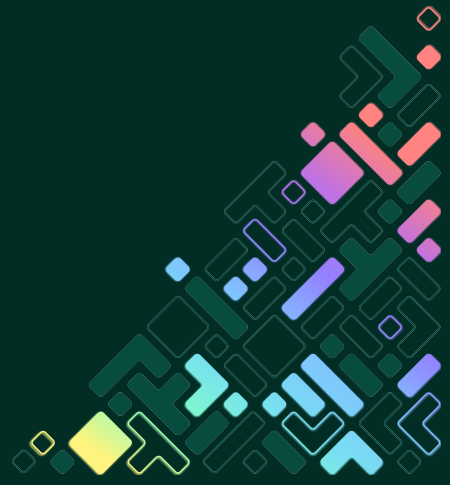
EMBEDDED
OPEN SOURCE
SUMMIT

A root canal static analysis based audit of Zephyr

Munawar Hafiz, OpenRefactory



Background: Munawar Hafiz

Ph.D. from UIUC
Formative work on feasibility of fixing security automatically

coverity®
A Synopsys Company

Senior Soft. Eng. at Coverity
Team released first commercial vulnerability
detection tools for JavaScript and Android

Assistant Professor at Auburn
First research on practical bug fixing tools.
Best Student Research in all disciplines of CS in 2013 (Awarded at the Turing Award Event)

Open|Refactory

OpenRefactory CEO
Started OpenRefactory with seed money awarded by the National Science Foundation

Background: OpenRefactory

Intelligent Code Repair (iCR) Static Analysis Tool

Finds more critical bugs

Less than 5% false positives

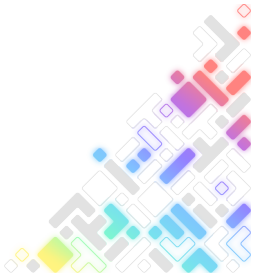
Automatically synthesizes fixes

Background: Open Source Security Audit

- Scale thorough security audit
- Work with Alpha-Omega, Linux Foundation and Python Software Foundation
- Scan top 2000 Python open source projects
- Detect 32 kinds of critical security problems
- Report the bug to maintainers and work with them to fix the bugs
- Last 5 months: 350 bugs, 120 security related, 40 high severity, 60% fixed

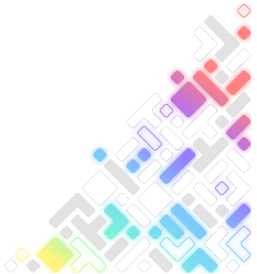
Background: How This Talk Was Planned?

- **OpenRefactory is working on iCR for C**
- **We wanted understand the need of the C developers**
- **Zephyr is a major C developer community**
- **There is an active push to improve the code quality overall**



Plan: Root Canal Static Analysis Based Audit

- **Root Canal Term Borrowed from Refactoring Literature**
- **Interview maintainers about current practices**
- **Evaluate the results from current practices**
- **Analyze source code using other solutions**

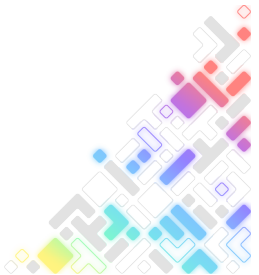


Current Practices

- Coverity scanner used in the CI/CD pipeline
- We looked into the bugs filed by the Coverity scanner between Jan 1, 2024 and Mar 31, 2024 (Q1 of 2024)
- These reports are public (Search with “Coverity” issue tag)
- The bug reports typically do not have much explanation. More inside the Coverity portal which has restricted access.

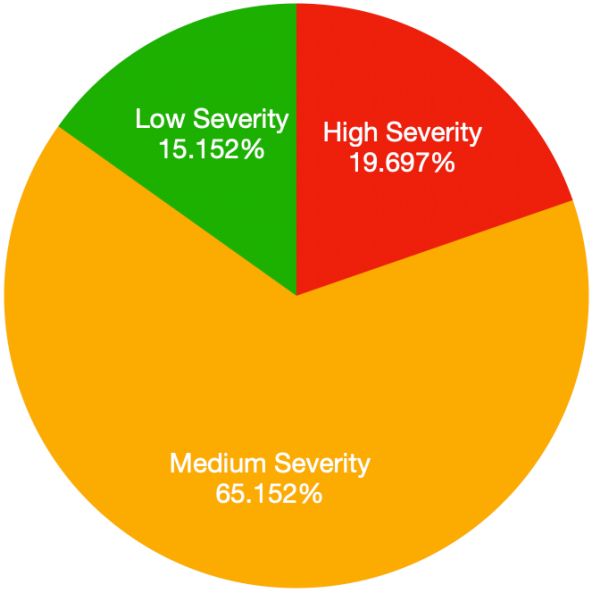
Coverity Code Scan (Q1 2024): Bug Resolution Status

- **Total 77 bugs reported in 90 days, 11 duplicates**
- **40 (35 unique) bugs were fixed (35/66 = 53%)**
- **9 false warnings, 7 WONTFIX issues (16/66 = 24%)**
- **17 Pending, 15 unique (15/66 = 23%)**

