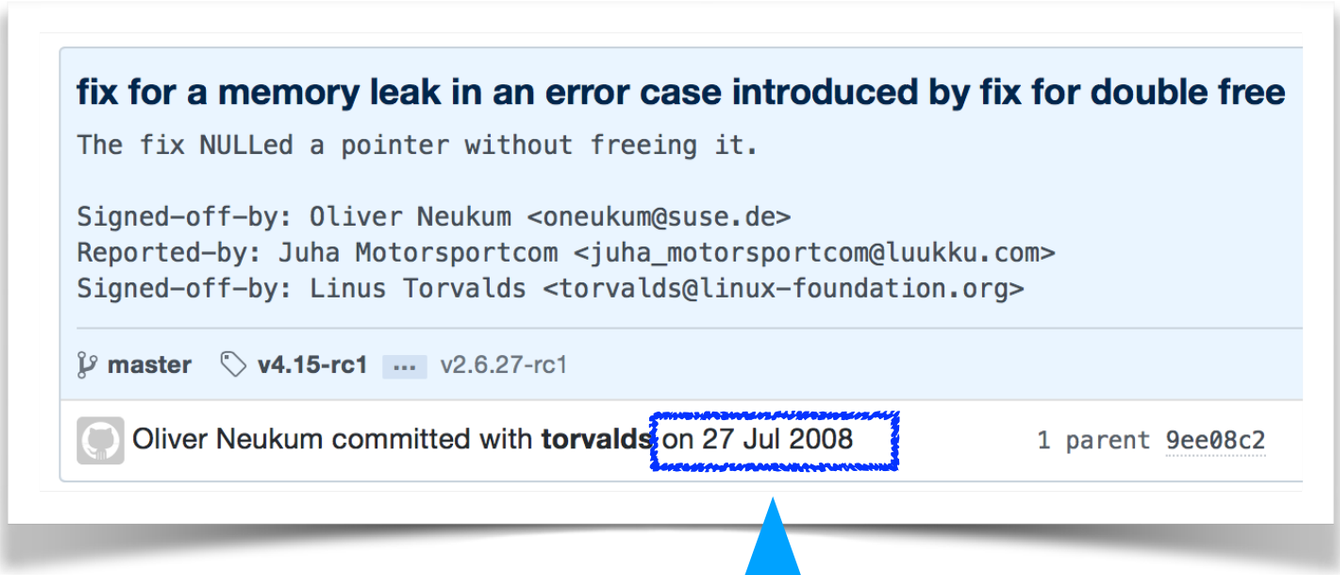
Signed-off-by: Oliver Neukum <oneukum@suse.de>
Signed-off-by: Greg Kroah-Hartman <gregkh@suse.de>

master v4.15-rc1 ... v2.6.27-rc1

Oliver Neukum committed with gregkh on 30 Jun 2008 1 parent 35

Second attempt (9 months later)

(1) Double-Free in Linux Kernel

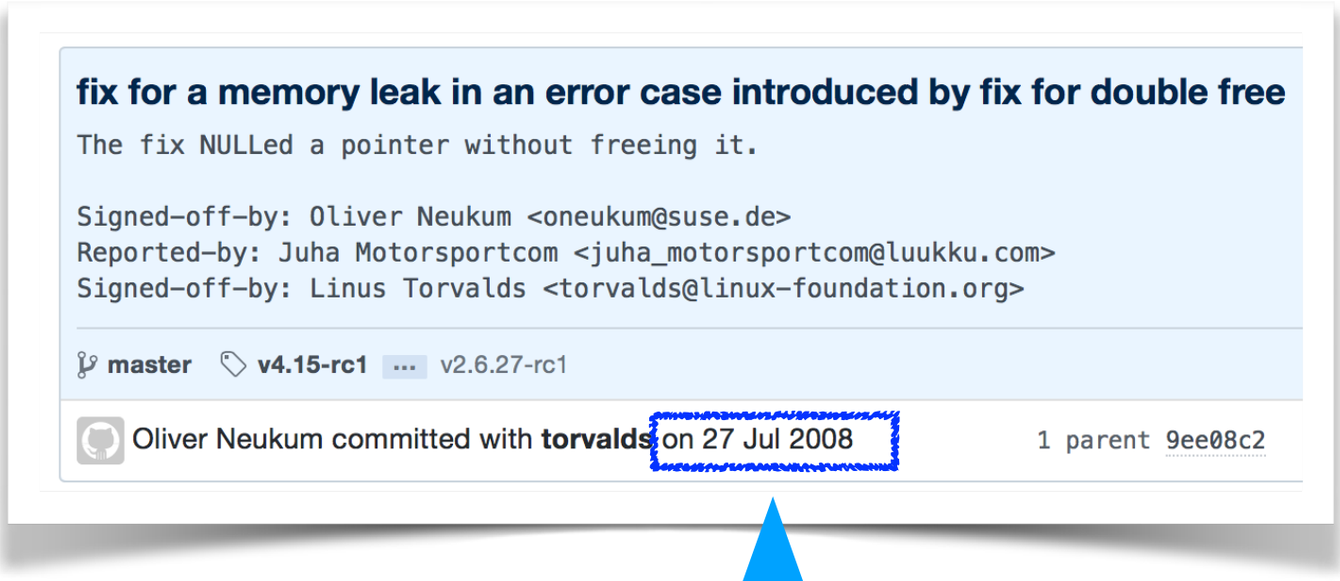


Third attempt
(10 months after bug detection)

```
in = malloc(1);
out = malloc(1);
... // use in, out
free(out);
free(in);
out = NULL;
in = malloc(2);
if (in == NULL) {
  out = NULL;
  goto err;
}
free(out);
out = malloc(2);
if (out == NULL) {
  free(in);
  in = NULL;
  goto err;
}
... // use in, out
err:
  free(in);
  free(out);
  return;
```

(1) Double-Free in Linux Kernel

Challenge 3: The resulting patches are often not of high quality



Third attempt
(10 months after bug detection)

```
in = malloc(1);
out = malloc(1);
... // use in, out
free(out);
free(in);
out = NULL;
in = malloc(2);
if (in == NULL) {
  out = NULL;
  goto err;
}
~~free(out);~~
out = malloc(2);
if (out == NULL) {
  free(in);
  in = NULL;
  goto err;
}
... // use in, out
err:
  free(in);
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  return;
```

SAVER-Generated Patch

```
in = malloc(1);
out = malloc(1);
... // use in, out
free(out);
free(in);

in = malloc(2);
if (in == NULL) {
  goto err;
}

out = malloc(2);
if (out == NULL) {
  free(in);

  goto err;
}
... // use in, out
err:
  free(in); // double-free
  free(out);// double-free
  return;
```

✓Fast (few mins)

✓Safety guarantee

```
in = malloc(1);
out = malloc(1);
... // use in, out
~~free(out);~~
free(in);

in = malloc(2);
if (in == NULL) {
  goto err;
}
free(out);
out = malloc(2);
if (out == NULL) {
  ~~free(in);~~

  goto err;
}
... // use in, out
err:
  free(in);
  free(out);
  return;
```

(2) Memory Leak in Snort

```
1  int append_data (Node *node, int *ndata) {
2      if (!(Node *n = malloc(sizeof(Node)))
3          return -1; // failed to be appended
4      n->data = ndata;
5      n->next = node->next; node->next = n;
6      return 0; // successfully appended
7  }
8
9  Node *lx = ... // a linked list
10 Node *ly = ... // a linked list
11 for (Node *node = lx; node != NULL; node = node->next) {
12     int *dptr = malloc(sizeof(int));
13     if (!dptr) return;
14     *dptr = *(node->data);
15 (-) append_data(ly, dptr); // potential memory-leak
16
17 }
```

Infer

Memory Leak:
An object allocated at line 12
becomes unreachable after line 15

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17 }
```

Normal execution

Infer

```
Memory Leak:
An object allocated at line 12
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```

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17 }
```

Buggy execution

Infer

Memory Leak:
An object allocated at line 12
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11 for (Node *node = lx; node != NULL; node = node->next) {
12     int *dptr = malloc(sizeof(int));
13     if (!dptr) return;
14     *dptr = *(node->data);
15 (-) append_data(ly, dptr); // potential memory-leak
16 (+) if ((append_data(ly, dptr)) == -1) free(dptr);
17 }
```

Infer

Memory Leak:
An object allocated at line 12
becomes unreachable after line 15

cf) SAVER vs. Generative AI

- LLMs do not guarantee safety, e.g., GPT4-generated patch:

