



Automated Patching

Holistic Software Security

Aravind Machiry



Fixing code automatically!

```
13 else if(request_method == "POST") {  
14     buff=calloc(length, sizeof(char));  
15     rc=recv(socket, buff, length)  
16     buff[length]='\0';  
17 }
```



```
else if(request_method == "POST") {  
+     if (length <= 0)  
+         return null;  
    buff=calloc(length, sizeof(char));  
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    buff[length]='\0';  
}
```



What is it?

Patching a defect (bug or vulnerability) automatically, also known as Automated Program Repair:

- Where and how to fix?
- How to specify the defect?



What is it?

Patching a defect (bug or vulnerability) automatically:

- Where and how to fix? => **On source code, by making source level changes (i.e., editing code statements).**
- How to specify the defect? => **Failing Test cases.**



What is it?

Patching a defect (bug or vulnerability) automatically:

- Where and how to fix? => **On source code, by making source level changes (i.e., editing code statements).**
 - Alternatives:
 - On binaries by doing binary rewriting.
 - Runtime by avoiding error behavior (error recovery).
- How to specify the defect? => **Failing Test cases.**
 - Alternatives:
 - High level specification: All memory errors.



What is it?

Patching a defect (bug or vulnerability) automatically:

- Where and how to fix? => **On source code, by making source level changes (i.e., editing code statements).**
 - Alternatives:
 - ~~On binaries by doing binary rewriting.~~
 - ~~Runtime by avoiding error behavior (error recovery).~~
- How to specify the defect? => **Failing Test cases.**
 - Alternatives:
 - ~~High level specification: All memory errors.~~

Not in this course.

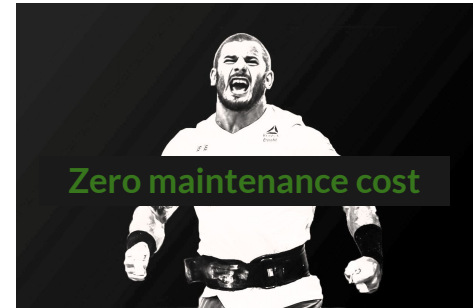
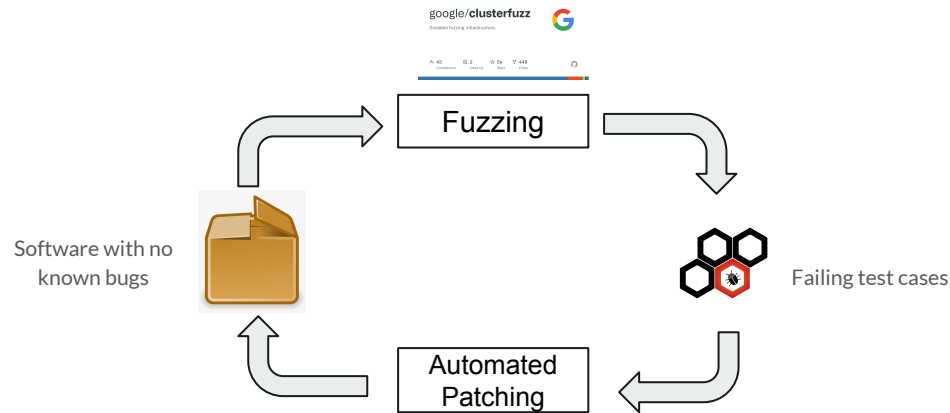


Clarifications

Bug => Root cause and Symptom.

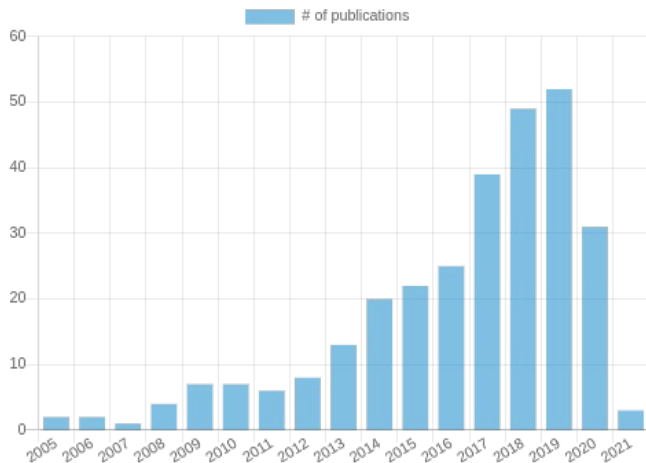
- Root cause => Uninitialized variable, out of bounds access, etc.
 - Fixing Root cause => Program Repair or Automated Patching.
- Symptom => SIGSEGV, Failing test case, etc.
 - Fixing Symptom => Error recovery.

Why is it needed: Automated and continuous software maintenance.