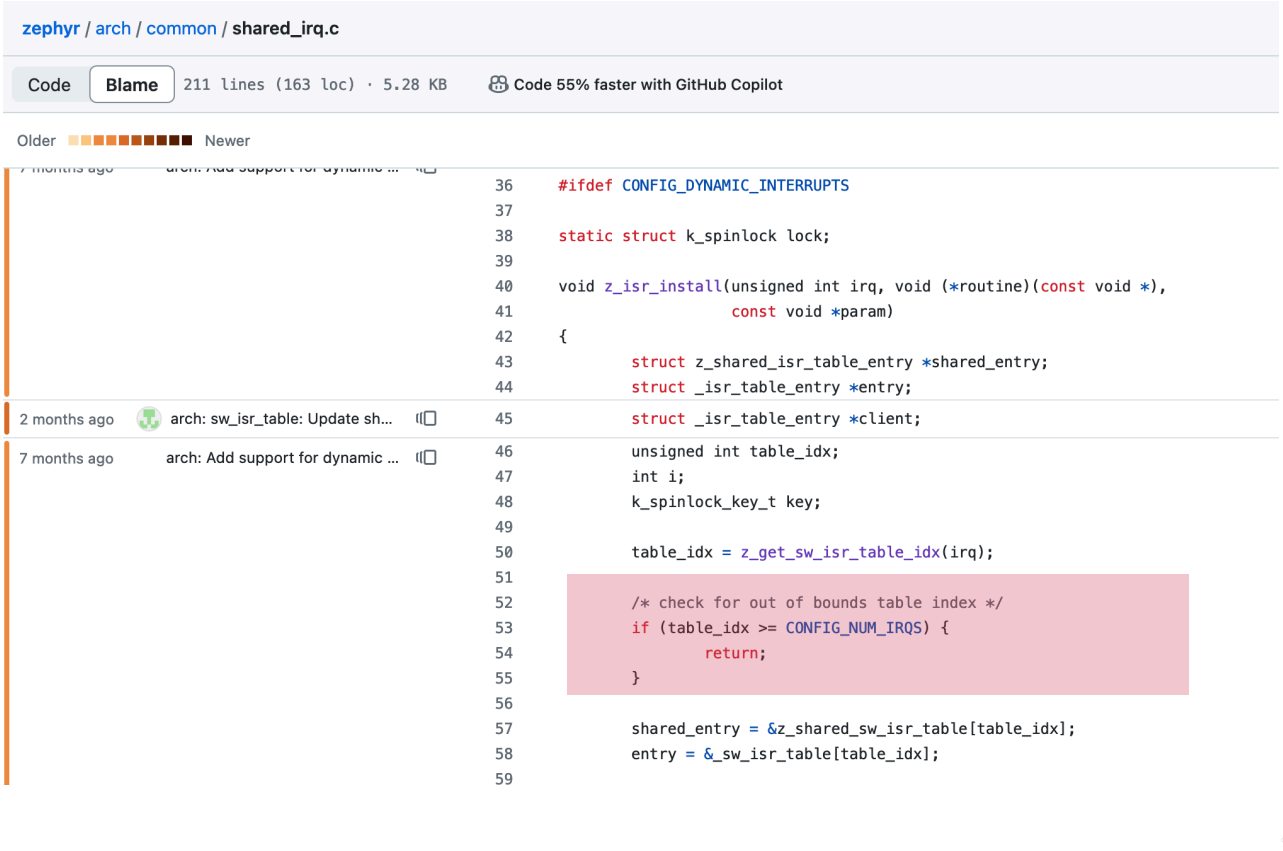


Coverity Code Scan (Q1 2024): Bug Severity

- **Total 77 bugs reported in 90 days, 11 duplicates**
- **13 High Severity**
- **43 Medium Severity**
- **10 Low Severity**



Sample High Severity Bug, 1/4



zephyr / arch / common / shared_irq.c

Code | Blame | 211 lines (163 loc) · 5.28 KB | Code 55% faster with GitHub Copilot

Older Newer

7 months ago	arch: Add support for dynamic ...	36	`#ifdef CONFIG_DYNAMIC_INTERRUPTS`
		37	
		38	`static struct k_spinlock lock;`
		39	
		40	`void z_isr_install(unsigned int irq, void (*routine)(const void *),`
		41	`const void *param)`
		42	`{`
		43	`struct z_shared_isr_table_entry *shared_entry;`
		44	`struct _isr_table_entry *entry;`
2 months ago	arch: sw_isr_table: Update sh...	45	`struct _isr_table_entry *client;`
7 months ago	arch: Add support for dynamic ...	46	`unsigned int table_idx;`
		47	`int i;`
		48	`k_spinlock_key_t key;`
		49	
		50	`table_idx = z_get_sw_isr_table_idx(irq);`
		51	
		52	`/* check for out of bounds table index */`
		53	`if (table_idx >= CONFIG_NUM_IRQS) {`
		54	`return;`
		55	`}`
		56	
		57	`shared_entry = &z_shared_sw_isr_table[table_idx];`
		58	`entry = &_sw_isr_table[table_idx];`
		59	

Sample High Severity Bug, 2/4

zephyr / include / arch / xtensa / irq.h

Code | Blame | 131 lines (102 loc) · 2.94 KB | Code 55% faster with GitHub Copilot

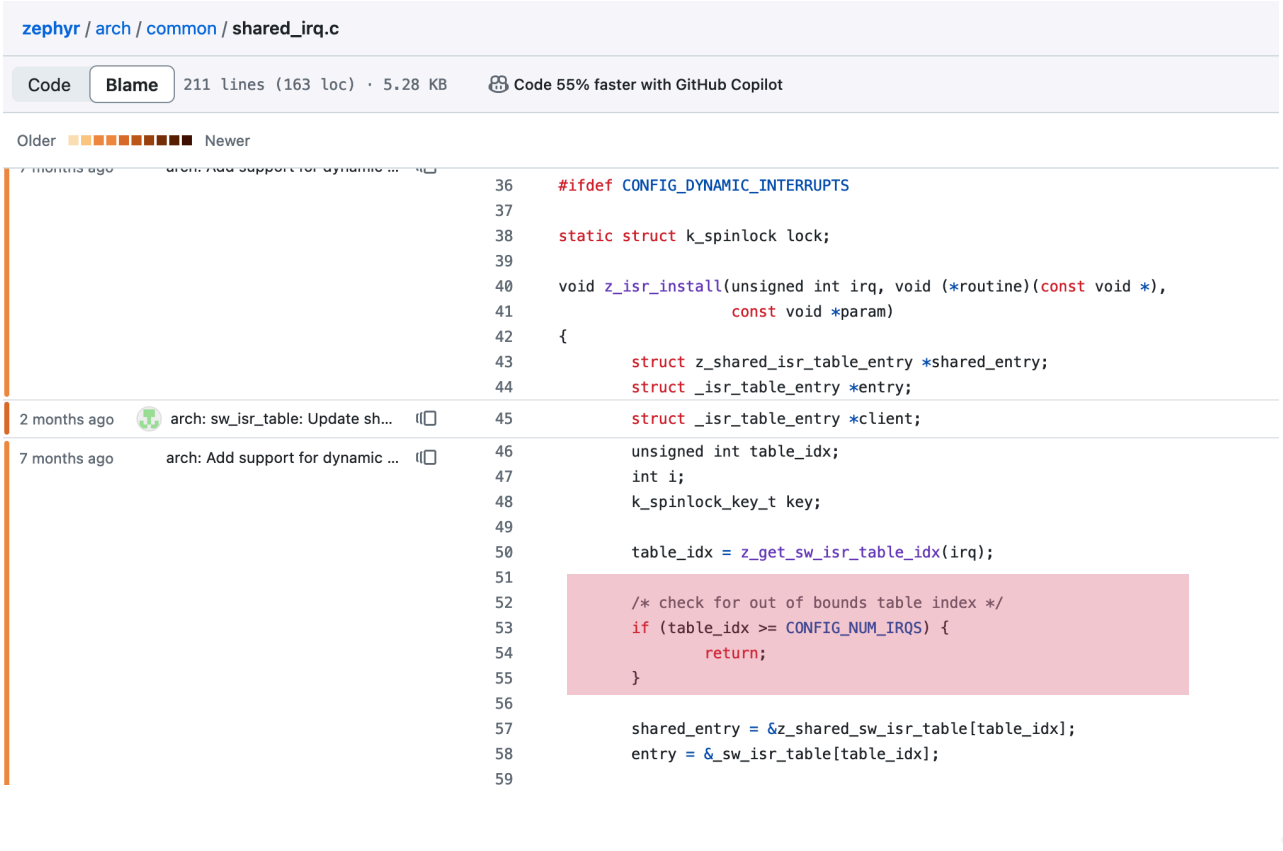
```
59
60  #ifdef CONFIG_2ND_LEVEL_INTERRUPTS
61  #ifdef CONFIG_3RD_LEVEL_INTERRUPTS
62  #define CONFIG_NUM_IRQS (XCHAL_NUM_INTERRUPTS +\
63                           (CONFIG_NUM_2ND_LEVEL_AGGREGATORS +\
64                           CONFIG_NUM_3RD_LEVEL_AGGREGATORS) *\
65                           CONFIG_MAX_IRQ_PER_AGGREGATOR)
66  #else
67  #define CONFIG_NUM_IRQS (XCHAL_NUM_INTERRUPTS +\
68                           CONFIG_NUM_2ND_LEVEL_AGGREGATORS *\
69                           CONFIG_MAX_IRQ_PER_AGGREGATOR)
70  #endif
71  #else
72  #define CONFIG_NUM_IRQS XCHAL_NUM_INTERRUPTS
73  #endif
```