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UAF or DF introduced

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```

UAF or DF introduced

(3) Use-After-Free in Binutils

```
1   struct node *cleanup; // list of objects to be deallocated
2   struct node *first = NULL;
3   for (...) {
4       struct node *new = xmalloc(sizeof(*new));
5       make_cleanup(new); // add new to the cleanup list
6       new->name = ...;
7       ...
8       if (...) {
9           first = new;
10
11          continue;
12      }
13    /* potential use-after-free: `first->name` */
14  (-)   if (first == NULL || new->name != first->name)
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16          continue;
17    do_cleanups(); // deallocate all objects in cleanup
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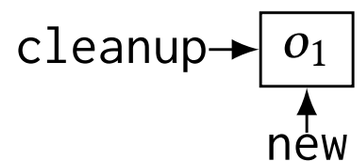

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6       new->name = ...;
7       ...                          true
8       if (...) {
9           first = new;
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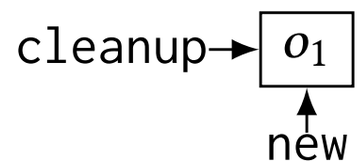

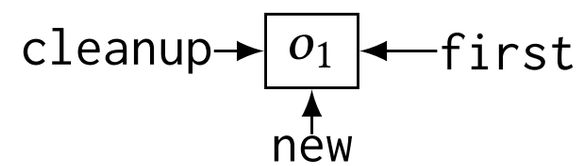

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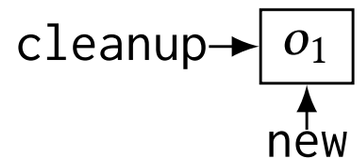

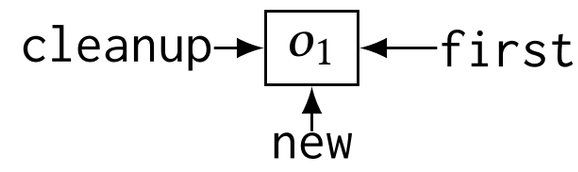

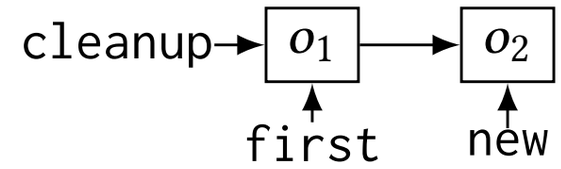

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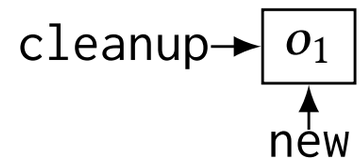

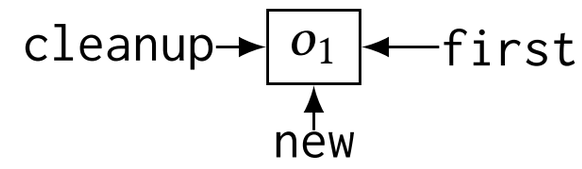

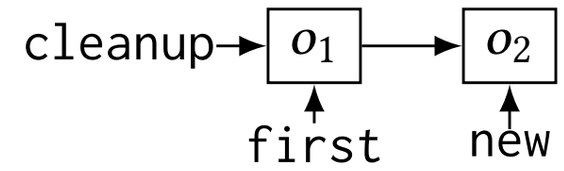

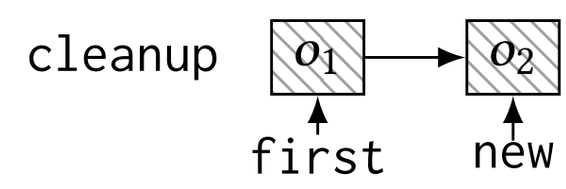

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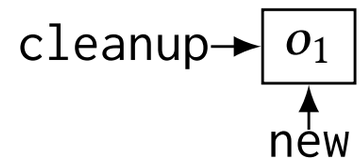

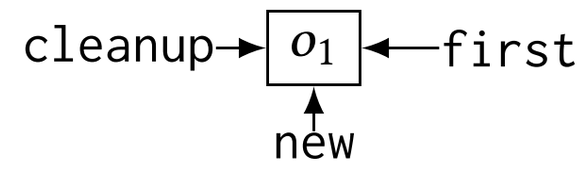

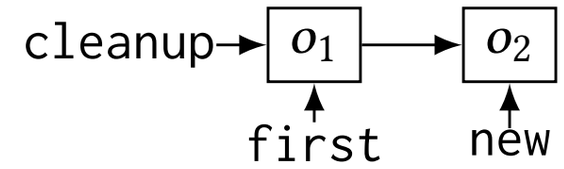

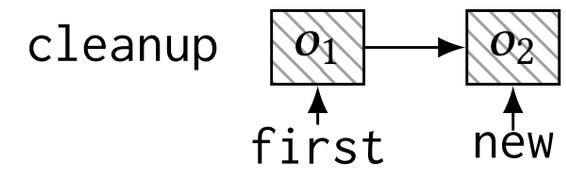

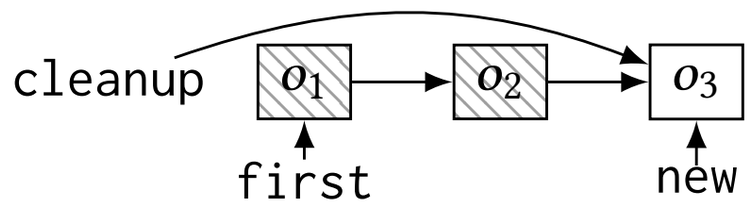

(3) Use-After-Free in Binutils

```
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3  for (...) {
4      struct node *new = xmalloc(sizeof(*new));
5      make_cleanup(new); // add new to the cleanup list
6      new->name = ...;
7      ...                                    false
8      if (...) {
9          first = new;
10
11         continue;
12     }
13   /* potential use-after-free: `first->name` */
14 (-)  if (first == NULL || new->name != first->name)
15
16         continue;
17   do_cleanups(); // deallocate all objects in cleanup
18 }
```
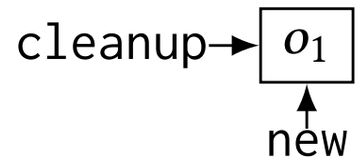
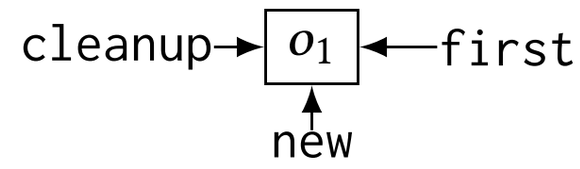
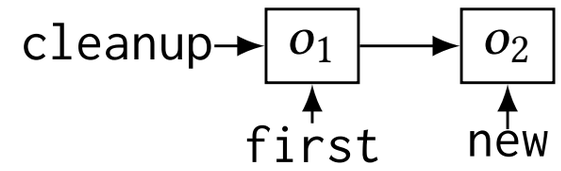
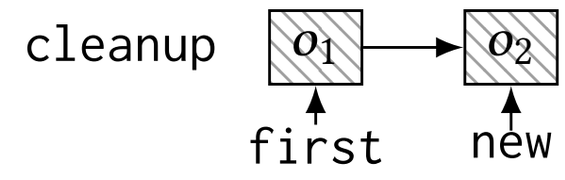
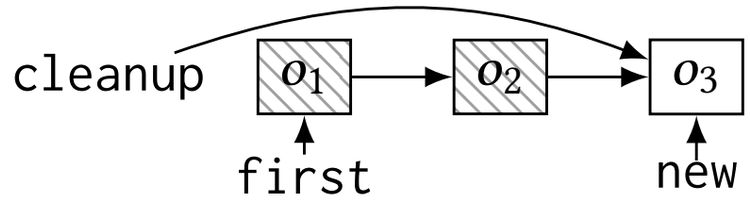





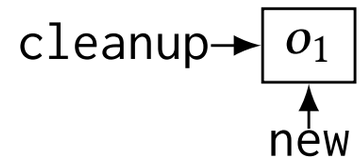


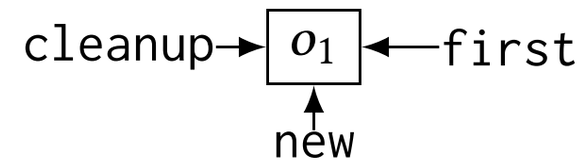


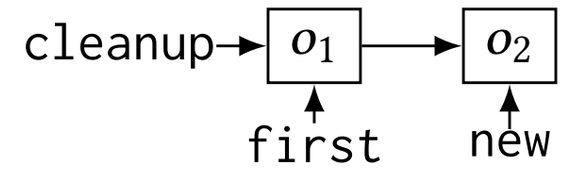


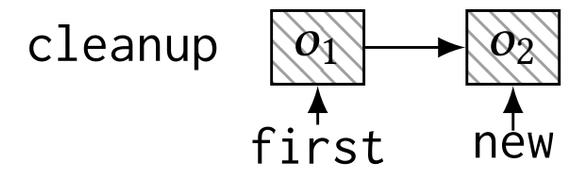
(3) Use-After-Free in Binutils

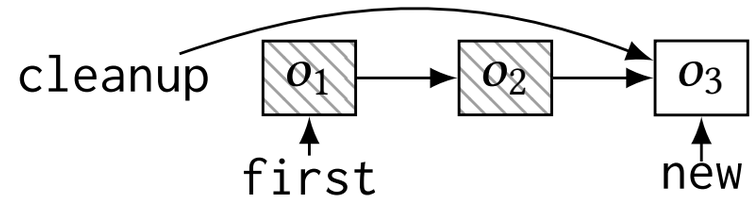
```
1  struct node *cleanup; // list of objects to be deallocated
2  struct node *first = NULL;
3  for (...) {
4      struct node *new = xmalloc(sizeof(*new));
5      make_cleanup(new); // add new to the cleanup list
6      new->name = ...;
7      ...                                  false
8      if (...) {
9          first = new;
10
11         continue;
12     }
13   /* potential use-after-free: `first->name` */
14 (-)  if (first == NULL || new->name != first->name)
15
16         continue;                        use-after-free
17   do_cleanups(); // deallocate all objects in cleanup
18 }
```











SAVER-Generated Patch

```
1   struct node *cleanup; // list of objects to be deallocated
2   struct node *first = NULL;
3   for (...) {
4       struct node *new = xmalloc(sizeof(*new));
5       make_cleanup(new); // add new to the cleanup list
6       new->name = ...;
7       ...
8       if (...) {
9           first = new;
10  (+)     tmp = first->name;
11          continue;
12      }
13    /* potential use-after-free: `first->name` */
14  (-)   if (first == NULL || new->name != first->name)
15  (+)   if (first == NULL || new->name != tmp)
16          continue;
17    do_cleanups(); // deallocate all objects in cleanup
18  }
```

How SAVER Works

```
1  p = malloc(1); //o1
2  if (C)
3    q = p;
4  else
5    q = malloc(1); //o2
6  *p = 1;
7  free(q);
```

Memory leak: o_1 is not freed when the false branch is taken

How SAVER Works