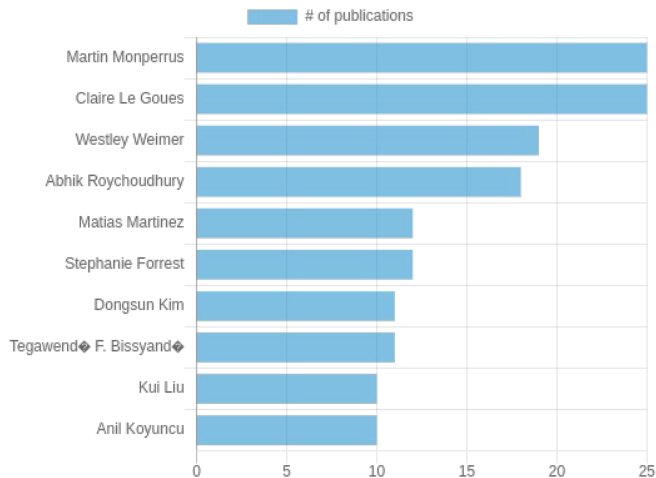


“What one would like ideally [...] is the automatic detection and correction of bugs” R. J. Abbott, 1990

Very active research area



Leaders





Approaches: Overview

- Genetic Programming: GenProg and family.
- Program Analysis: Senx, Talos, SAVER, SPR, etc.
- Machine Learning: Prophet, DeepFix, etc.



Approaches: Overview

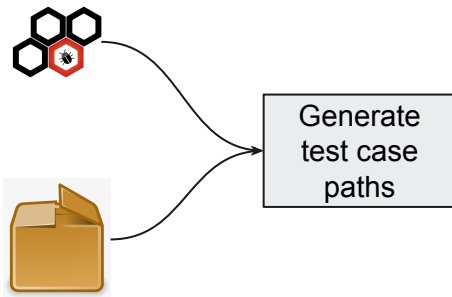
- Genetic Programming: **GenProg** and family.
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GenProg: Fixing by genetic programming

- Intuition: “The fix for a bug is most likely already present somewhere in the program.”
- The developer might have written mostly bug-free code except for a few cases where the bug might have crept in.

GenProg: Generate paths



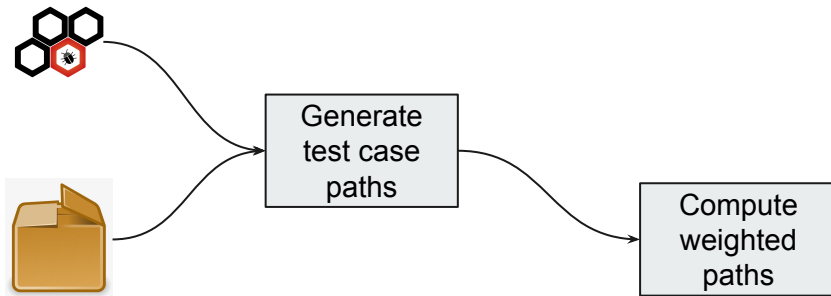


GenProg: Test case paths

For each test case:

- Get the path, i.e., sequence of statements executed.
- Remove duplicate statements, i.e., statements in loops.

GenProg: Weighted paths



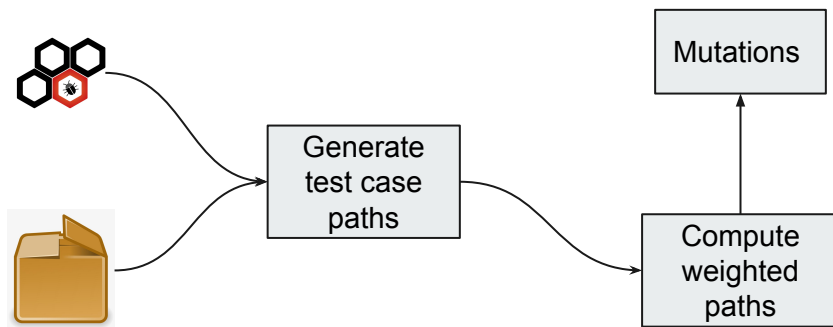


GenProg: Weighted paths

For each path:

- Assign a weight for each statement:
 - Statement executed only in failure test case, Weight = 1.
 - Statement executed in successful test case, Weight = 0.01.