zephyr / include / sw_isr_table.h

Code | Blame | 86 lines (71 loc) · 2.17 KB | Code 55% faster with GitHub Copilot

```
71                          (irq, flags, (void *)&func, (const void *)param);
72
73  #define IRQ_TABLE_SIZE (CONFIG_NUM_IRQS - CONFIG_GEN_IRQ_START_VECTOR)
74
75  #ifdef CONFIG_DYNAMIC_INTERRUPTS
```

Sample High Severity Bug, 3/4



zephyr / arch / common / shared_irq.c

Code | Blame | 211 lines (163 loc) · 5.28 KB | Code 55% faster with GitHub Copilot

Older Newer

7 months ago	arch: Add support for dynamic ...	36	`#ifdef CONFIG_DYNAMIC_INTERRUPTS`
		37	
		38	`static struct k_spinlock lock;`
		39	
		40	`void z_isr_install(unsigned int irq, void (*routine)(const void *),`
		41	`const void *param)`
		42	`{`
		43	`struct z_shared_isr_table_entry *shared_entry;`
		44	`struct _isr_table_entry *entry;`
2 months ago	arch: sw_isr_table: Update sh...	45	`struct _isr_table_entry *client;`
7 months ago	arch: Add support for dynamic ...	46	`unsigned int table_idx;`
		47	`int i;`
		48	`k_spinlock_key_t key;`
		49	
		50	`table_idx = z_get_sw_isr_table_idx(irq);`
		51	
		52	`/* check for out of bounds table index */`
		53	`if (table_idx >= CONFIG_NUM_IRQS) {`
		54	`return;`
		55	`}`
		56	
		57	`shared_entry = &z_shared_sw_isr_table[table_idx];`
		58	`entry = &_sw_isr_table[table_idx];`
		59	

Sample High Severity Bug, 4/4

4 arch/common/shared_irq.c

```
@@ -50,7 +50,7 @@ void z_isr_install(unsigned int irq, void (*routine)(const void *),
50  50          table_idx = z_get_sw_isr_table_idx(irq);
51  51
52  52          /* check for out of bounds table index */
53      -       if (table_idx >= CONFIG_NUM_IRQS) {
    53  +       if (table_idx >= IRQ_TABLE_SIZE) {
54  54                  return;
55  55          }
56  56
@@ -170,7 +170,7 @@ int z_isr_uninstall(unsigned int irq,
170 170         table_idx = z_get_sw_isr_table_idx(irq);
171 171
172 172         /* check for out of bounds table index */
173     -       if (table_idx >= CONFIG_NUM_IRQS) {
    173 +       if (table_idx >= IRQ_TABLE_SIZE) {
174 174                 return -EINVAL;
175 175         }
176 176
```

Sample Medium Severity Bug

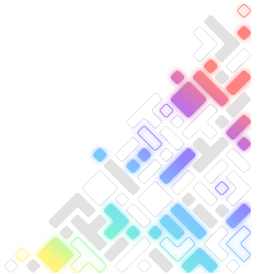
14 subsys/bluetooth/audio/shell/bap.c

```
@@ -2511,10 +2511,10 @@ static void stream_released_cb(struct bt_bap_stream *stream)
2511 2511
2512 2512                         if (bap_stream->ep != NULL) {
2513 2513                                 struct bt_bap_ep_info ep_info;
     2514 +                               int err;
2514 2515
2515      -                               bt_bap_ep_get_info(bap_stream->ep, &ep_info);
2516      -
2517      -                               if (ep_info.state != BT_BAP_EP_STATE_CODEC_CONFIGURED &&
     2516 +                               err = bt_bap_ep_get_info(bap_stream->ep, &ep_info);
     2517 +                               if (err == 0 && ep_info.state != BT_BAP_EP_STATE_CODEC_CONFIGURED &&
2518 2518                                     ep_info.state != BT_BAP_EP_STATE_IDLE) {
2519 2519                                         group_can_be_deleted = false;
2520 2520                                         break;
@@ -3408,10 +3408,12 @@ static int cmd_recv_stats(const struct shell *sh, size_t argc, char *argv[])
3408 3408 static void print_ase_info(struct bt_bap_ep *ep, void *user_data)
3409 3409 {
3410 3410         struct bt_bap_ep_info info;
     3411 +       int err;
3411 3412
3412      -       bt_bap_ep_get_info(ep, &info);
3413      -       printk("ASE info: id %u state %u dir %u\n", info.id, info.state,
3414      -              info.dir);
     3413 +       err = bt_bap_ep_get_info(ep, &info);
     3414 +       if (err == 0) {
     3415 +               printk("ASE info: id %u state %u dir %u\n", info.id, info.state, info.dir);
     3416 +       }
3415 3417 }
3416 3418
3417 3419 static int cmd_print_ase_info(const struct shell *sh, size_t argc, char *argv[])
```

CVEs in Zephyr

Year	Number of CVEs
2017	3
2019	1
2020	29
2021	19
2022	7
2023	24
2024	2

Source: https://docs.zephyrproject.org/latest/security/vulnerabilities.html



Recent Buffer Overflow

fs: fuse: buffer overflow vulnerability in the Zephyr FS

High **ceolin** published **GHSA-mh67-4h3q-p437** on Feb 20

Package	Affected versions	Patched versions
zephyr (zephyr)	<= 3.5	None

Description

Summary

Possible buffer overflow in is_mount_point:
https://github.com/zephyrproject-rtos/zephyr/blob/main/subsys/fs/fuse_fs_access.c#L69

