What IF Is Not Enough?
Fixing Null Pointer Dereference With Contextual Check

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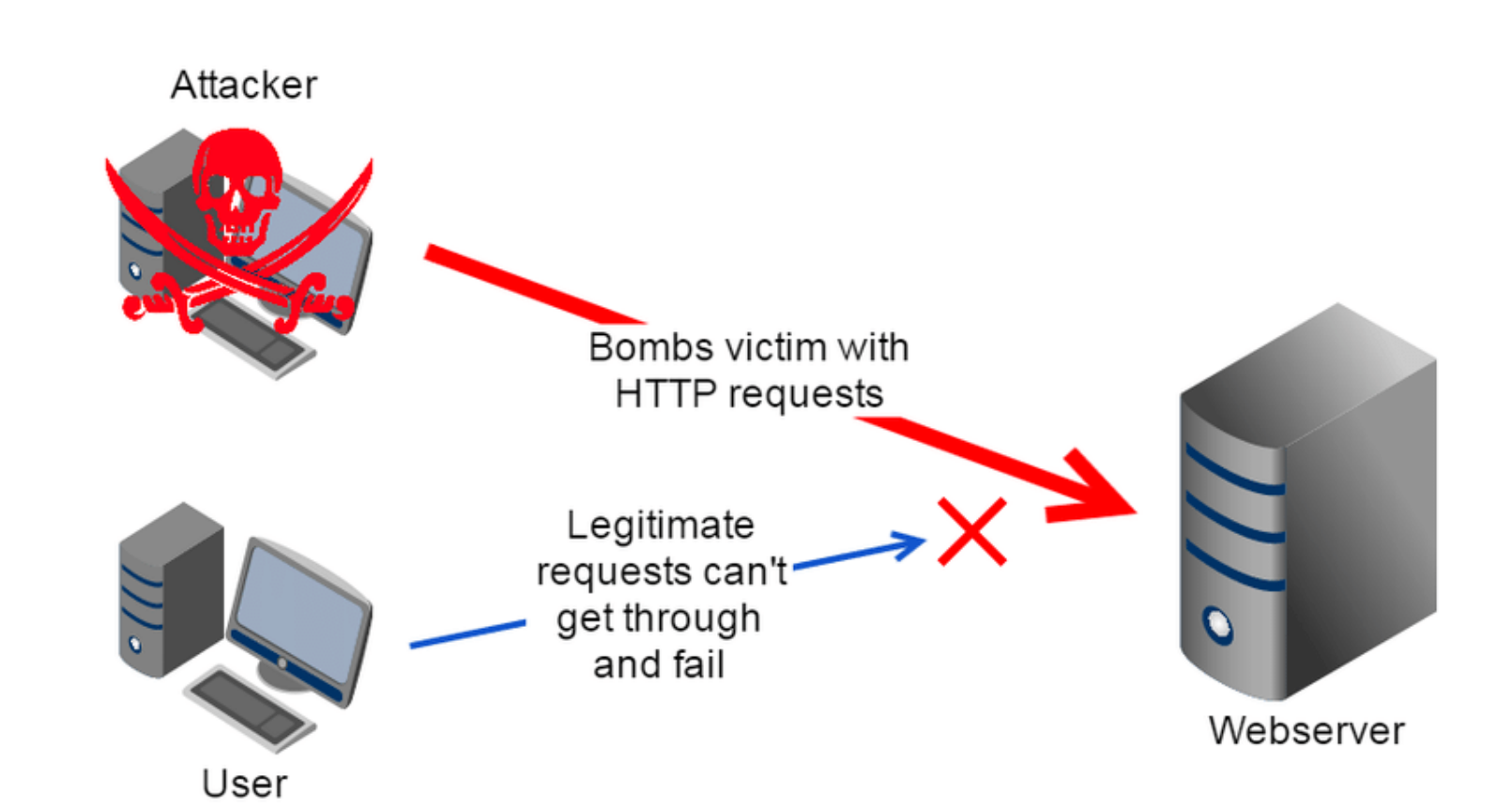
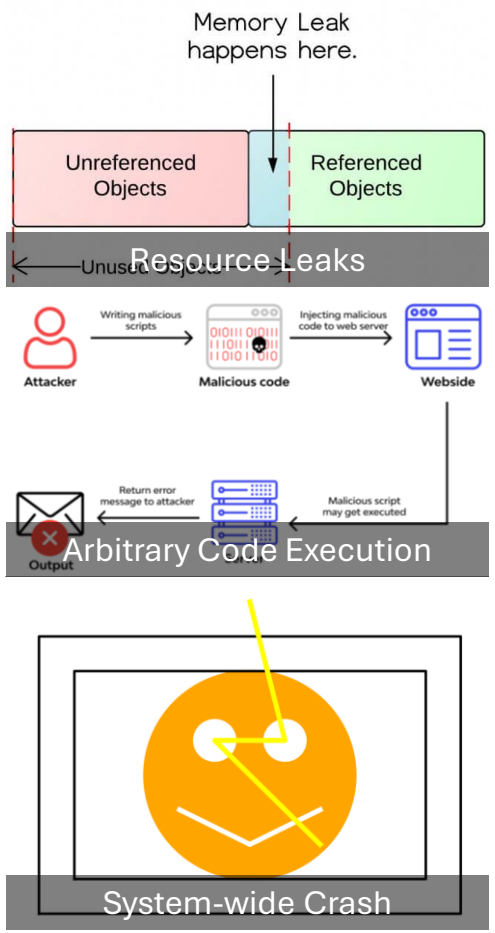
Threats of Null Pointer Dereference (NPD)