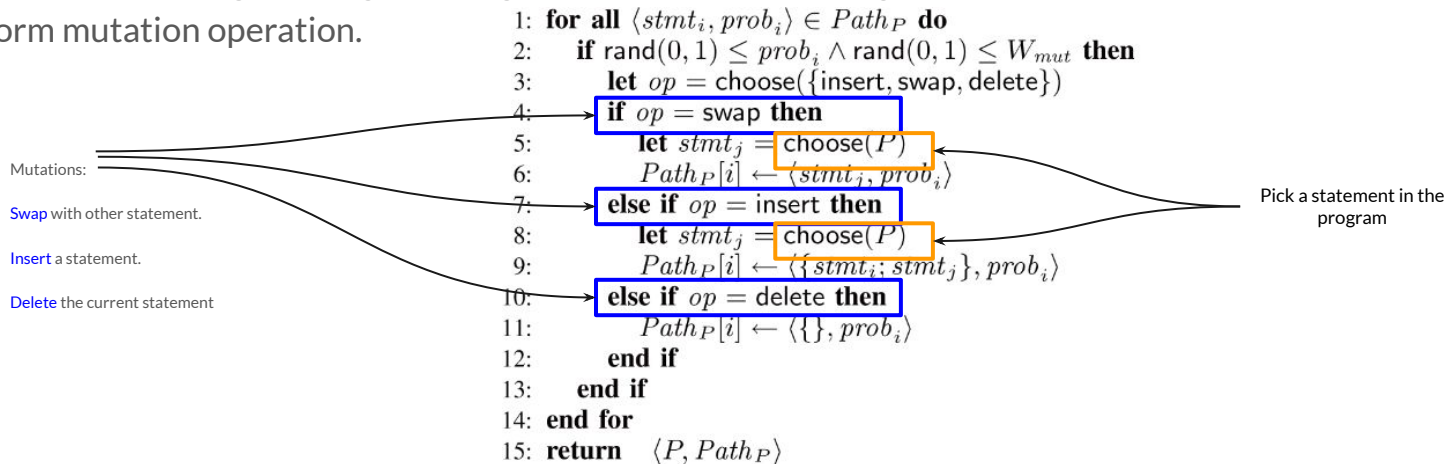
GenProg: Mutations



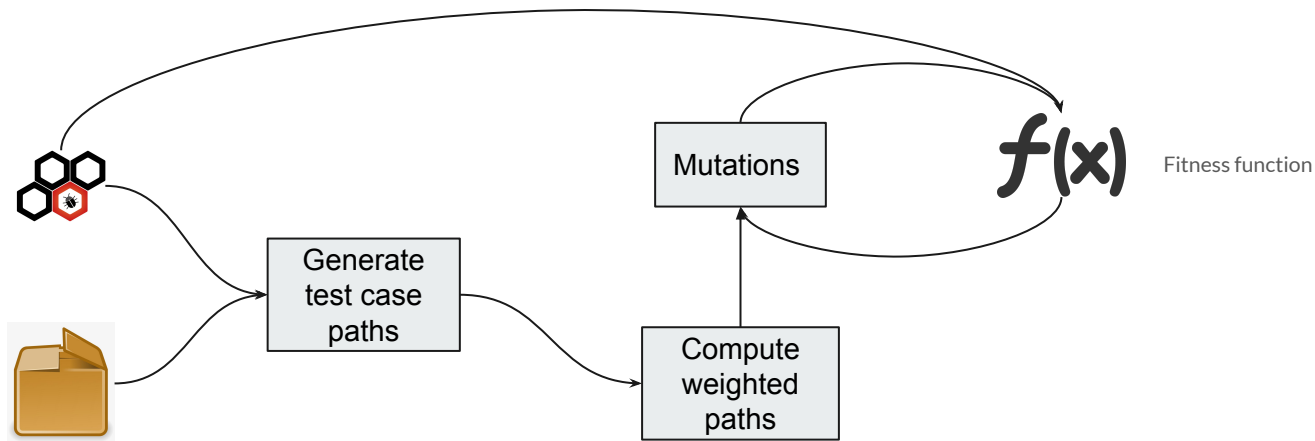
GenProg: Mutations

For each path:

- Pick a statement: Higher weight => Higher probability of picking.
- Perform mutation operation.



GenProg: Fitness function



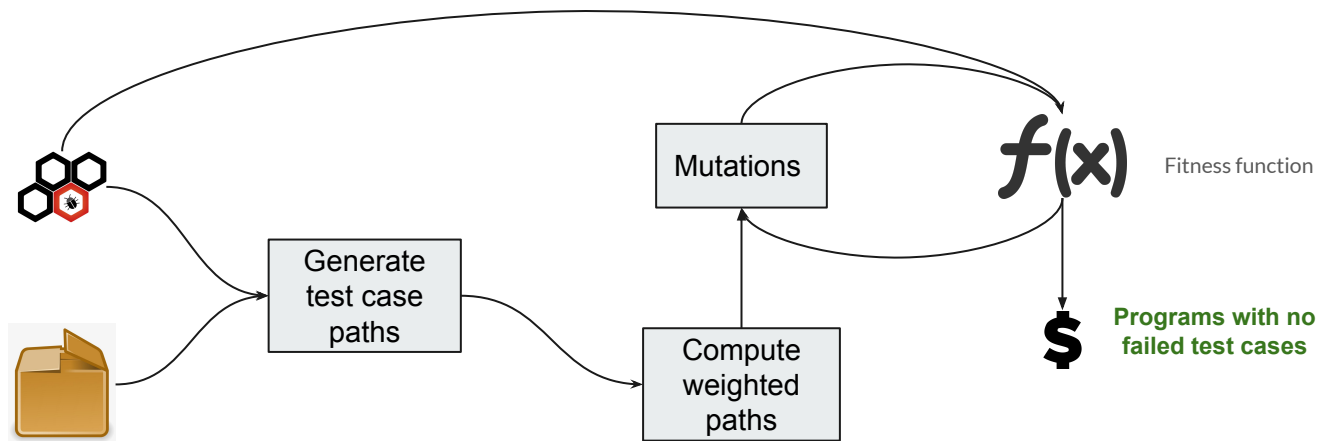


GenProg: Fitness function

Higher score => Passes most of the positive test cases and fails least of the test cases.

$$\text{fitness}(P) = W_{PosT} \times |\{t \in PosT \mid P \text{ passes } t\}| \\ + W_{NegT} \times |\{t \in NegT \mid P \text{ passes } t\}|.$$

GenProg: Post processing





GenProg: Post processing

- Minimize the patched program:
 - Delta debugging : Iteratively remove statements unless there is a failed test case.