```
1  p = malloc(1); //o1
2  if (C)
3    q = p;
4  else
5    q = malloc(1); //o2
6  *p = 1;
7  free(q);
```

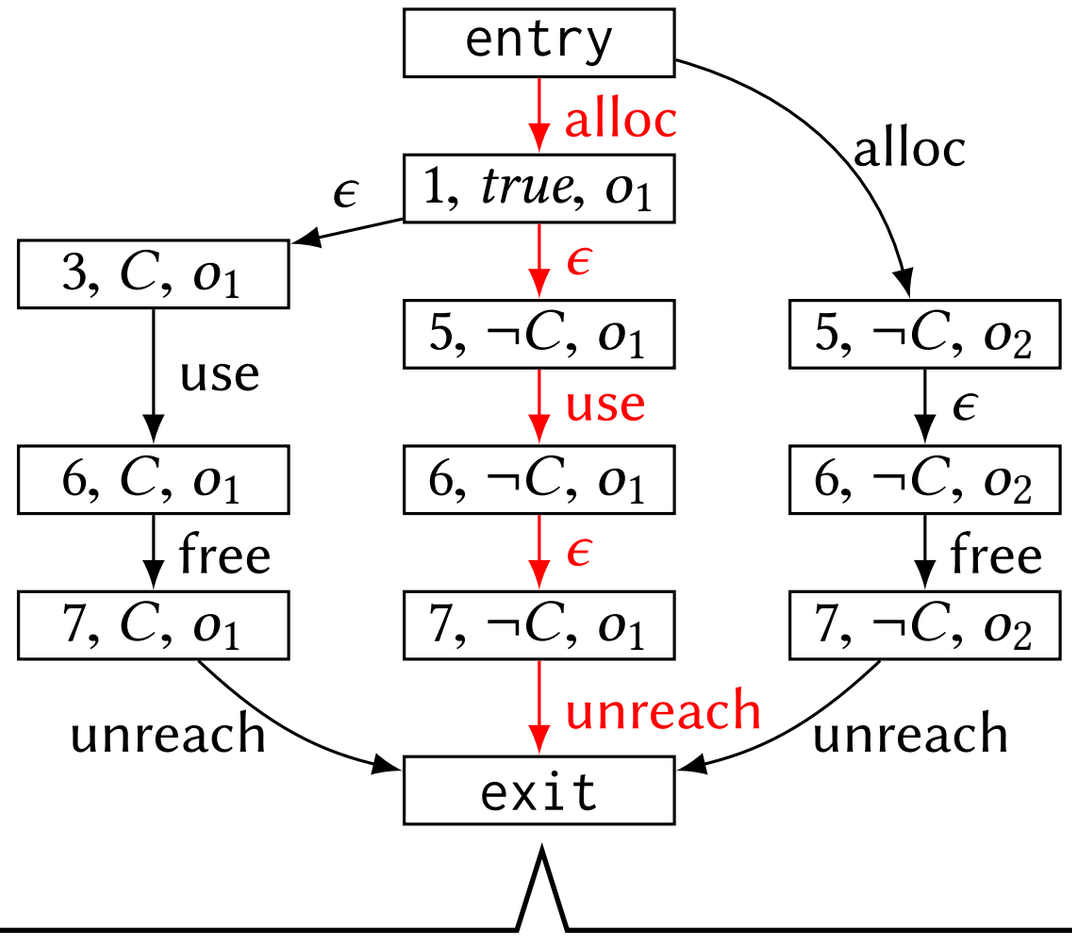
if (!C) free(p);

Memory leak: o_1 is not freed when the false branch is taken

How SAVER Works

1. Run a static analysis to generate *object flow graph*

```
1  p = malloc(1); //o1
2  if (C)
3    q = p;
4  else
5    q = malloc(1); //o2
6  *p = 1;
7  free(q);
```

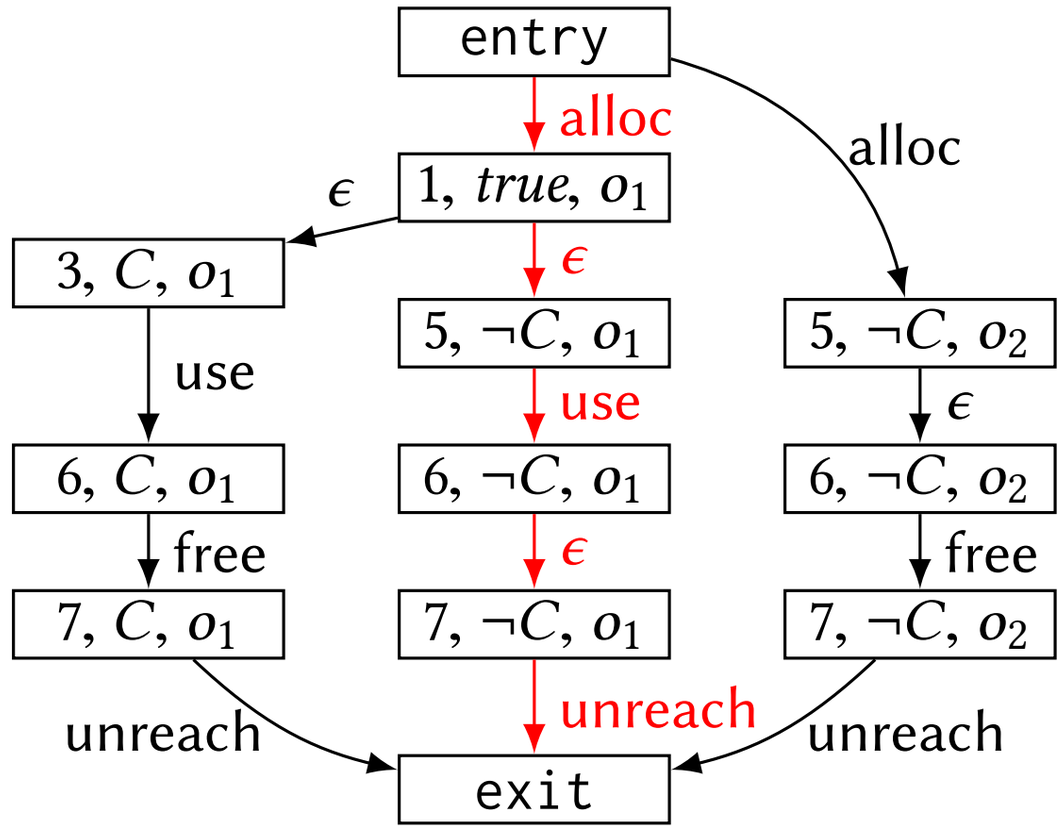


- Vertex: (program point, path condition, available heap object)
- Edge: control flow labeled w/ events that could occur for objects

How SAVER Works

2. Relabel object flow graph to eliminate buggy paths

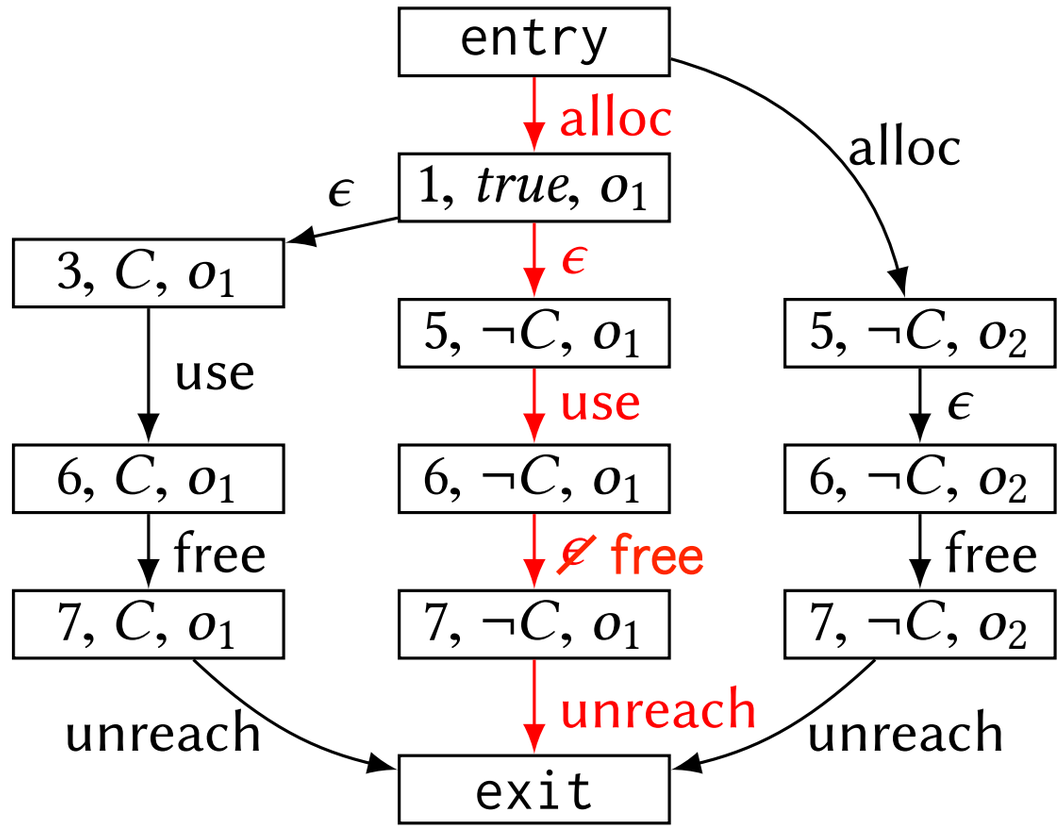
```
1  p = malloc(1); //o1
2  if (C)
3    q = p;
4  else
5    q = malloc(1); //o2
6  *p = 1;
7  free(q);
```