DoS Attack



How SOTA Approaches Address NPD?

- Selecting Repair Locations
  - e.g., path congestion calculation in VFix*
- Applying Repair Operations
  - General repair framework:

```
if (variable == NULL)
    return;
normal execution;
```

OR

```
if (variable != NULL)
    normal execution;
```

However, the valuable contextual information is ignored by all SOTA approaches, resulting in incorrect patches.

* VFix: Value-Flow-Guided Precise Program Repair for Null Pointer Dereferences, in ICSE 2019.

Motivating Example 1

Intraprocedural State Retrogression

```
1 void buggy(param1, param2){
2     spin_lock(&sl->lock);
3 +   if(sl->tty == NULL){
4 +
5 +       return;
6 +   }
7     function(sl->tty, … );
8 }
```

Fixed by SOTA approach

```
1 void buggy(param1, param2){
2     spin_lock(&sl->lock);
3 +   if(sl->tty == NULL){
4 +       spin_unlock(&sl->lock);
5 +       return;
6 +   }
7     function(sl->tty, … );
8 }
```

Fixed by our method

SOTA approaches ignore the valuable intraprocedural information, such as memory freeing and lock releasing.

Motivating Example 2

Interprocedural State Propagation (Function Argument Resetting)

```
1  bool buggy(int *r, … ){
2      *r = -1;
3      if(condition1){
4  +       if (src == NULL){
5  +
6  +           return true;
7  +       }
8          // return 0 if discarded
9          *r = func(src->vcpu, …);
10         return true;
11     }
12 }
13 int caller( … ){
14     int r = -1;
15     if(buggy(&r, … ))
16         return r;
17 }
18 int caller_caller( … ){
19     if(caller( … ))
20         schedule_work();
21 }
```

Fixed by SOTA approach

```
1  bool buggy(int *r, … ){
2      *r = -1;
3      if(condition1){
4  +       if (src == NULL){
5  +           *r = 0;
6  +           return true;
7  +       }
8          // return 0 if discarded
9          *r = func(src->vcpu, …);
10         return true;
11     }
12 }
13 int caller( … ){
14     int r = -1;
15     if(buggy(&r, … ))
16         return r;
17 }
18 int caller_caller( … ){
19     if(caller( … ))
20         schedule_work();
21 }
```

Fixed by our method

Failing to reset variable ***r*** could lead to an incorrect program status.

Motivating Example 3

Interprocedural State Propagation (Call Chain Assessment)

```
1  void buggy(param1, param2,… ){
2
3      struct *new_ts;
4      new_ts = kzalloc(sizeof());
5  +   if(new_ts == NULL)
6  +       return;
7      new_ts->ts = ts;
8  }
9  int caller(param1, param2){
10     int ret;
11     if(error)
12         return -EAGAIN;
13     buggy( … );
14
15
16
17     …
18     return 0;
19 }
20 void caller_caller(param) {
21     if(caller( … ) < 0)
22         break;
23 }
```

Fixed by SOTA approach

```
1  - void buggy(param1, param2,… ){
2  + int buggy(param1, param2, … ){
3      struct *new_ts;
4      new_ts = kzalloc(sizeof());
5  +   if(new_ts == NULL)
6  +       return -ENOMEM;
7      new_ts->ts = ts;
8  }
9  int caller(param1, param2){
10     int ret;
11     if(error)
12         return -EAGAIN;
13 -   buggy( … );
14 +   ret = buggy( … );
15 +   if(ret)
16 +       return ret;
17     …
18     return 0;
19 }
20 void caller_caller(param) {
21     if(caller( … ) < 0)
22         break;
23 }
```