GenProg: Results

```
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```



```
      else if(request_method == "POST") {  
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        buff=calloc(length, sizeof(char));  
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```



GenProg: Improvements

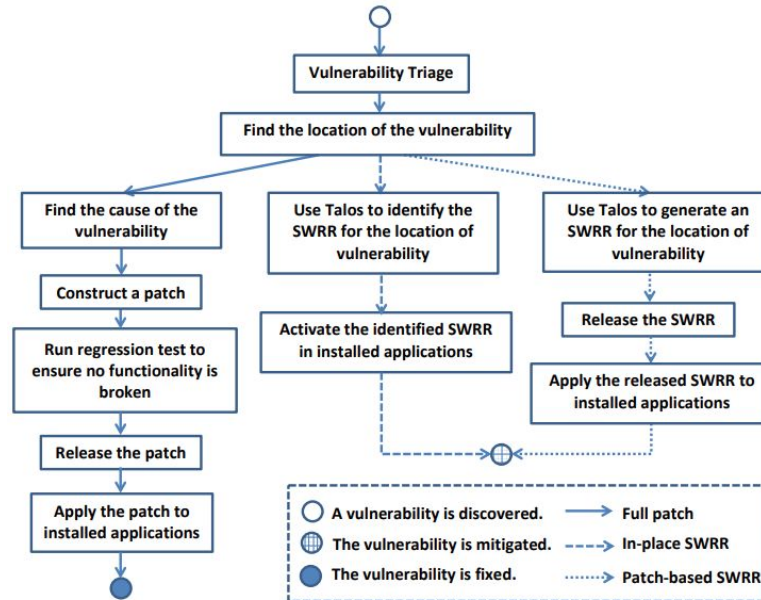
- Improved search: Randomized Search



Defect Specific Techniques

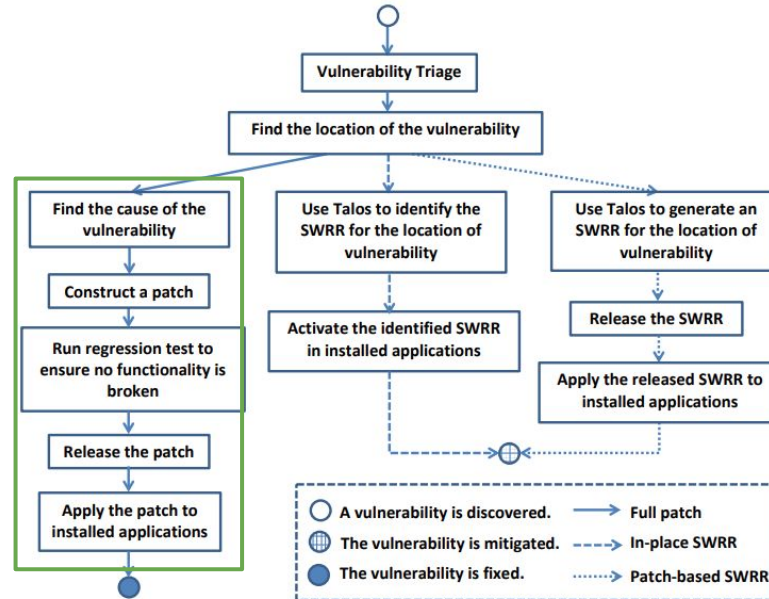
- Workarounds => Talos: Instead of fixing, avoid the bug
- Buffer overflow, Integer overflow, Bad casts => Senx
- Temporal heap errors => SAVER

Security Workarounds

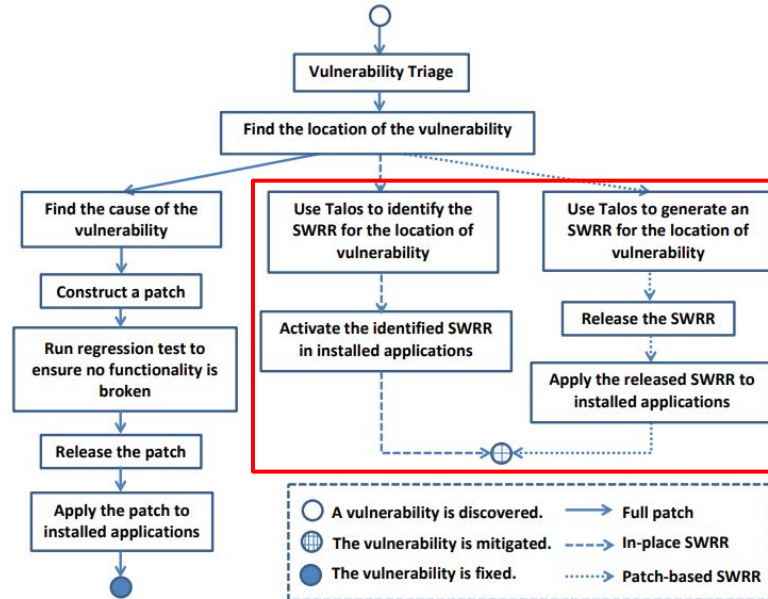


Security Workarounds

Regular flow:
Patching vulnerability



Security Workarounds



**Vulnerability Mitigation:
Security Workarounds**



Talos: Security Workarounds

Basic Idea: Selectively disable execution of certain (i.e., vulnerable) functions.

Instrument appropriate functions and disable execution of those functions.

Novelty: Correctly disabling functions without affecting “major” functionality of the application.