How SAVER Works

2. Relabel object flow graph to eliminate buggy paths

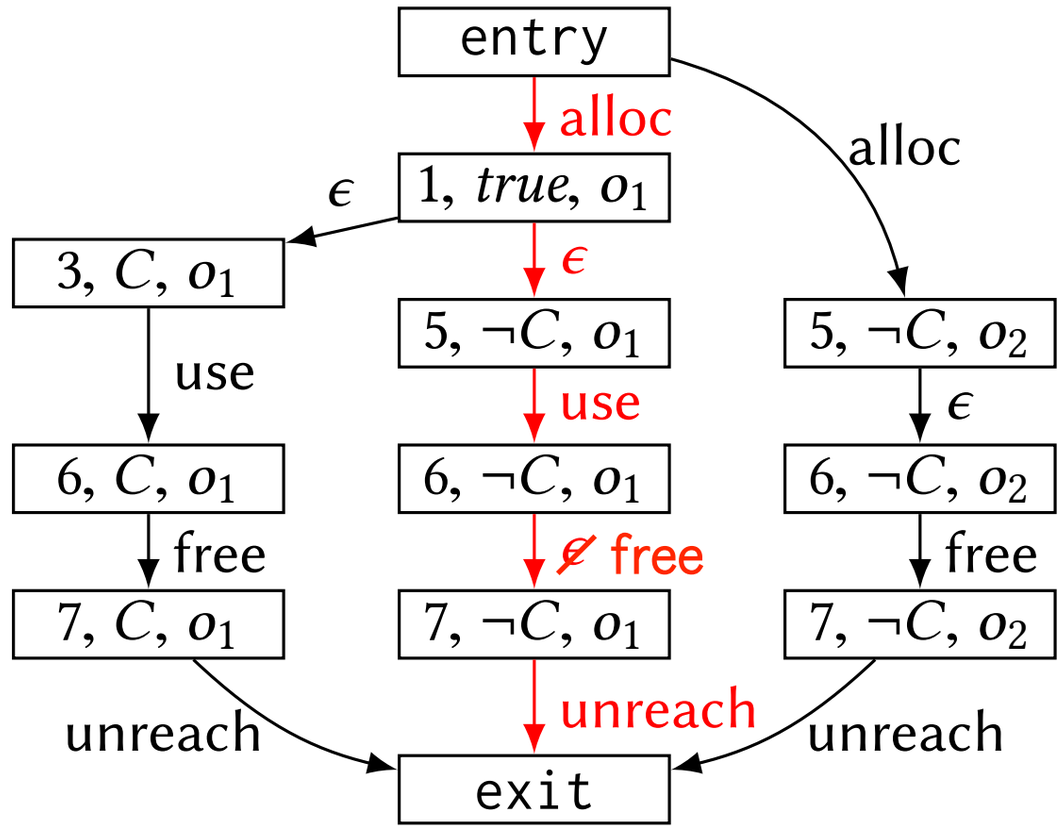
```
1  p = malloc(1); //o1
2  if (C)
3    q = p;
4  else
5    q = malloc(1); //o2
6  *p = 1;
7  free(q);
```



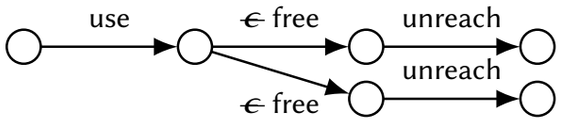
How SAVER Works

2. Relabel object flow graph to eliminate buggy paths

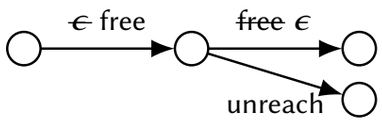
```
1  p = malloc(1); //o1
2  if (C)
3    q = p;
4  else
5    q = malloc(1); //o2
6  *p = 1;
7  free(q);
```



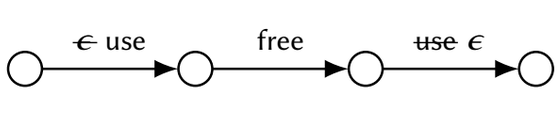
- SAVER supports four types of re-labeling strategies:



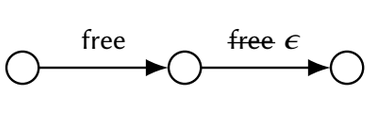
(a) Inserting free



(b) Relocating free



(c) Relocating use (dereference)



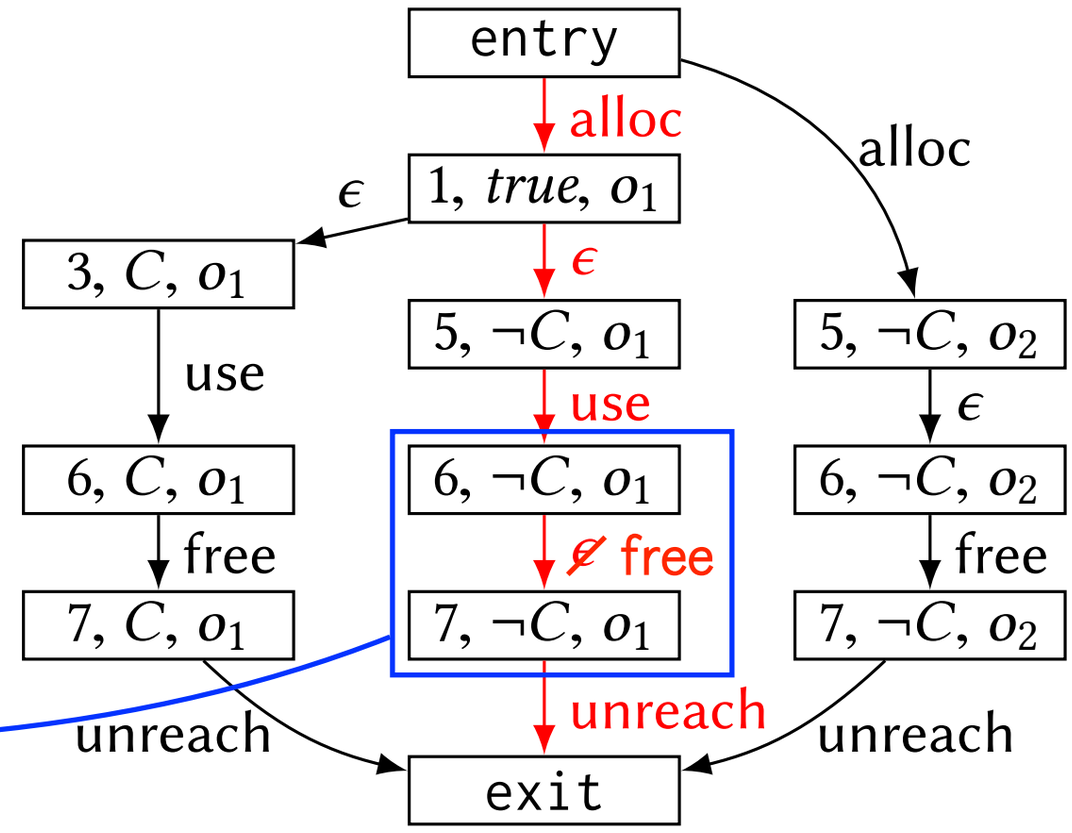
(d) Deleting free

How SAVER Works

3. Generate a patch from the re-labeled edge