Details

If the string passed via path parameter is PATH_MAX long, sprintf will overflow dir_path by one byte.

```
static bool is_mount_point(const char *path)
{
    char dir_path[PATH_MAX];

    sprintf(dir_path, "%s", path);
    return strcmp(dirname(dir_path), "/") == 0;
}
```

Severity

High 7.3 / 10

CVSS base metrics

Attack vector	Local
Attack complexity	Low
Privileges required	None
User interaction	None
Scope	Unchanged
Confidentiality	Low
Integrity	Low
Availability	High

CVSS:3.1/AV:L/AC:L/PR:N/UI:N/S:U/C:L/I:L/A:H

Weaknesses

CWE-120

Credits

sploitem Reporter

Source: https://github.com/zephyrproject-rtos/zephyr/security/advisories/GHSA-mh67-4h3q-p437

Proposed Fix

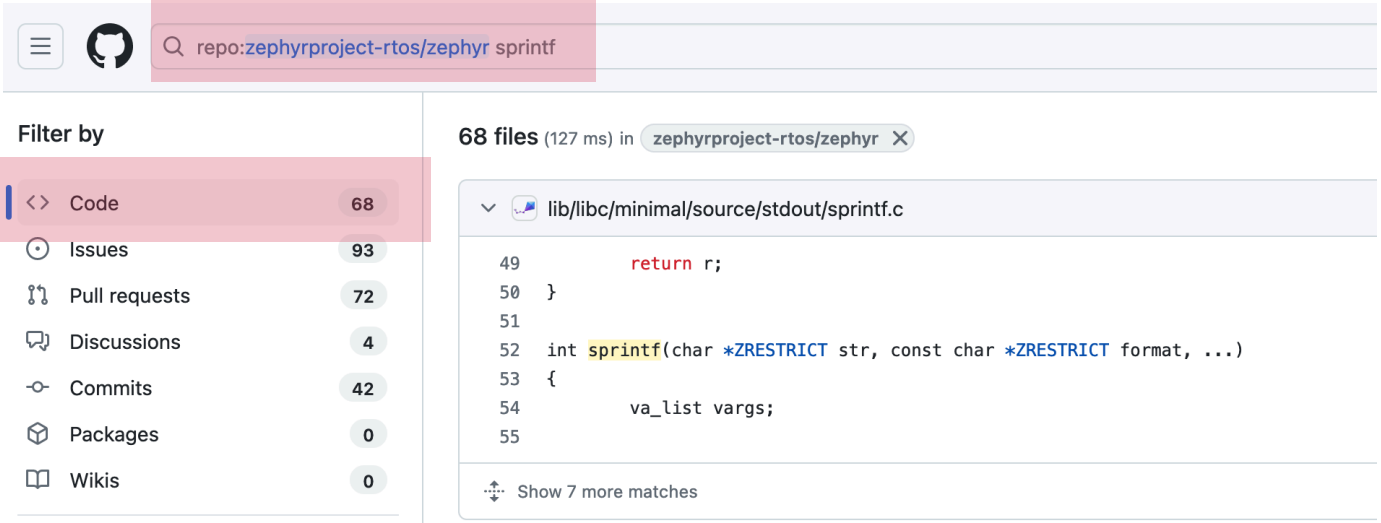
zephyr / subsys / fs / **fuse_fs_access.c**

Code | Blame | 557 lines (445 loc) · 10.2 KB

```
65  static bool is_mount_point(const char *path)
66  {
67          char dir_path[PATH_MAX];
68          size_t len;
69
70          len = strlen(path);
71          if (len >=  sizeof(dir_path)) {
72                  return false;
73          }
74
75          memcpy(dir_path, path, len);
76          dir_path[len] = '\0';
77          return strcmp(dirname(dir_path), "/") == 0;
78  }
79
```


Source: https://github.com/zephyrproject-rtos/zephyr/blob/main/subsys/fs/fuse_fs_access.c#L69

Are There Similar Problems? 1/7



Source: https://github.com/search?q=repo%3Azephyrproject-rtos%2Fzephyr%20sprintf&type=code

Are There Similar Problems? 2/7

zephyr / samples / boards / 96b_argonkey / sensors / src / main.c

Code | Blame | 356 lines (295 loc) · 9.7 KB

```
53          sensor_channel_get(dev, SENSOR_CHAN_ACCEL_X, &accel_x);
54          sensor_channel_get(dev, SENSOR_CHAN_ACCEL_Y, &accel_y);
55          sensor_channel_get(dev, SENSOR_CHAN_ACCEL_Z, &accel_z);
56  #ifdef ARGONKEY_TEST_LOG
57          sprintf(out_str, "accel (%f %f %f) m/s2", (double)out_ev(&accel_x),
58                                                    (double)out_ev(&accel_y),
59                                                    (double)out_ev(&accel_z));
60          printk("TRIG %s\n", out_str);
61  #endif
62
63          /* lsm6dsl gyro */
64          sensor_sample_fetch_chan(dev, SENSOR_CHAN_GYRO_XYZ);
65          sensor_channel_get(dev, SENSOR_CHAN_GYRO_X, &gyro_x);
66          sensor_channel_get(dev, SENSOR_CHAN_GYRO_Y, &gyro_y);
67          sensor_channel_get(dev, SENSOR_CHAN_GYRO_Z, &gyro_z);
```


Source: https://github.com/zephyrproject-rtos/zephyr/blob/5ff8249d198135492d0080efc9be47802004618e/samples/boards/96b_argonkey/sensors/src/main.c#L57