Talos: Disabling functions

Find error handling behavior of each function:

- `return error_code/NULL.`
- `log error message.`
- `Other heuristics.`

Instrument function to have error handling behavior.



Talos: Disabling functions

```
int example_function(...) {  
    /* SWRR inserted at top of function */  
    if (SWRR_enabled(<SWRR_option>))  
        return <error_code>;  
  
    /* original function body */  
    ...  
}
```



Talos: Disabling functions

```
int example_function(...) {  
    /* SWRR inserted at top of function */  
    return <error_code>;  
  
    /* original function body */  
    ...  
}
```

If the vulnerability is known then just disable the function.



Talos: Results

App.	CVE ID	Heuristics	Security?	Unobtrusive?
lighttpd	CVE-2011-4362	NULL Return	Yes	Yes
lighttpd	CVE-2012-5533	Indirect	Yes	No
lighttpd	CVE-2014-2323	Error-Propagation	Yes	No
apache	CVE-2014-0226	Error-Logging	Yes	Yes
squid	CVE-2009-0478	Indirect	Yes	No
squid	CVE-2014-3609	Error-Logging	Yes	Yes
sqlite	CVE-2015-3414	Error-Propagation	Yes	Yes
sqlite	OSVDB-119730	Error-Logging	Yes	Yes
proftpd	OSVDB-69562	Error-Propagation	Yes	Yes
proftpd	CVE-2010-3867	Error-Logging	Yes	Yes
proftpd	CVE-2015-3306	Error-Logging	Yes	Yes

Affected major functionality
of the application



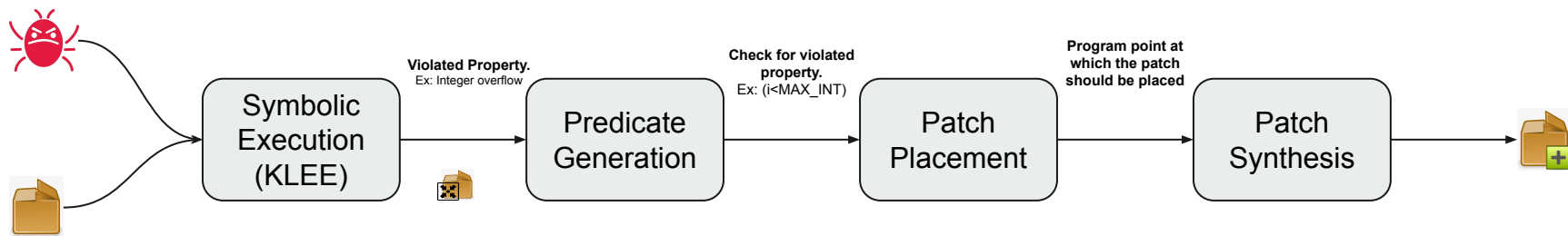
Senx: Vulnerability Specific Patches

Given a vulnerability triggering input => Create a patch that avoids the vulnerability.

Vulnerability types:

- Buffer overflow.
- Bad-cast.
- Integer overflow.

Senx: Overview





Senx: Symbolic Execution

Given program and vulnerability triggering input:

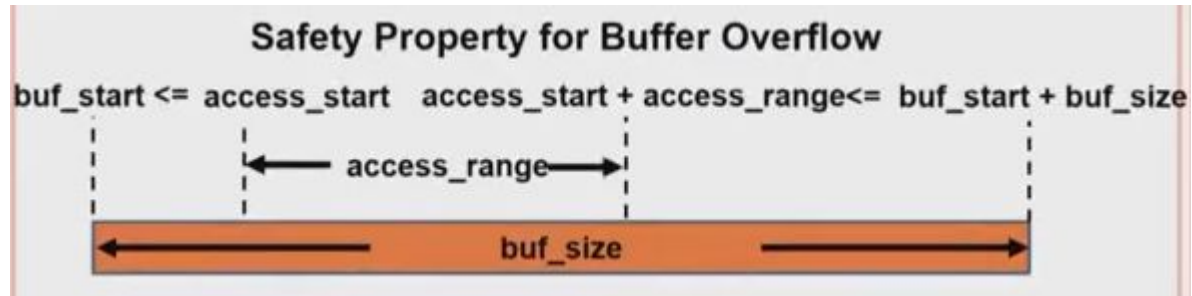
Symbolically trace the program with pre-constraining the input.

At each program point, check for vulnerability condition:

- Out of memory access.
- Integer overflow
- Bad casts.

Vulnerability point: Program point at which the vulnerability condition (security property violation) occurs