```
1  p = malloc(1); //o1
2  if (C)
3    q = p;
4  else
5    q = malloc(1); //o2
6  *p = 1;
7  free(q);
```

if (!C) free(p);



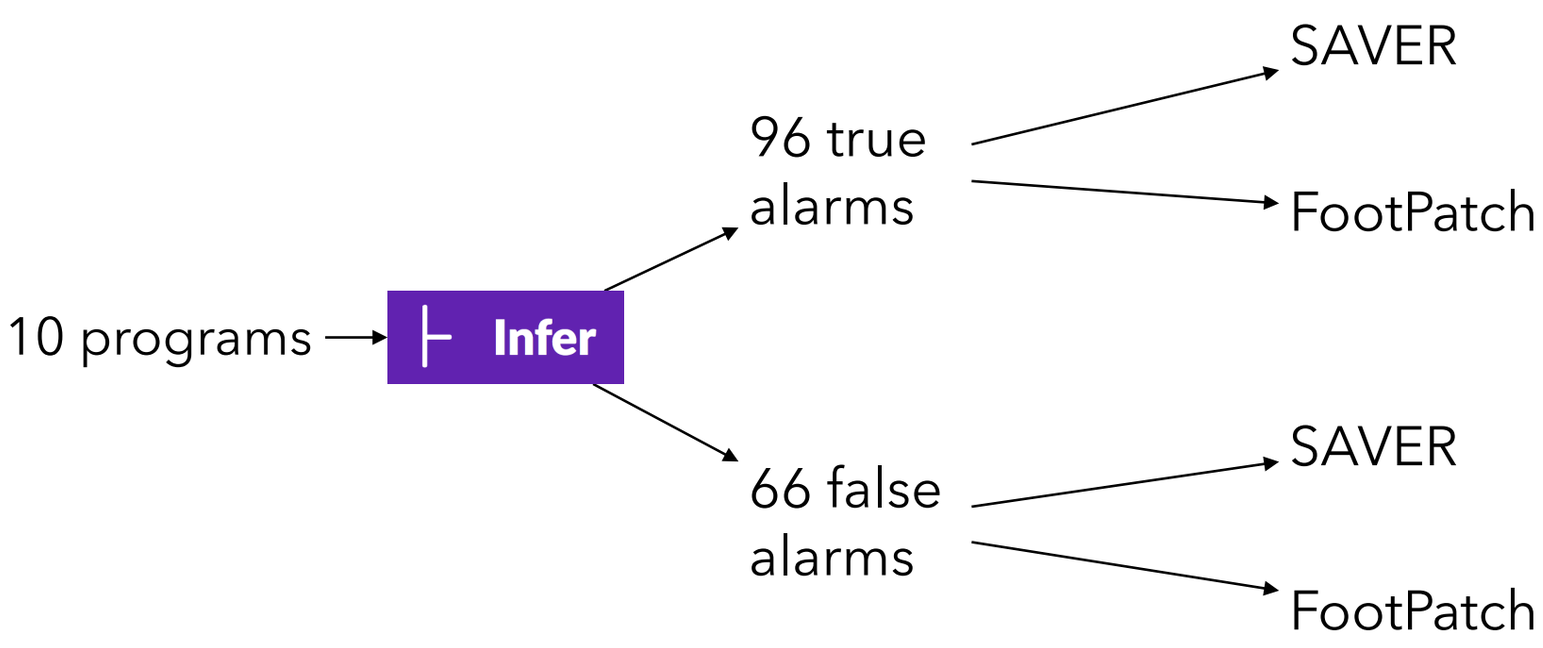
For Deployment

- Improved scalability (in the paper)
  - Selective path sensitivity
  - Program slicing
- Improved usability (not in the paper)
  - Build failures
  - Robust translation from IR-level patches to source-level

Effectiveness

Existing memory error repair tool [ICSE 2018]

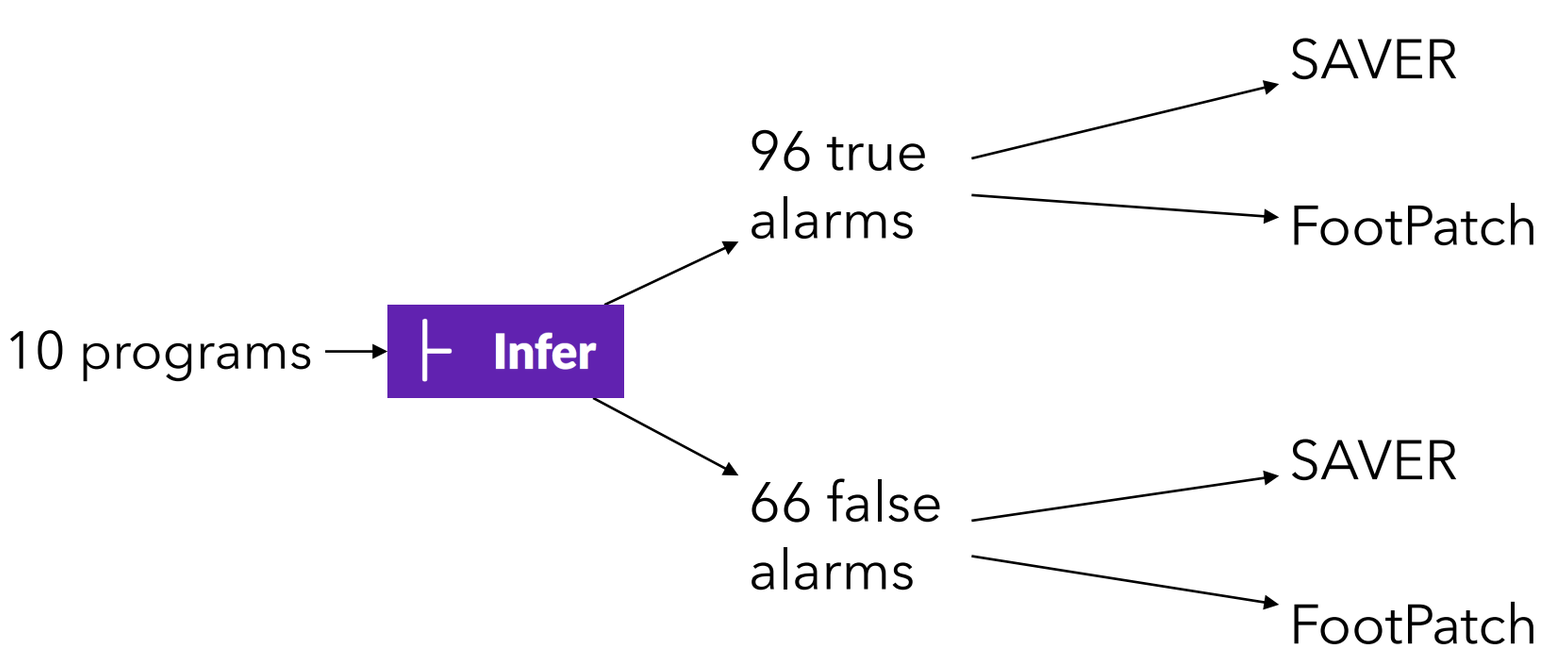
		Infer				SAVER						FootPatch [60]						
Program	**kLoC**	**#T**	**#F**	**Pre(s)**	**Fix(s)**	G_T	$✓_T$	$△_T$	$✗_T$	G_F	$✗_F$	**Fix(s)**	G_T	$✓_T$	$△_T$	$✗_T$	G_F	$✗_F$
rappel (ad8efd7)	2.2	1	0	2.2	0.0	1	1	0	0	0	0	8.9	1	1	0	0	0	0
flex (d3de49f)	22.3	3	4	26.3	2.5	0	0	0	0	0	0	51.0	0	0	0	0	1	1
WavPack (22977b2)	31.2	1	2	44.6	22.1	0	0	0	0	0	0	67.9	0	0	0	0	2	2
Swoole (a4256e4)	43.0	15	3	88.5	10.1	11	11	0	0	0	0	392.5	9	7	0	2	1	1
lxc (72cc48f)	49.9	3	5	230.6	5.8	3	3	0	0	0	0	179.6	0	0	0	0	1	1
p11-kit (ead7ara)	62.9	33	9	646.2	288.8	24	24	0	0	0	0	566.4	8	7	1	0	2	2
x264 (d4099dd)	73.2	10	0	144.3	9.9	10	10	0	0	0	0	426.9	2	2	0	0	0	0
recutils-1.8	92.0	10	11	144.1	44.4	8	8	0	0	0	0	662.2	3	2	1	0	0	0
inetutils-1.9.4	116.9	4	5	44.8	2.5	4	4	0	0	0	0	182.1	0	0	0	0	0	0
snort-2.9.13	320.8	16	27	2372.0	216.0	11	10	1	0	0	0	4636.4	3	0	0	3	19	18
Total	814.4	96	66	3743.6	602.1	72	71	1	0	0	0	7173.9	26	19	2	5	26	25



Effectiveness

Existing memory error repair tool [ICSE 2018]

		Infer				SAVER						FootPatch [60]						
Program	**kLoC**	**#T**	**#F**	**Pre(s)**	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$
rappel (ad8efd7)	2.2	1	0	2.2	0.0	1	1	0	0	0	0	8.9	1	1	0	0	0	0
flex (d3de49f)	22.3	3	4	26.3	2.5	0	0	0	0	0	0	51.0	0	0	0	0	1	1
WavPack (22977b2)	31.2	1	2	44.6	22.1	0	0	0	0	0	0	67.9	0	0	0	0	2	2
Swoole (a4256e4)	43.0	15	3	88.5	10.1	11	11	0	0	0	0	392.5	9	7	0	2	1	1
lxc (72cc48f)	49.9	3	5	230.6	5.8	3	3	0	0	0	0	179.6	0	0	0	0	1	1
p11-kit (ead7ara)	62.9	33	9	646.2	288.8	24	24	0	0	0	0	566.4	8	7	1	0	2	2
x264 (d4099dd)	73.2	10	0	144.3	9.9	10	10	0	0	0	0	426.9	2	2	0	0	0	0
recutils-1.8	92.0	10	11	144.1	44.4	8	8	0	0	0	0	662.2	3	2	1	0	0	0
inetutils-1.9.4	116.9	4	5	44.8	2.5	4	4	0	0	0	0	182.1	0	0	0	0	0	0
snort-2.9.13	320.8	16	27	2372.0	216.0	11	10	1	0	0	0	4636.4	3	0	0	3	19	18
Total	814.4	96	66	3743.6	602.1	72	71	1	0	0	0	7173.9	26	19	2	5	26	25



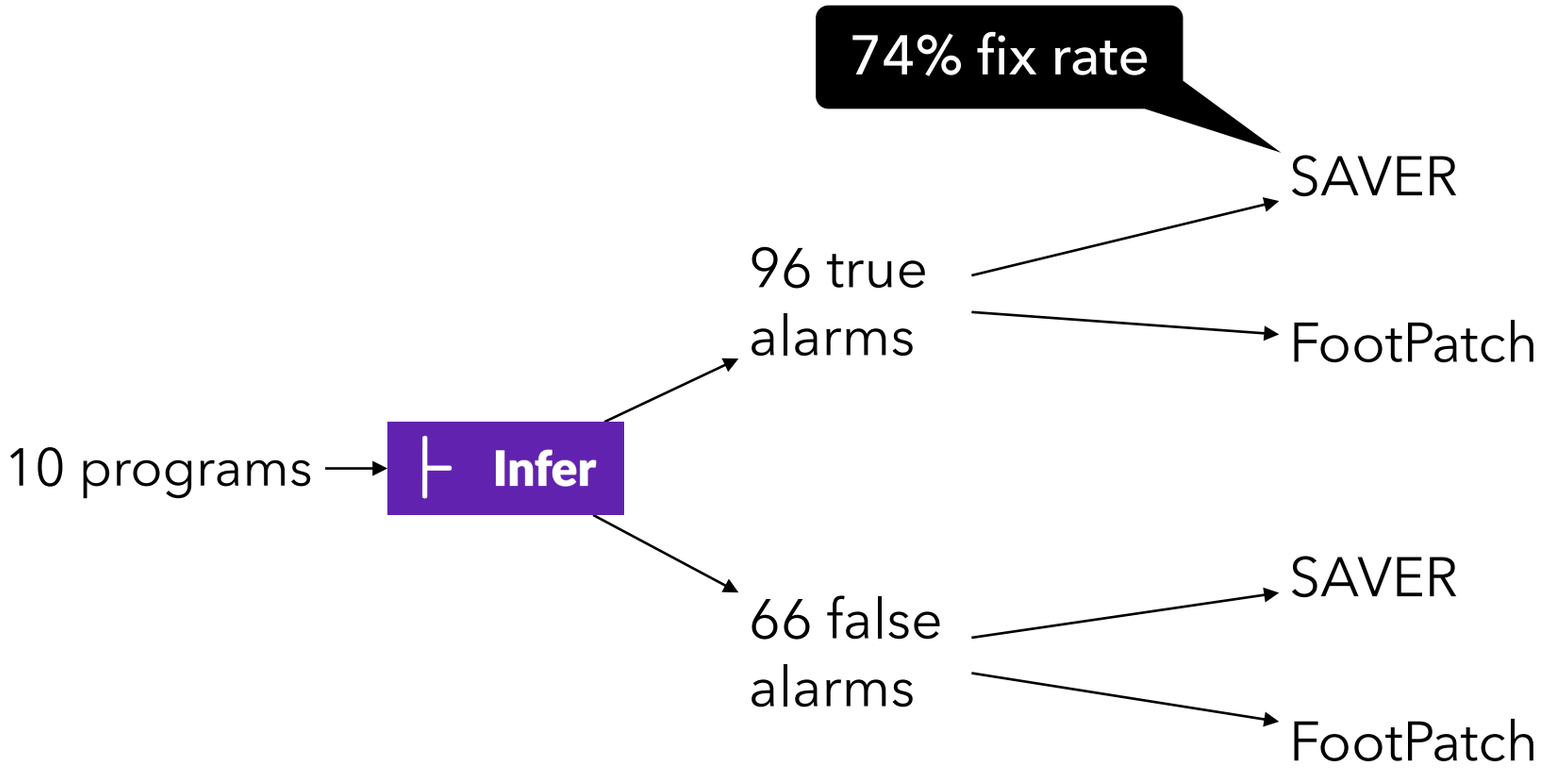