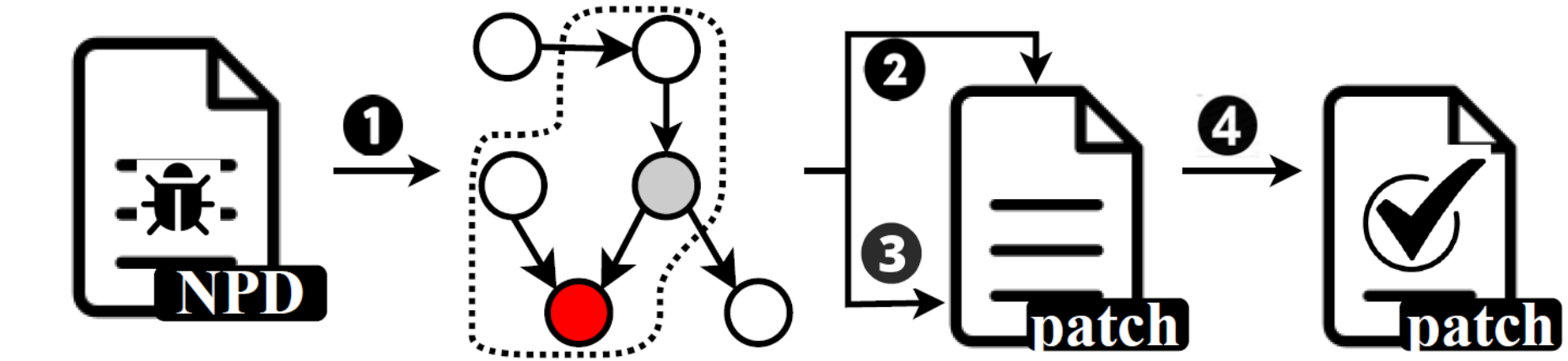
Fixed by our method

Function type modification and **call chain assessment** are required to fix this NPD issue.

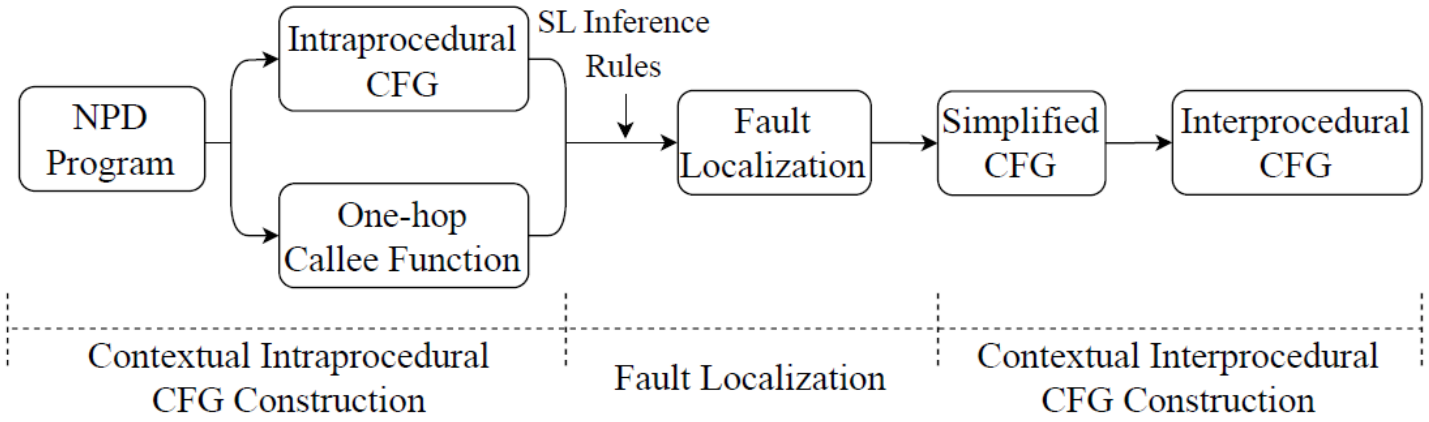
Our Contribution

We propose **CONCH** to generate accurate patches for NPD errors by considering the contextual information, including *Intraprocedural State Retrogression*, *Function Argument Resetting*, and *Call Chain Assessment*.