Senx: Safety property

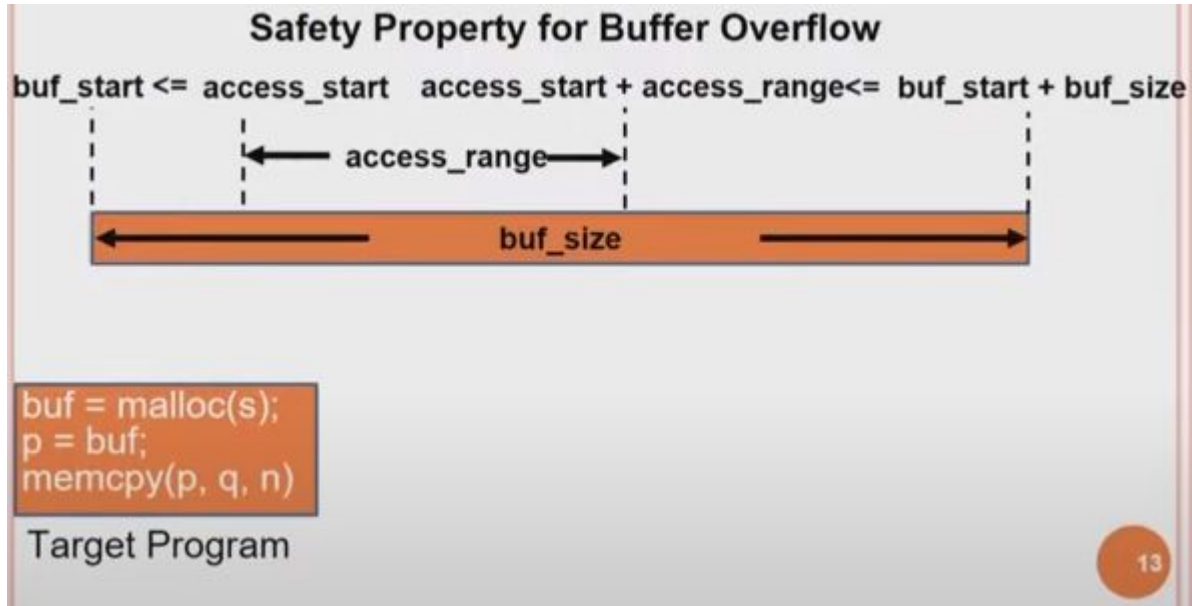




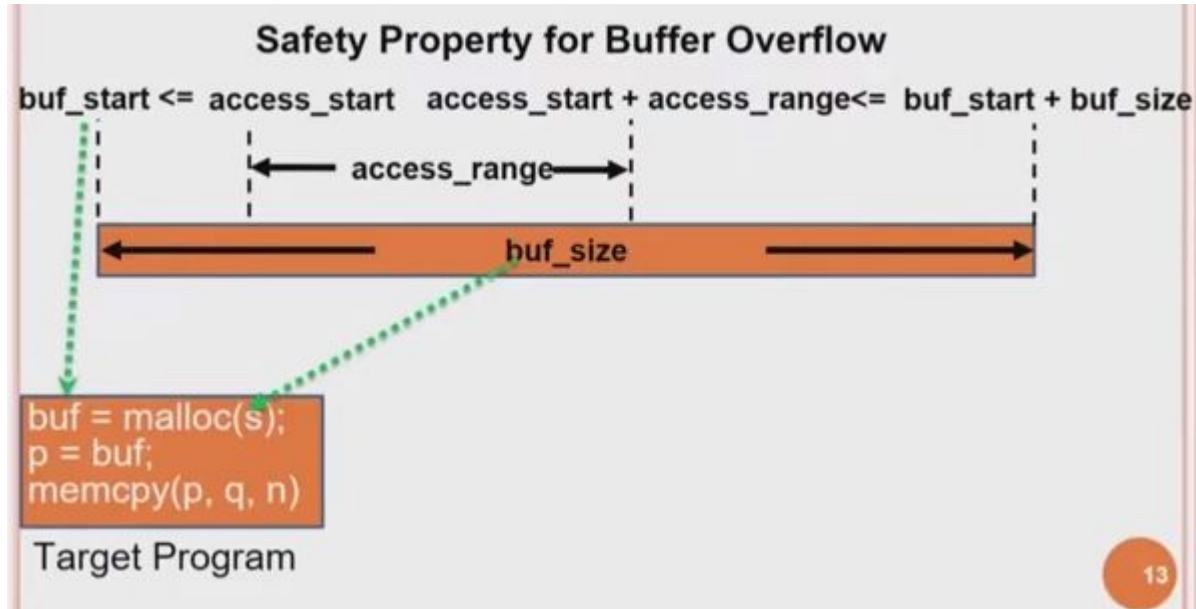
Senx: Predicate Generation

Generate a condition that prevents the vulnerable condition.