Generated 72 patches

(Fixed: 71, Safe: 1, Unsafe: 0)

Effectiveness

Existing memory error repair tool [ICSE 2018]

		Infer				SAVER						FootPatch [60]						
Program	**kLoC**	**#T**	**#F**	**Pre(s)**	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$
rappel (ad8efd7)	2.2	1	0	2.2	0.0	1	1	0	0	0	0	8.9	1	1	0	0	0	0
flex (d3de49f)	22.3	3	4	26.3	2.5	0	0	0	0	0	0	51.0	0	0	0	0	1	1
WavPack (22977b2)	31.2	1	2	44.6	22.1	0	0	0	0	0	0	67.9	0	0	0	0	2	2
Swoole (a4256e4)	43.0	15	3	88.5	10.1	11	11	0	0	0	0	392.5	9	7	0	2	1	1
lxc (72cc48f)	49.9	3	5	230.6	5.8	3	3	0	0	0	0	179.6	0	0	0	0	1	1
p11-kit (ead7ara)	62.9	33	9	646.2	288.8	24	24	0	0	0	0	566.4	8	7	1	0	2	2
x264 (d4099dd)	73.2	10	0	144.3	9.9	10	10	0	0	0	0	426.9	2	2	0	0	0	0
recutils-1.8	92.0	10	11	144.1	44.4	8	8	0	0	0	0	662.2	3	2	1	0	0	0
inetutils-1.9.4	116.9	4	5	44.8	2.5	4	4	0	0	0	0	182.1	0	0	0	0	0	0
snort-2.9.13	320.8	16	27	2372.0	216.0	11	10	1	0	0	0	4636.4	3	0	0	3	19	18
Total	814.4	96	66	3743.6	602.1	72	71	1	0	0	0	7173.9	26	19	2	5	26	25



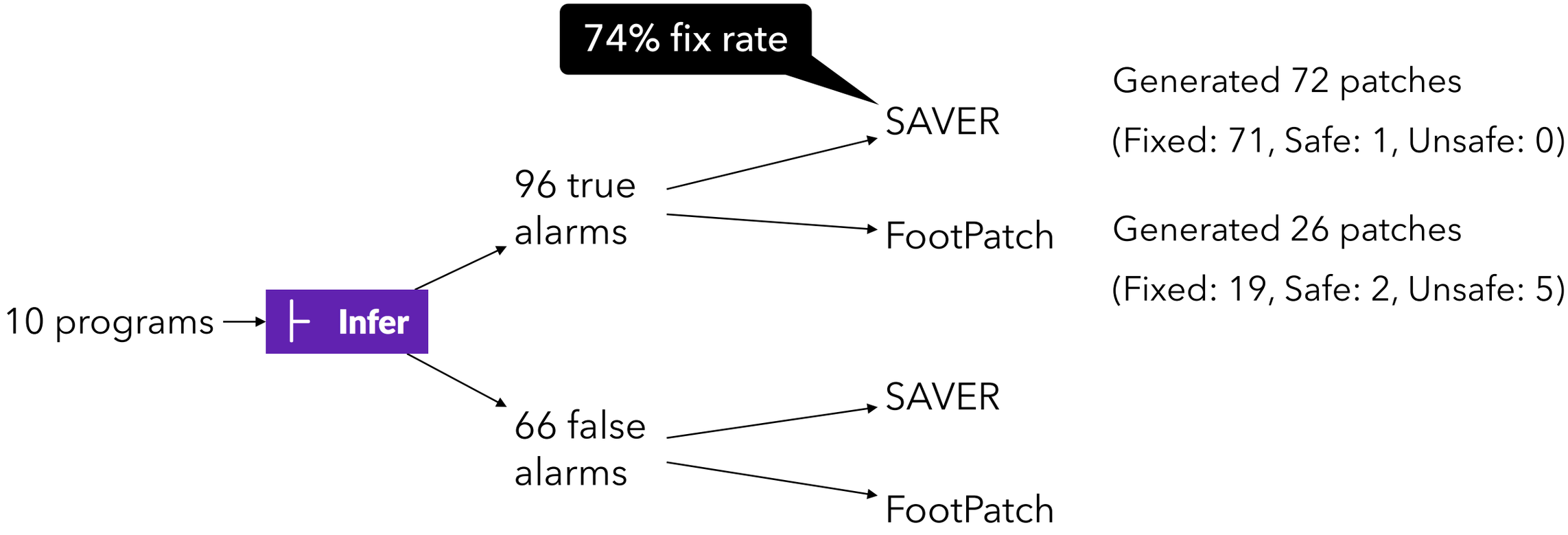
Generated 72 patches

(Fixed: 71, Safe: 1, Unsafe: 0)

Effectiveness

Existing memory error repair tool [ICSE 2018]

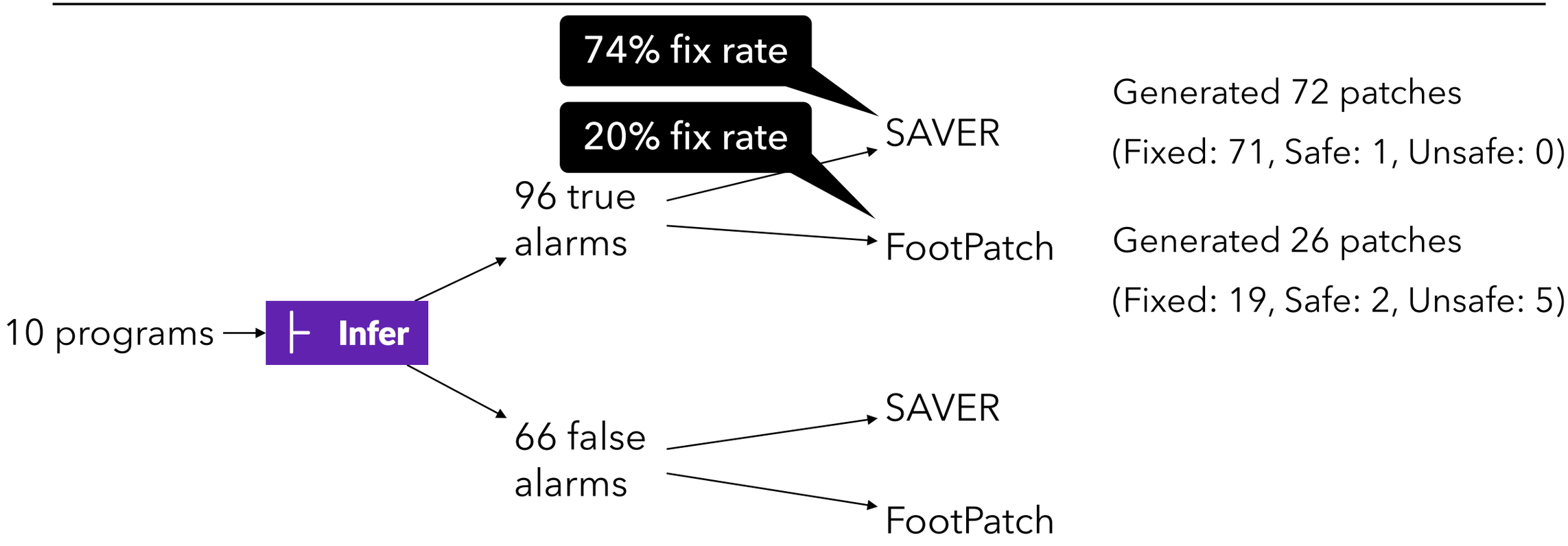
		Infer				SAVER						FootPatch [60]						
Program	**kLoC**	**#T**	**#F**	**Pre(s)**	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$
rappel (ad8efd7)	2.2	1	0	2.2	0.0	1	1	0	0	0	0	8.9	1	1	0	0	0	0
flex (d3de49f)	22.3	3	4	26.3	2.5	0	0	0	0	0	0	51.0	0	0	0	0	1	1
WavPack (22977b2)	31.2	1	2	44.6	22.1	0	0	0	0	0	0	67.9	0	0	0	0	2	2
Swoole (a4256e4)	43.0	15	3	88.5	10.1	11	11	0	0	0	0	392.5	9	7	0	2	1	1
lxc (72cc48f)	49.9	3	5	230.6	5.8	3	3	0	0	0	0	179.6	0	0	0	0	1	1
p11-kit (ead7ara)	62.9	33	9	646.2	288.8	24	24	0	0	0	0	566.4	8	7	1	0	2	2
x264 (d4099dd)	73.2	10	0	144.3	9.9	10	10	0	0	0	0	426.9	2	2	0	0	0	0
recutils-1.8	92.0	10	11	144.1	44.4	8	8	0	0	0	0	662.2	3	2	1	0	0	0
inetutils-1.9.4	116.9	4	5	44.8	2.5	4	4	0	0	0	0	182.1	0	0	0	0	0	0
snort-2.9.13	320.8	16	27	2372.0	216.0	11	10	1	0	0	0	4636.4	3	0	0	3	19	18
Total	814.4	96	66	3743.6	602.1	72	71	1	0	0	0	7173.9	26	19	2	5	26	25



Effectiveness

Existing memory error repair tool [ICSE 2018]

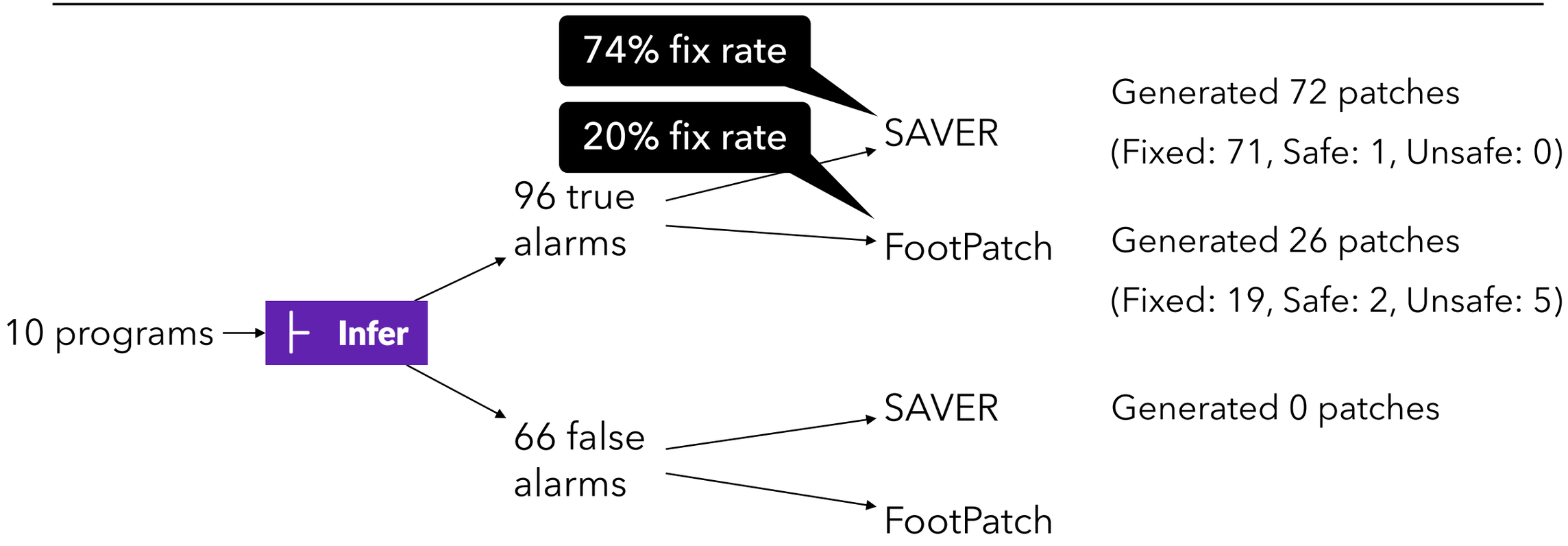
		Infer				SAVER						FootPatch [60]						
Program	**kLoC**	**#T**	**#F**	**Pre(s)**	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$
rappel (ad8efd7)	2.2	1	0	2.2	0.0	1	1	0	0	0	0	8.9	1	1	0	0	0	0