Are There Similar Problems? 3/7

zephyr / samples / boards / 96b_argonkey / sensors / src / main.c

Code | Blame | 356 lines (295 loc) · 9.7 KB

```
32  static int lsm6dsl_trig_cnt;
33  #ifdef CONFIG_LSM6DSL_TRIGGER
34  static void lsm6dsl_trigger_handler(const struct device *dev,
35                                      const struct sensor_trigger *trig)
36  {
37  #ifdef ARGONKEY_TEST_LOG
38          char out_str[64];
39  #endif
40          struct sensor_value accel_x, accel_y, accel_z;
41          struct sensor_value gyro_x, gyro_y, gyro_z;
42
43  #if defined(CONFIG_LSM6DSL_EXT0_LIS2MDL)
44          struct sensor_value magn_x, magn_y, magn_z;
45  #endif
46  #if defined(CONFIG_LSM6DSL_EXT0_LPS22HB)
47          struct sensor_value press, temp;
48  #endif
49
50          lsm6dsl_trig_cnt++;
51
52          sensor_sample_fetch_chan(dev, SENSOR_CHAN_ACCEL_XYZ);
53          sensor_channel_get(dev, SENSOR_CHAN_ACCEL_X, &accel_x);
54          sensor_channel_get(dev, SENSOR_CHAN_ACCEL_Y, &accel_y);
55          sensor_channel_get(dev, SENSOR_CHAN_ACCEL_Z, &accel_z);
56  #ifdef ARGONKEY_TEST_LOG
57          sprintf(out_str, "accel (%f %f %f) m/s2", (double)out_ev(&accel_x),
58                                                    (double)out_ev(&accel_y),
59                                                    (double)out_ev(&accel_z));
60          printk("TRIG %s\n", out_str);
```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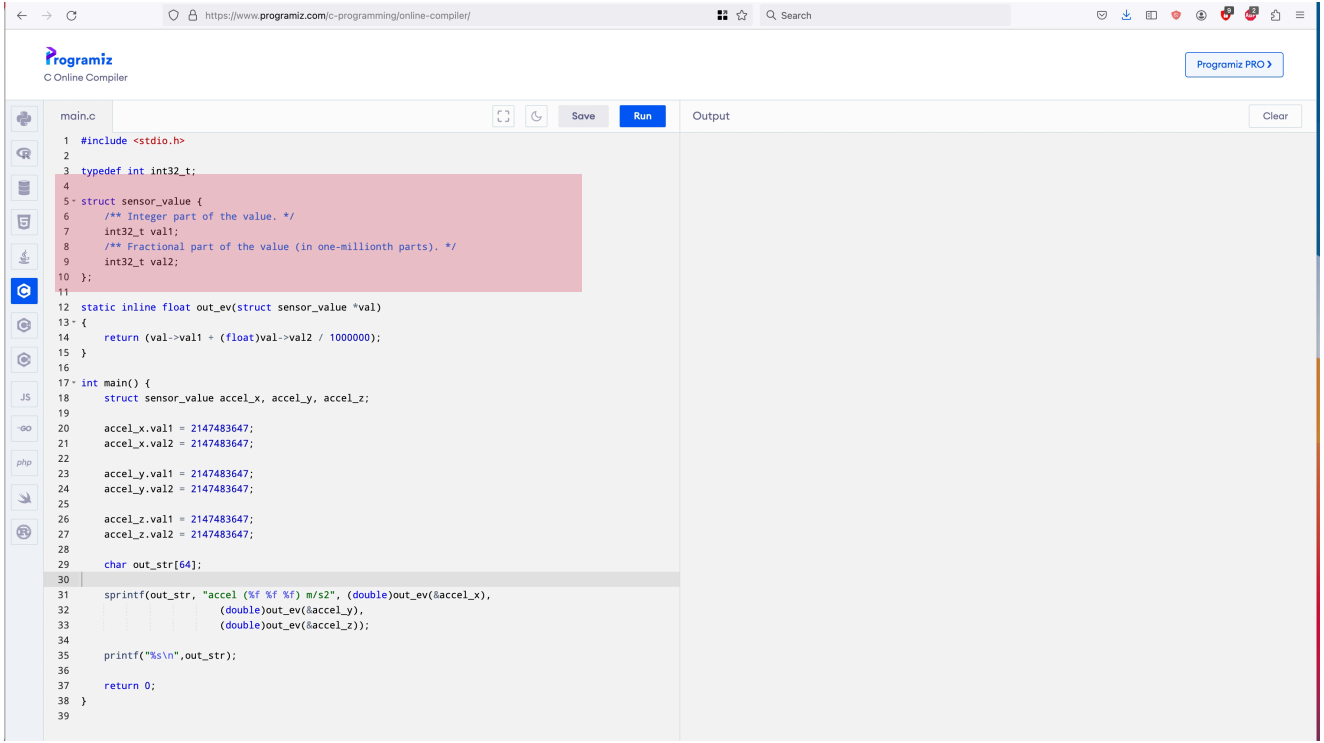
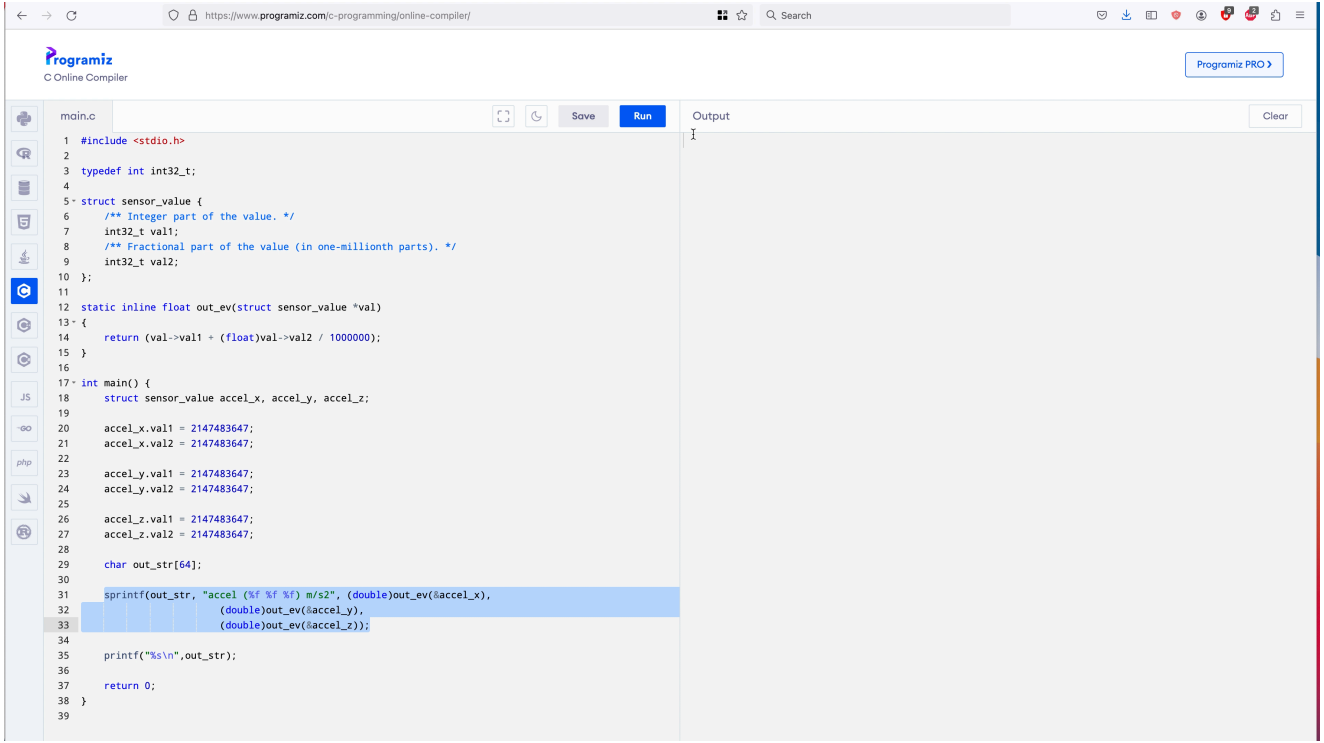
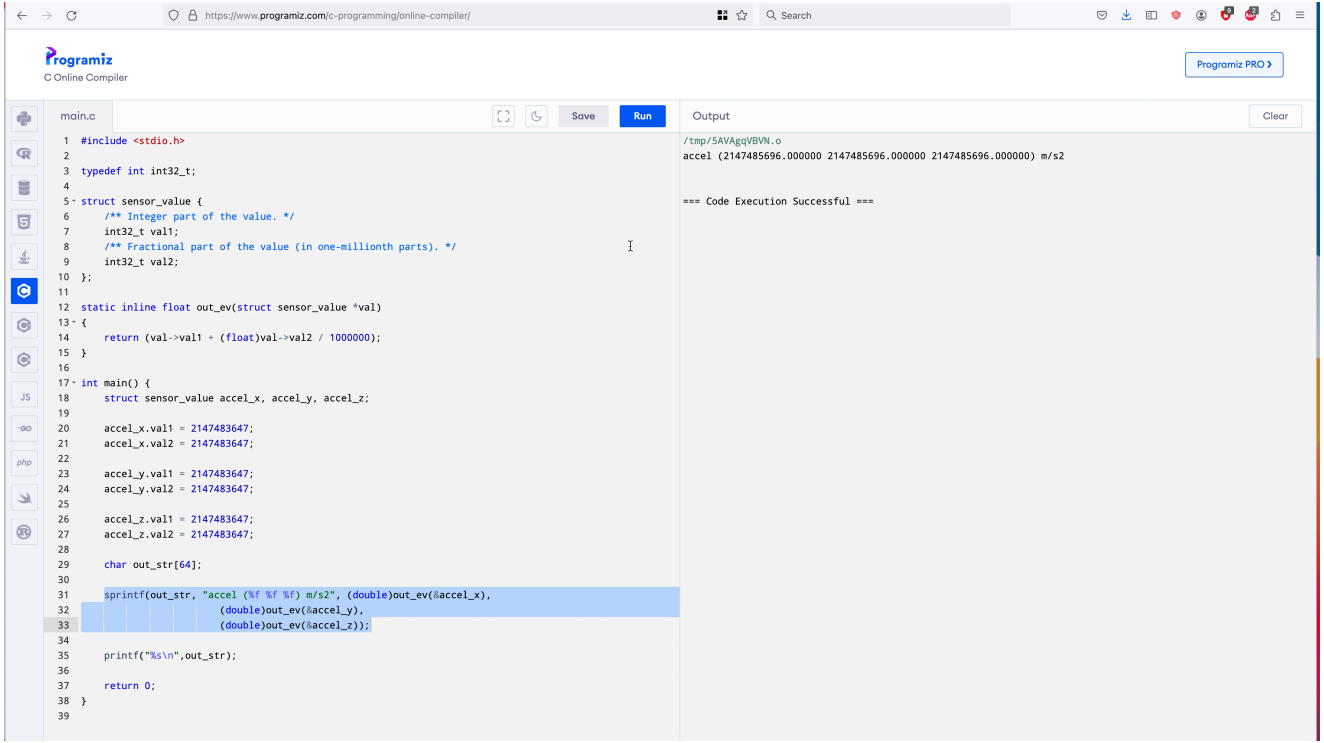
Are There Similar Problems? 4/7