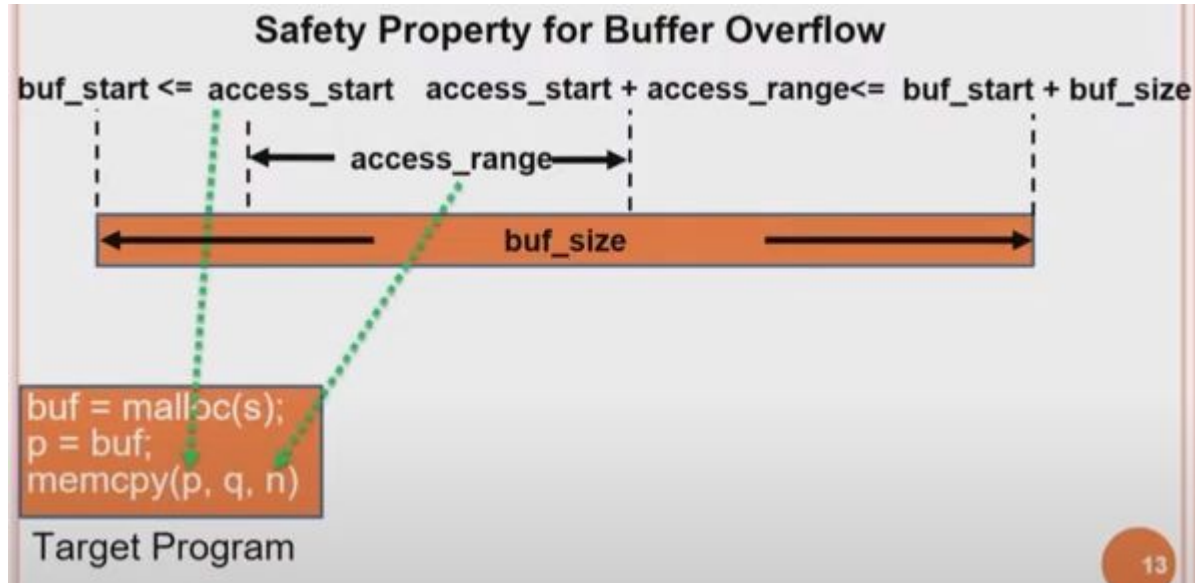
Senx: Predicate Generation



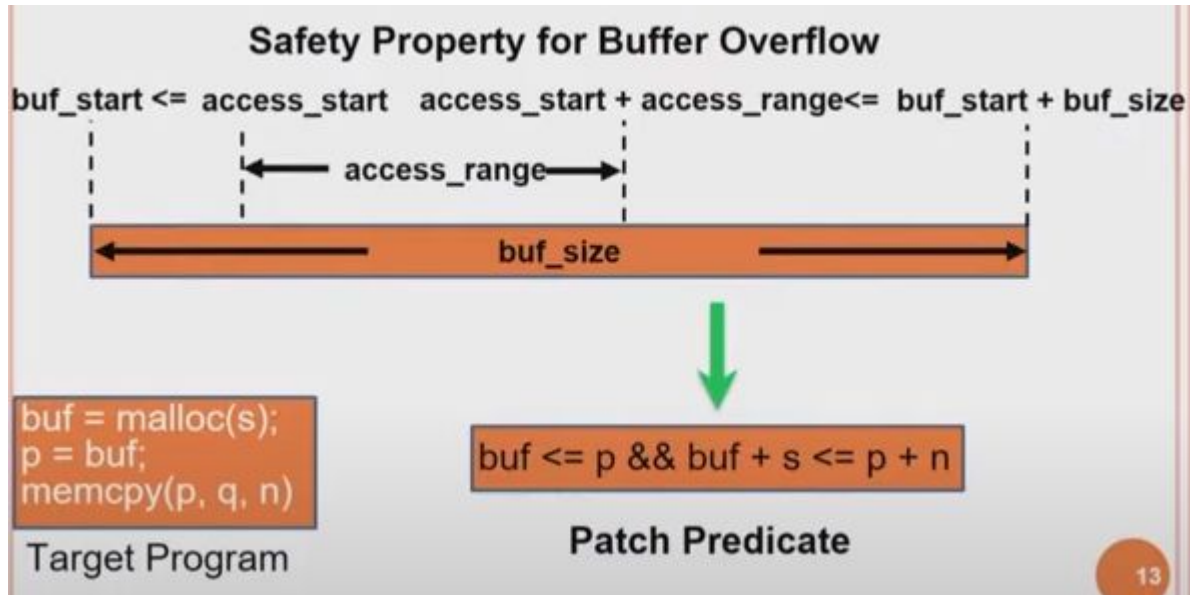
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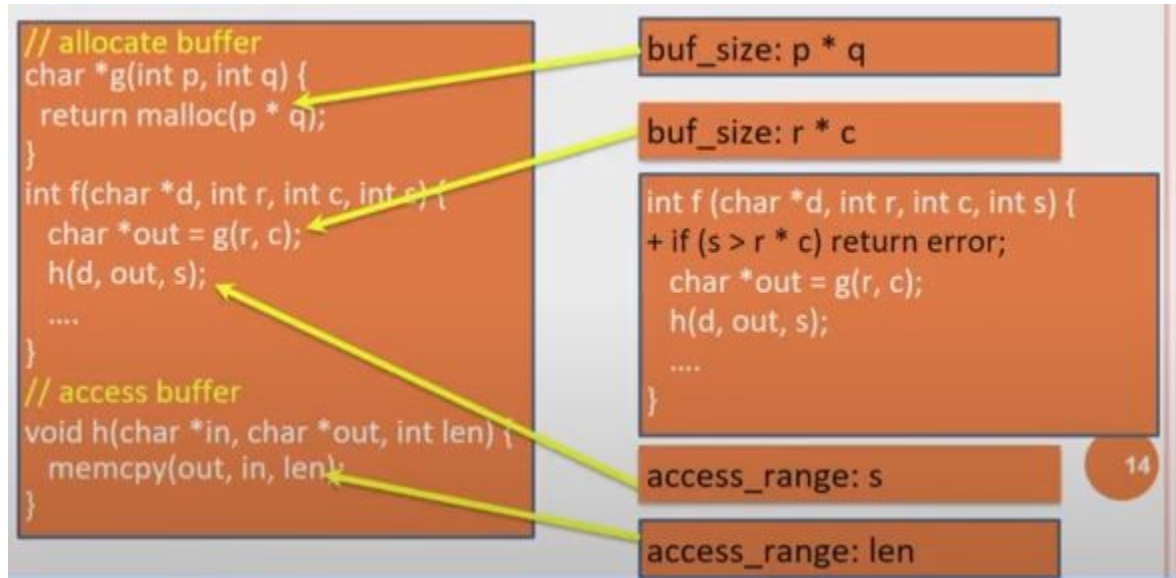




Senx: Patch Placement

Place the patch at the highest point in the call-graph where all the **variables needed for the predicate** are available.