CONCH Design



NPD Context Graph Construction



Three steps to construct NPD context graph

$\textsc{LoadErr}: \{y \nrightarrow\} x := [y] \{err: y \nrightarrow\}$

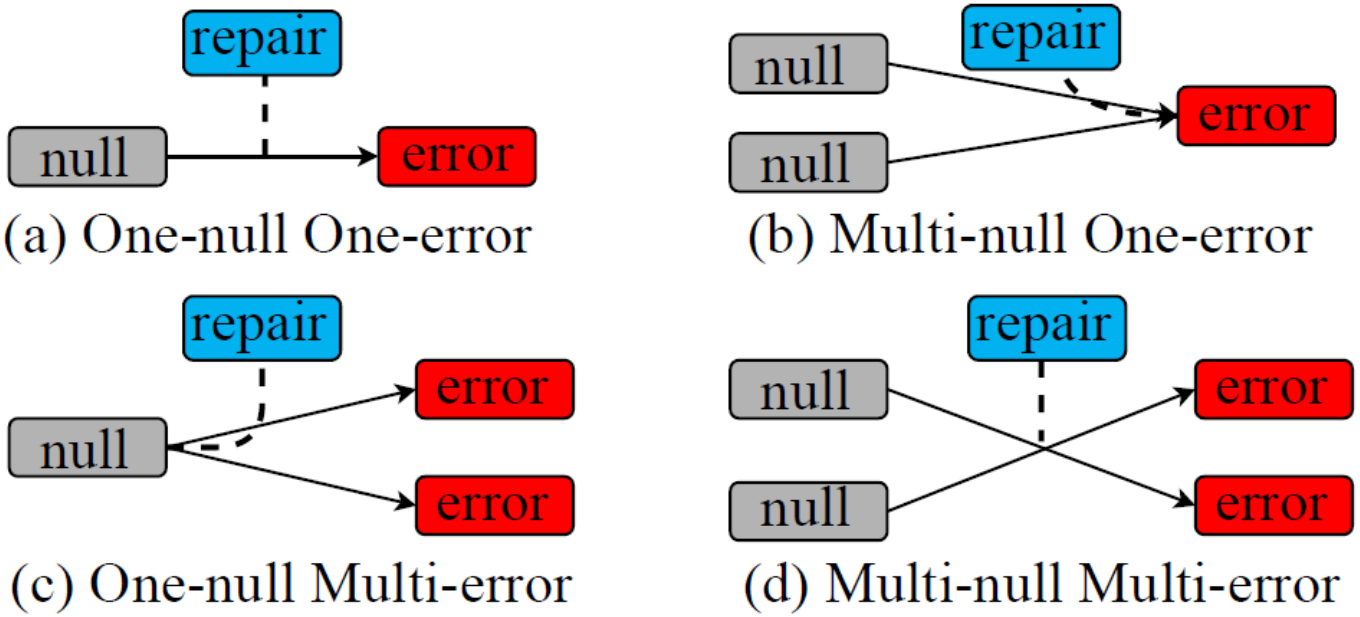
$\textsc{LoadNull}: \{y = null\} x := [y] \{err: y = null\}$

$\textsc{StoreErr}: \{x \nrightarrow\} [x] := y \{err: x \nrightarrow\}$

$\textsc{StoreNull}: \{x = null\} [x] := y \{err: x = null\}$

Separation Logic rules to localize the NPD errors

Path-sensitive Fixing Position Selection



Intraprocedural State Retrogression

- If Condition Construction

```
1      pcpu_sum = kvmalloc_array(param1, param2, param3)
2  +   if(pcpu_sum == null)
3  +       return;
4      this_sum = &pcpu_sum[cpu];
```

Null check for
CVE-2022-3107

```
1  -   amvdev_add_ts( … );  // return neg when fails
2  +   int ret = amvdec_add_ts( … );
3  +   if(ret)
4  +       return ret;
```

Exception value check for
CVE-2022-3112

```
1  +   if(info->st_info_list != NULL){
2          clist_foreach(info->st_info_list, NULL);
3          clist_free(info->st_info_list);
4  +   }
5      free(info);
```

Not-Null check for
CVE-2022-4121

Intraprocedural State Retrogression

- Local Resource Retrogression

```
1      rcu_read_lock();
2      slave = rcu_dereference(bond->curr_active_slave);
3  +   if(!slave){
4  +       rcu_read_unlock();
5  +       return -ENODEV;
6  +   }
7      xs->xso.real_dev = slave->dev;
```

Lock releasing for CVE-2022-0286

```
1      not_checked = kmalloc(sizeof(*not_checked) * 2);
2      checked = kmalloc(sizeof(*checked) * 2);
3  +   if(!not_checked || !checked){
4  +       kfree(not_checked);
5  +       kfree(checked);
6  +       return;
7  +   }
8      checked->data[] = …
9      not_checked->data[] = …
```