Are There Similar Problems? 5/7



Are There Similar Problems? 6/7



Are There Similar Problems? 7/7

zephyr / samples / boards / 96b_argonkey / sensors / src / main.c

Code | Blame | 356 lines (295 loc) · 9.7 KB

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53          sensor_channel_get(dev, SENSOR_CHAN_ACCEL_X, &accel_x);
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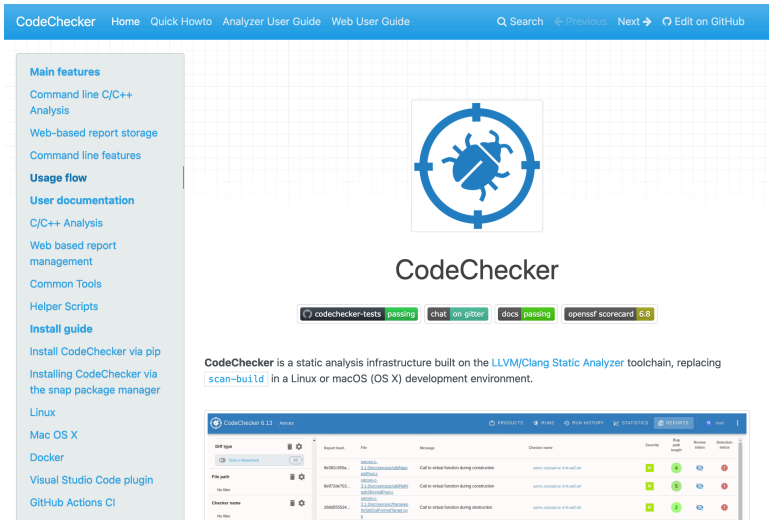
55          sensor_channel_get(dev, SENSOR_CHAN_ACCEL_Z, &accel_z);
56  #ifdef ARGONKEY_TEST_LOG
57          sprintf(out_str, "accel (%f %f %f) m/s2", (double)out_ev(&accel_x),
58                                                    (double)out_ev(&accel_y),
59                                                    (double)out_ev(&accel_z));
60          printk("TRIG %s\n", out_str);
61  #endif
62
63          /* lsm6dsl gyro */
64          sensor_sample_fetch_chan(dev, SENSOR_CHAN_GYRO_XYZ);
65          sensor_channel_get(dev, SENSOR_CHAN_GYRO_X, &gyro_x);
66          sensor_channel_get(dev, SENSOR_CHAN_GYRO_Y, &gyro_y);
67          sensor_channel_get(dev, SENSOR_CHAN_GYRO_Z, &gyro_z);
```


Source: https://github.com/zephyrproject-rtos/zephyr/blob/5ff8249d198135492d0080efc9be47802004618e/samples/boards/96b_argonkey/sensors/src/main.c#L57

Beyond Coverity: CodeChecker

- **CodeChecker introduced in Release v3.5 (October 2023)**
- **Easy way for end users to run an open source static analysis tool**
- **0 bugs found saying that “CodeChecker” was used (Q1 2024)**



Source: https://codechecker.readthedocs.io/en/latest/

Bug Filed By CodeChecker

3 arch/x86/core/acpi.c