flex (d3de49f)	22.3	3	4	26.3	2.5	0	0	0	0	0	0	51.0	0	0	0	0	1	1
WavPack (22977b2)	31.2	1	2	44.6	22.1	0	0	0	0	0	0	67.9	0	0	0	0	2	2
Swoole (a4256e4)	43.0	15	3	88.5	10.1	11	11	0	0	0	0	392.5	9	7	0	2	1	1
lxc (72cc48f)	49.9	3	5	230.6	5.8	3	3	0	0	0	0	179.6	0	0	0	0	1	1
p11-kit (ead7ara)	62.9	33	9	646.2	288.8	24	24	0	0	0	0	566.4	8	7	1	0	2	2
x264 (d4099dd)	73.2	10	0	144.3	9.9	10	10	0	0	0	0	426.9	2	2	0	0	0	0
recutils-1.8	92.0	10	11	144.1	44.4	8	8	0	0	0	0	662.2	3	2	1	0	0	0
inetutils-1.9.4	116.9	4	5	44.8	2.5	4	4	0	0	0	0	182.1	0	0	0	0	0	0
snort-2.9.13	320.8	16	27	2372.0	216.0	11	10	1	0	0	0	4636.4	3	0	0	3	19	18
Total	814.4	96	66	3743.6	602.1	72	71	1	0	0	0	7173.9	26	19	2	5	26	25



Effectiveness

Existing memory error repair tool [ICSE 2018]

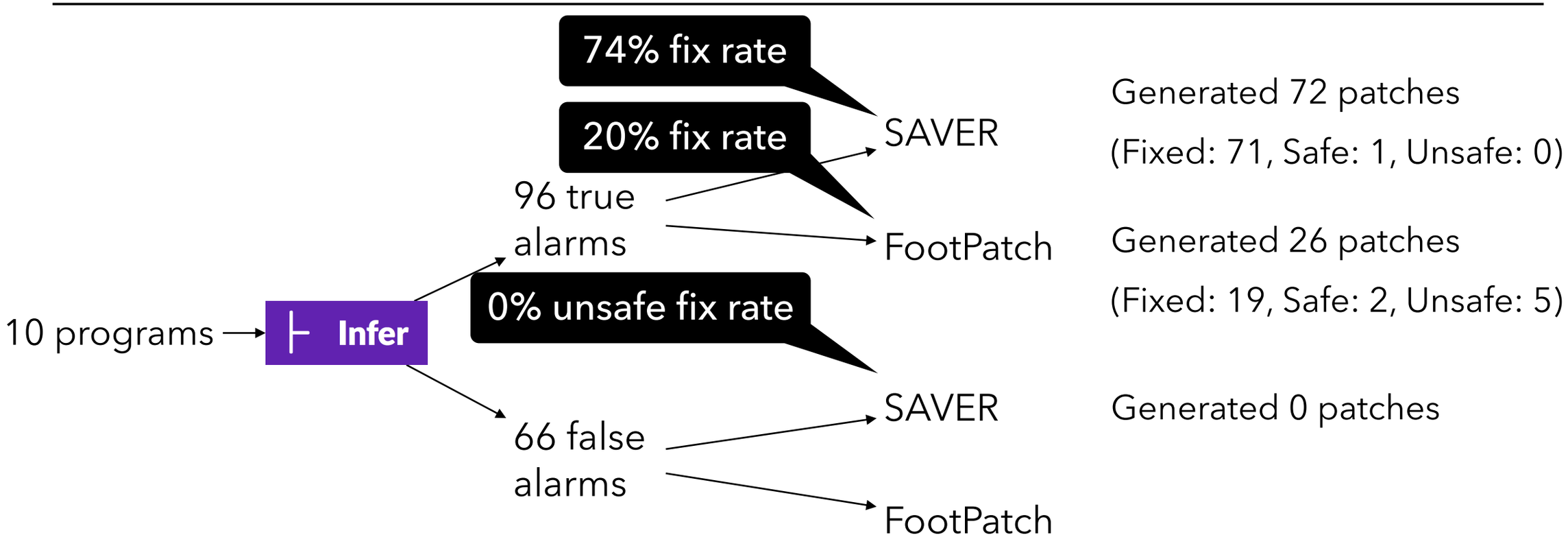
		Infer				SAVER						FootPatch [60]						
Program	**kLoC**	**#T**	**#F**	**Pre(s)**	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$
rappel (ad8efd7)	2.2	1	0	2.2	0.0	1	1	0	0	0	0	8.9	1	1	0	0	0	0
flex (d3de49f)	22.3	3	4	26.3	2.5	0	0	0	0	0	0	51.0	0	0	0	0	1	1
WavPack (22977b2)	31.2	1	2	44.6	22.1	0	0	0	0	0	0	67.9	0	0	0	0	2	2
Swoole (a4256e4)	43.0	15	3	88.5	10.1	11	11	0	0	0	0	392.5	9	7	0	2	1	1
lxc (72cc48f)	49.9	3	5	230.6	5.8	3	3	0	0	0	0	179.6	0	0	0	0	1	1
p11-kit (ead7ara)	62.9	33	9	646.2	288.8	24	24	0	0	0	0	566.4	8	7	1	0	2	2
x264 (d4099dd)	73.2	10	0	144.3	9.9	10	10	0	0	0	0	426.9	2	2	0	0	0	0
recutils-1.8	92.0	10	11	144.1	44.4	8	8	0	0	0	0	662.2	3	2	1	0	0	0
inetutils-1.9.4	116.9	4	5	44.8	2.5	4	4	0	0	0	0	182.1	0	0	0	0	0	0
snort-2.9.13	320.8	16	27	2372.0	216.0	11	10	1	0	0	0	4636.4	3	0	0	3	19	18
Total	814.4	96	66	3743.6	602.1	72	71	1	0	0	0	7173.9	26	19	2	5	26	25



Effectiveness

Existing memory error repair tool [ICSE 2018]

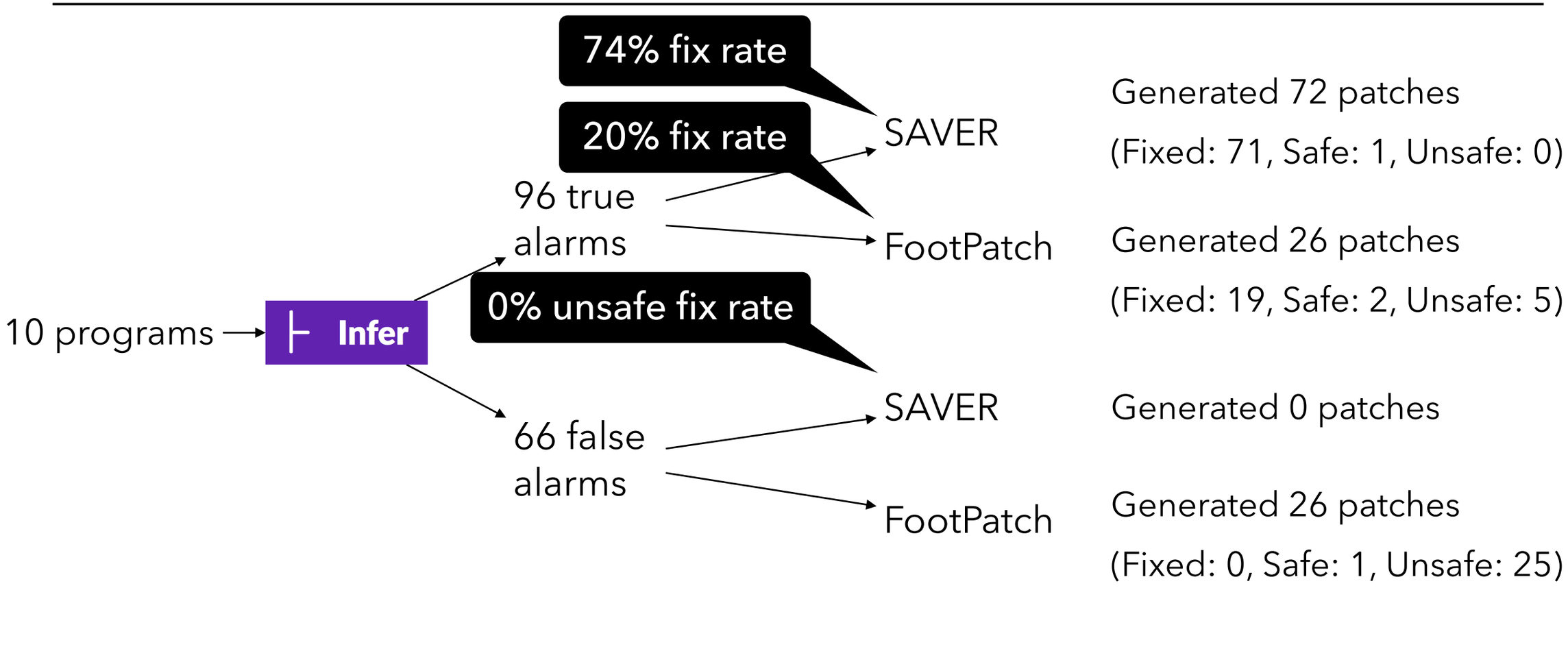
		Infer				SAVER						FootPatch [60]						
Program	**kLoC**	**#T**	**#F**	**Pre(s)**	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$
rappel (ad8efd7)	2.2	1	0	2.2	0.0	1	1	0	0	0	0	8.9	1	1	0	0	0	0
flex (d3de49f)	22.3	3	4	26.3	2.5	0	0	0	0	0	0	51.0	0	0	0	0	1	1
WavPack (22977b2)	31.2	1	2	44.6	22.1	0	0	0	0	0	0	67.9	0	0	0	0	2	2
Swoole (a4256e4)	43.0	15	3	88.5	10.1	11	11	0	0	0	0	392.5	9	7	0	2	1	1
lxc (72cc48f)	49.9	3	5	230.6	5.8	3	3	0	0	0	0	179.6	0	0	0	0	1	1
p11-kit (ead7ara)	62.9	33	9	646.2	288.8	24	24	0	0	0	0	566.4	8	7	1	0	2	2
x264 (d4099dd)	73.2	10	0	144.3	9.9	10	10	0	0	0	0	426.9	2	2	0	0	0	0
recutils-1.8	92.0	10	11	144.1	44.4	8	8	0	0	0	0	662.2	3	2	1	0	0	0