Memory freeing for CVE-2022-3104

Intraprocedural State Retrogression

- Return Statement Construction

```
1      if(IstensorIdControlling(tensor_id))
2          return false;
3      input_node = graph.GetNode(tensor_id.node());
4  +   if(input_node == nullptr)
5  +       return false;
6      return IsSwitch(*input_node);
```

Return false for CVE-2022-23589

```
1      if(imx_keep_uart_clocks){
2          imx_uart_clocks = kcalloc(clk_count, … );
3  +       if(!imx_uart_clocks)
4  +           return;
5          if(!of_stdout)
6              return;
7      }
```

Return nothing for CVE-2022-3114

```
1      if(rettv->vval.v_object == NULL)
2          return FAIL;
3      cl = rettv->vvval.v_object->obj->class;
4  +   if(cl == NULL)
5  +       return FAIL;
6      if(get_func_argument(…) == FAIL)
7          return FAIL;
```

Return macro for CVE-2023-1355

```
1      while(scanindent(s)){
2          var = scanname(s);
3  +       if(!val)
4  +           continue;
5          if(strcmp(var, "command") == 0)
6      }
```

Continue for CVE-2021-30219

Interprocedural State Propagation

- Global variable and function argument resetting
  - Global variable and function argument identification
  - Inferring the expected value from the data flow in the caller function
- Call chain assessment
  - Assessing the *void* function type that may execute normally when failing

Evaluation

- Datasets
  - 80 real-world NPD vulnerabilities, 18 NPD errors in Defects4j
- Other repair methods
  - VFix (SOTA approach), NPEfix (NPD repair), SimFix (general repair)
- System runtime
  - Intel i7 CPU and 16GB memory, running Ubuntu 22.04 with FBinfer 1.1.0

Performance on CVE Dataset

- CONCH can generate 68 correct and 12 incorrect patches

	Same Fixing	Semantic Equivalence	Incorrect Patches	Proportion
VFix	29	18	33	58.75%
NPEfix	15	4	61	23.75%
SimFix	18	8	54	32.5%
CONCH	**36**	**32**	**12**	**85%**

Performance on CVE Dataset

- Incorrect patches and their reasons

Category	CVE ID	If Condition	Generated Patches	Why CONCH Cannot Generate Correct Patches
Unobtainable Member	CVE-2022-1674	rmp->regprog != NULL	rmp != NULL	member *regprog* cannot be obtained in context
	CVE-2022-1620	rmp->regprog != NULL	rmp != NULL	member *regprog* cannot be obtained in context
	CVE-2016-2782	serial->num_bulk_in < 2	serial != NULL	member *num_bulk_in* cannot be obtained in context
	CVE-2014-0101	!net->sctp.auth_enable	net == NULL	member *sctp.auth_enable* cannot be obtained in context
	CVE-2013-0313	inode->i_op->removexattr != NULL	inode->i_op != NULL	`removexattr` is not a function in context
Unobtainable Relation	CVE-2022-2874	cctx->ctx_skip != SKIP_YES	cctx != NULL	relation with SKIP_YES cannot be obtained in context
	CVE-2018-1092	ino == EXT4_ROOT_INO	ino == 0	relation with EXT4_ROOT_INO cannot be obtained in context
	CVE-2012-6647	uaddr == uaddr2	uaddr && uaddr2	relation that *uaddr* is equal to *uaddr2* cannot be obtained in context
Special Function	CVE-2022-3621	nilfs_is_metadata_file_inode(inode)	-	special function for sanity check
	CVE-2022-2302	JFS_IP(ipimap)->i_imap	-	special function for validation check
	CVE-2013-5634	!kvm_vcpu_initialized(vcpu)	-	special function for initializing vCPU
	CVE-2013-4119	!SecIsValidHandle(handle)	-	special function for validation check

Performance on Defects4j

- CONCH can generate 16 correct patches and 2 incorrect patches

Project	#NPD	Fixed by VFix			Fixed by CONCH		
		Same	Semantic	Incorrect	Same	Semantic	Incorrect
Chart	7	5	0	2	5	2	0
Closure	6	2	1	3	2	2	2
Lang	2	1	0	1	2	0	0
Math	2	1	1	0	1	1	0
Time	1	1	0	0	1	0	0
Total	18	10	2	6	11	5	2

Conclusion

- We propose CONCH to fix NPD errors with contextual checks, ensuring a more effective and complete vulnerability control
- We are the first to address local resource retrogression and reset global variable and function argument in NPD fixing
- The experimental results show that CONCH outperforms the SOTA approaches

Q & A