```
@@ -27,7 +27,7 @@ static void find_rsdp(void)
27  27  {
28  28          uint8_t *bda_seg, *zero_page_base;
29  29          uint64_t *search;
30      -       uintptr_t search_phys, rsdp_phys = 0U;
    30  +       uintptr_t search_phys, rsdp_phys;
31  31          size_t search_length = 0U, rsdp_length;
32  32
33  33          if (is_rsdp_searched) {
@@ -94,7 +94,6 @@ static void find_rsdp(void)
94  94          search_length = 128 * 1024;
95  95          z_phys_map((uint8_t **)&search, search_phys, search_length, 0);
96  96
97      -       rsdp_phys = 0U;
98  97          for (int i = 0; i < 128*1024/8; i++) {
99  98                  if (search[i] == ACPI_RSDP_SIGNATURE) {
100 99                          rsdp_phys = search_phys + i * 8;
```


Source: https://github.com/zephyrproject-rtos/zephyr/pull/61706/commits/11a28a5d93f02f41e71620b1c9a1bf1e1e13ece0

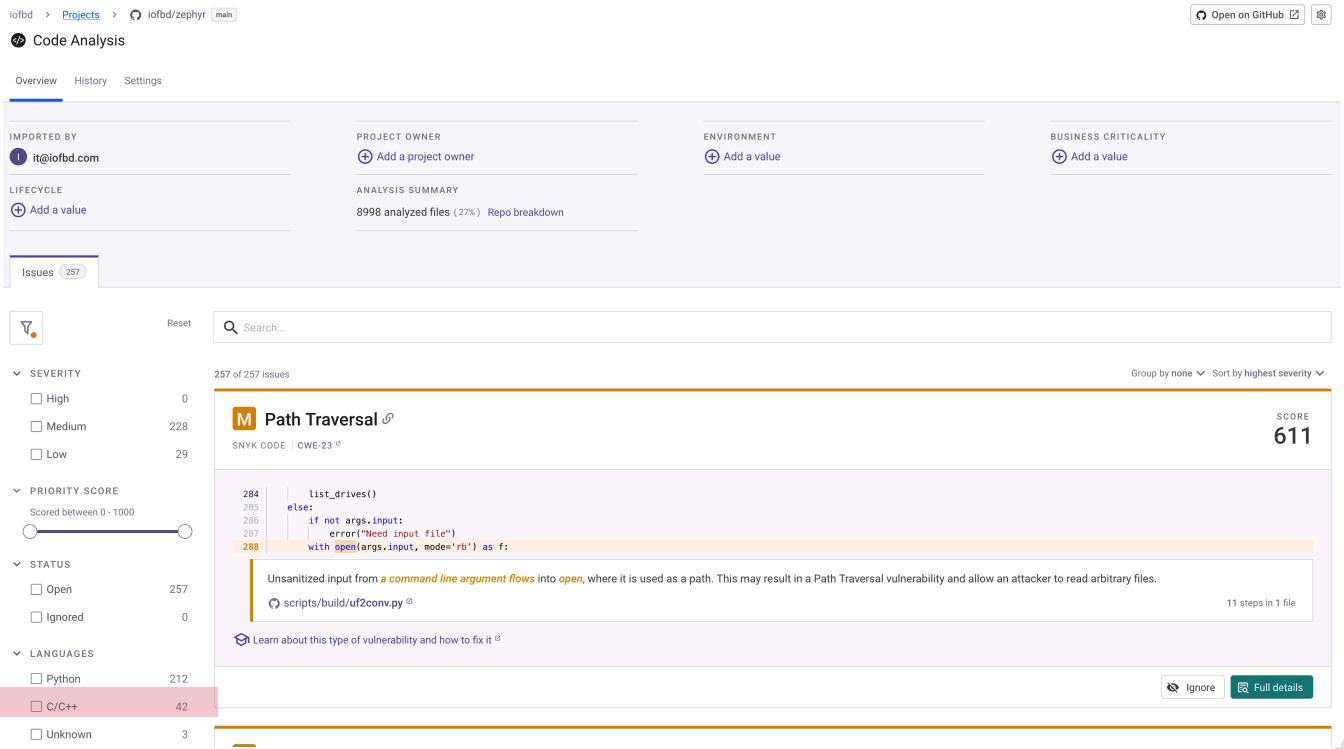
Bug Filed By CodeChecker

4 lsm6dsv16x_reg.c