inetutils-1.9.4	116.9	4	5	44.8	2.5	4	4	0	0	0	0	182.1	0	0	0	0	0	0
snort-2.9.13	320.8	16	27	2372.0	216.0	11	10	1	0	0	0	4636.4	3	0	0	3	19	18
Total	814.4	96	66	3743.6	602.1	72	71	1	0	0	0	7173.9	26	19	2	5	26	25



Effectiveness

Existing memory error repair tool [ICSE 2018]

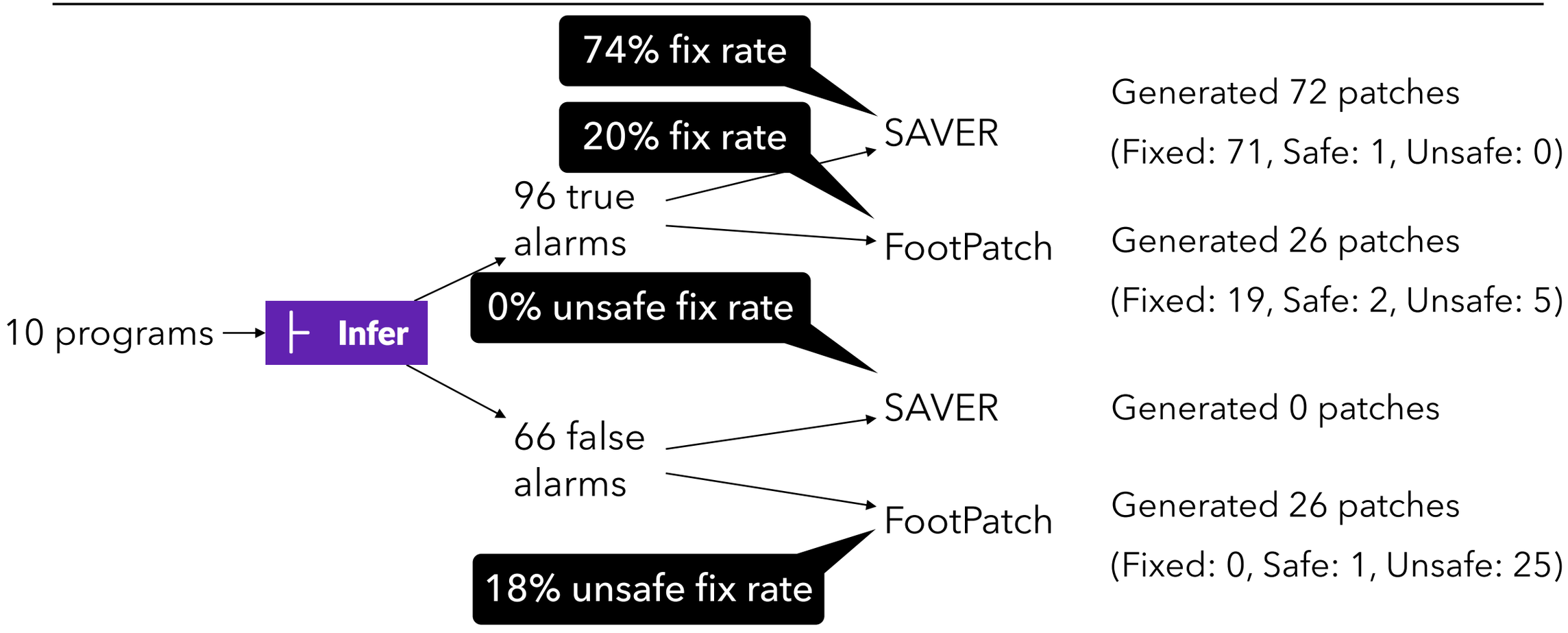
		Infer				SAVER						FootPatch [60]						
Program	**kLoC**	**#T**	**#F**	**Pre(s)**	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$
rappel (ad8efd7)	2.2	1	0	2.2	0.0	1	1	0	0	0	0	8.9	1	1	0	0	0	0
flex (d3de49f)	22.3	3	4	26.3	2.5	0	0	0	0	0	0	51.0	0	0	0	0	1	1
WavPack (22977b2)	31.2	1	2	44.6	22.1	0	0	0	0	0	0	67.9	0	0	0	0	2	2
Swoole (a4256e4)	43.0	15	3	88.5	10.1	11	11	0	0	0	0	392.5	9	7	0	2	1	1
lxc (72cc48f)	49.9	3	5	230.6	5.8	3	3	0	0	0	0	179.6	0	0	0	0	1	1
p11-kit (ead7ara)	62.9	33	9	646.2	288.8	24	24	0	0	0	0	566.4	8	7	1	0	2	2
x264 (d4099dd)	73.2	10	0	144.3	9.9	10	10	0	0	0	0	426.9	2	2	0	0	0	0
recutils-1.8	92.0	10	11	144.1	44.4	8	8	0	0	0	0	662.2	3	2	1	0	0	0
inetutils-1.9.4	116.9	4	5	44.8	2.5	4	4	0	0	0	0	182.1	0	0	0	0	0	0
snort-2.9.13	320.8	16	27	2372.0	216.0	11	10	1	0	0	0	4636.4	3	0	0	3	19	18
Total	814.4	96	66	3743.6	602.1	72	71	1	0	0	0	7173.9	26	19	2	5	26	25



Effectiveness

Existing memory error repair tool [ICSE 2018]

		Infer				SAVER						FootPatch [60]						
Program	**kLoC**	**#T**	**#F**	**Pre(s)**	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$	**Fix(s)**	G_T	✓$_T$	△$_T$	✗$_T$	G_F	✗$_F$
rappel (ad8efd7)	2.2	1	0	2.2	0.0	1	1	0	0	0	0	8.9	1	1	0	0	0	0
flex (d3de49f)	22.3	3	4	26.3	2.5	0	0	0	0	0	0	51.0	0	0	0	0	1	1
WavPack (22977b2)	31.2	1	2	44.6	22.1	0	0	0	0	0	0	67.9	0	0	0	0	2	2
Swoole (a4256e4)	43.0	15	3	88.5	10.1	11	11	0	0	0	0	392.5	9	7	0	2	1	1
lxc (72cc48f)	49.9	3	5	230.6	5.8	3	3	0	0	0	0	179.6	0	0	0	0	1	1
p11-kit (ead7ara)	62.9	33	9	646.2	288.8	24	24	0	0	0	0	566.4	8	7	1	0	2	2
x264 (d4099dd)	73.2	10	0	144.3	9.9	10	10	0	0	0	0	426.9	2	2	0	0	0	0
recutils-1.8	92.0	10	11	144.1	44.4	8	8	0	0	0	0	662.2	3	2	1	0	0	0
inetutils-1.9.4	116.9	4	5	44.8	2.5	4	4	0	0	0	0	182.1	0	0	0	0	0	0
snort-2.9.13	320.8	16	27	2372.0	216.0	11	10	1	0	0	0	4636.4	3	0	0	3	19	18
Total	814.4	96	66	3743.6	602.1	72	71	1	0	0	0	7173.9	26	19	2	5	26	25



Summary

- **Static analysis-based program repair** for C memory errors
  - Scalable, precise, and safe
  - Successfully deployed in industry
  - https://github.com/kupl/kaprese

Thank you!