Senx: Patch Placement





SAVER: Memory Error Repair

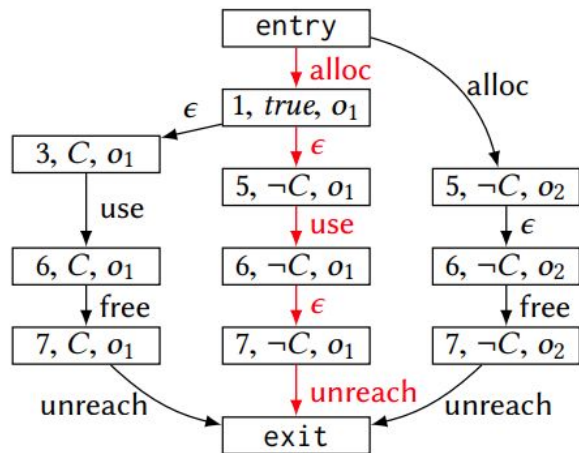
Fixes temporal memory errors using static analysis warning.

Run Infer (static analysis tool) to find temporal memory errors, i.e., use-after-free, memory leak, double free.

SAVER: Object flow graph

Construct Object flow graph from Infer warning: “Object allocated at 1 is unreachable at 7”

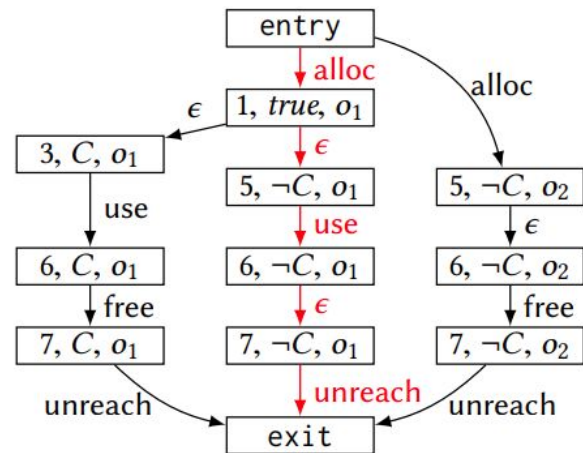
```
1  p = malloc(1); //o1
2  if (C)
3    q = p;
4  else
5    q = malloc(1); //o2
6    *p = 1;
7  free(q);
```



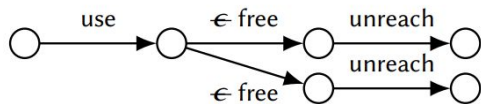
SAVER: Buggy Paths

We need to fix paths containing invalid event sequences by inserting appropriate memory allocation/deallocation operations.

$\text{alloc} \cdot \epsilon \cdot \text{use} \cdot \epsilon \cdot \text{unreach}$

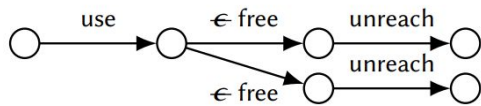


SAVER: Fixing strategies

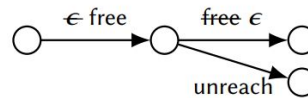


(a) Inserting free

SAVER: Fixing strategies

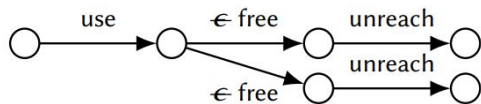


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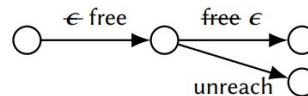


(b) Relocating free

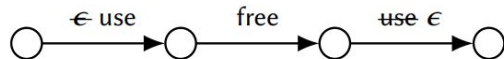
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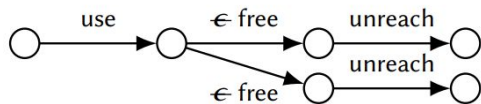


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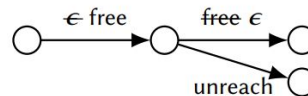


(c) Relocating use (dereference)

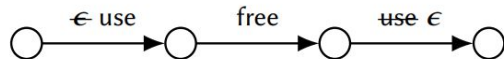
SAVER: Fixing strategies



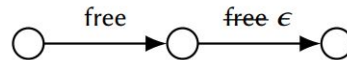
(a) Inserting free



(b) Relocating free



(c) Relocating use (dereference)



(d) Deleting free



SAVER: Results

```
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     (+) if ((append_data(ly, dptr)) == -1) free(dptr);
17 }
```



Automated Patching: Final Thoughts

- Defect specific techniques and ML techniques are on rise.
- Should explore interactive patching strategies => Active learning for patching strategies!!?
- Can we ask developer for some input that would make the patching easier and more precise!?
- Keep an eye on: <https://program-repair.org/index.html>