```
@@ -5330,8 +5330,8 @@ int32_t lsm6dsv16x_fsm_mode_set(stmdev_ctx_t *ctx, lsm6dsv16x_fsm_mode_t val)
5330  5330    ret += lsm6dsv16x_read_reg(ctx, LSM6DSV16X_FSM_ENABLE, (uint8_t *)&fsm_enable, 1);
5331  5331    if (ret != 0) { goto exit; }
5332  5332
5333        -   if ((val.fsm1_en | val.fsm2_en | val.fsm1_en | val.fsm1_en
5334        -        | val.fsm1_en | val.fsm2_en | val.fsm1_en | val.fsm1_en) == PROPERTY_ENABLE)
      5333  +   if ((val.fsm1_en | val.fsm2_en | val.fsm3_en | val.fsm4_en
      5334  +        | val.fsm5_en | val.fsm6_en | val.fsm7_en | val.fsm8_en) == PROPERTY_ENABLE)
5335  5335    {
5336  5336      emb_func_en_b.fsm_en = PROPERTY_ENABLE;
5337  5337    }
```


Source: https://github.com/STMicroelectronics/lsm6dsv16x-pid/commit/9dca50889c8a4f7ea70b585a138e6841d4cc40c6

Beyond Coverity: Snyk

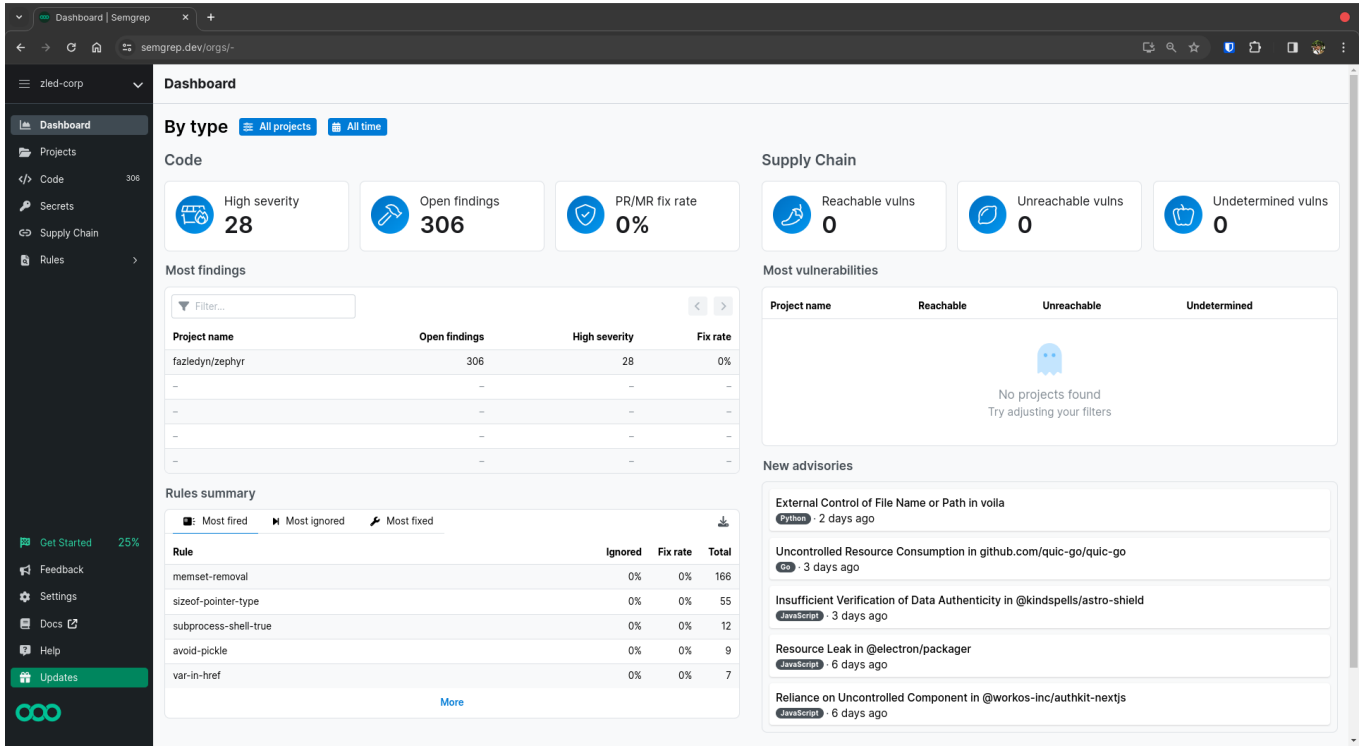


What Does Snyk Find?

- **41 bugs**
- **31 medium, 10 low**
- **27 FP**
- **14 worth a look**

Bug Type	Severity	Total Bugs	TP	FP
Improper NULL termination	Low	1	0	1
NULL Dereference	Medium	1	0	1
Missing Release of Memory	Low	1	0	1
Division By Zero	Medium	2	2(potentially)	0
	Low	1	0	1
Integer Overflow	Medium	8	3(potentially)	5
	Low	7	0	7
User Controlled Poinrter	Medium	9	9(potentially)	0
Use After Free	Medium	8	0	8
Double Free	Medium	3	0	3

Beyond Coverity: Semgrep



What Does Semgrep Find?

- 233 bugs
- 3 high
- 60 medium, 170 low
- 2 TP, 231 FP

Bug Type	Severity	Total Bugs	TP	FP
Memset Removal	Low	166	0	166
Sizeof Pointer Type	Medium	55	0	55
Don't Call System	Low	4	0	4
Local Variable Malloc Free	High	3	0	3
Insecure Use strtok Function	Medium	2	2 (Wontfix)	0
Snprintf Return Value	Medium	2	0	2
Snprintf Source Size	Medium	1	0	1

High Severity Bug, 1/4

Local Variable Malloc Free

This expression points to memory that has been freed. This can lead to a segmentation fault or memory corruption.

zephyr / lib / libc / newlib / libc-hooks.c

Code | Blame | 576 lines (478 loc) · 13.2 KB

```
396  /* Close dynamic non-recursive lock */
397  void __retarget_lock_close(_LOCK_T lock)
398  {
399          __ASSERT_NO_MSG(lock != NULL);
400  #ifndef CONFIG_USERSPACE
401          free(lock);
402  #else
403          k_object_release(lock);
404  #endif /* !CONFIG_USERSPACE */
405  }
```

High Severity Bug, 2/4

zephyr / tests / lib / newlib / thread_safety / src / **locks.c**

Code | Blame | 465 lines (377 loc) · 13.3 KB

```
60  ZTEST(newlib_thread_safety_locks, test_retargetable_lock_sem)
61  {
62          _LOCK_T lock = NULL;
63
64          /* Dynamically allocate and initialise a new lock */
65          __retarget_lock_init(&lock);
66          zassert_not_null(lock, "non-recursive lock init failed");
67
68          /* Acquire lock and verify acquisition */
69          __retarget_lock_acquire(lock);
70          zassert_equal(__retarget_lock_try_acquire(lock), 0,
71                        "non-recursive lock acquisition failed");
72
73          /* Release lock and verify release */
74          __retarget_lock_release(lock);
75          zassert_not_equal(__retarget_lock_try_acquire(lock), 0,
76                            "non-recursive lock release failed");
77
78          /* Close and deallocate lock */
79          __retarget_lock_close(lock);
80  }
```

High Severity Bug, 3/4

zephyr / lib / libc / newlib / **libc-hooks.c**

Code | Blame | 576 lines (478 loc) · 13.2 KB

```
358  /* Create a new dynamic non-recursive lock */
359  void __retarget_lock_init(_LOCK_T *lock)
360  {
361          __ASSERT_NO_MSG(lock != NULL);
362
363          /* Allocate semaphore object */
364  #ifndef CONFIG_USERSPACE
365          *lock = malloc(sizeof(struct k_sem));
366  #else
367          *lock = k_object_alloc(K_OBJ_SEM);
368  #endif /* !CONFIG_USERSPACE */
369          __ASSERT(*lock != NULL, "non-recursive lock allocation failed");
370
371          k_sem_init((struct k_sem *)*lock, 1, 1);
372  #ifdef CONFIG_USERSPACE
373          k_object_access_all_grant(*lock);
374  #endif /* CONFIG_USERSPACE */
375  }
```

High Severity Bug, 4/4

zephyr / lib / libc / newlib / libc-hooks.c

Code | Blame | 576 lines (478 loc) · 13.2 KB

```
396  /* Close dynamic non-recursive lock */
397  void __retarget_lock_close(_LOCK_T lock)
398  {
399          __ASSERT_NO_MSG(lock != NULL);
400  #ifndef CONFIG_USERSPACE
401          free(lock);
402  #else
403          k_object_release(lock);
404  #endif /* !CONFIG_USERSPACE */
405  }
```

zephyr / lib / libc / picolibc / libc-hooks.c

Code | Blame | 253 lines (209 loc) · 5.48 KB

```
111  #define _LOCK_T void *
```

Key Takeaways

- **Zephyr has a good security posture**
- **Coverity does a pretty good job, but it does not find everything**
- **Other tools are occasionally useful, but they generate tons of noise**
- **An active focus should be on tools that can come up with fixes of the problems**