ITiCSE 2024

# Embedded-check: a Code Quality Tool for Automatic Firmware Verification

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UNICAMP

# Insper

A small private non-profit institution in São Paulo, Brazil

Scholarships + stipends for 10-15% of students

Cohort-based (no courses outside of major)

Enrollment: 50 students per semester

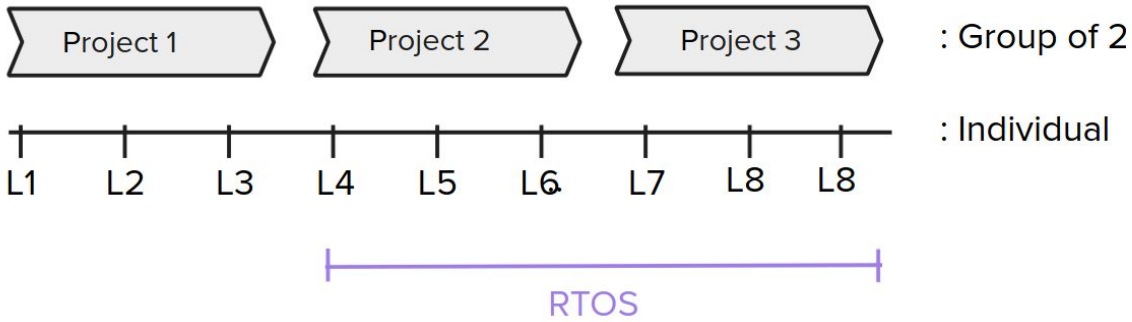
# Context

Embedded Systems

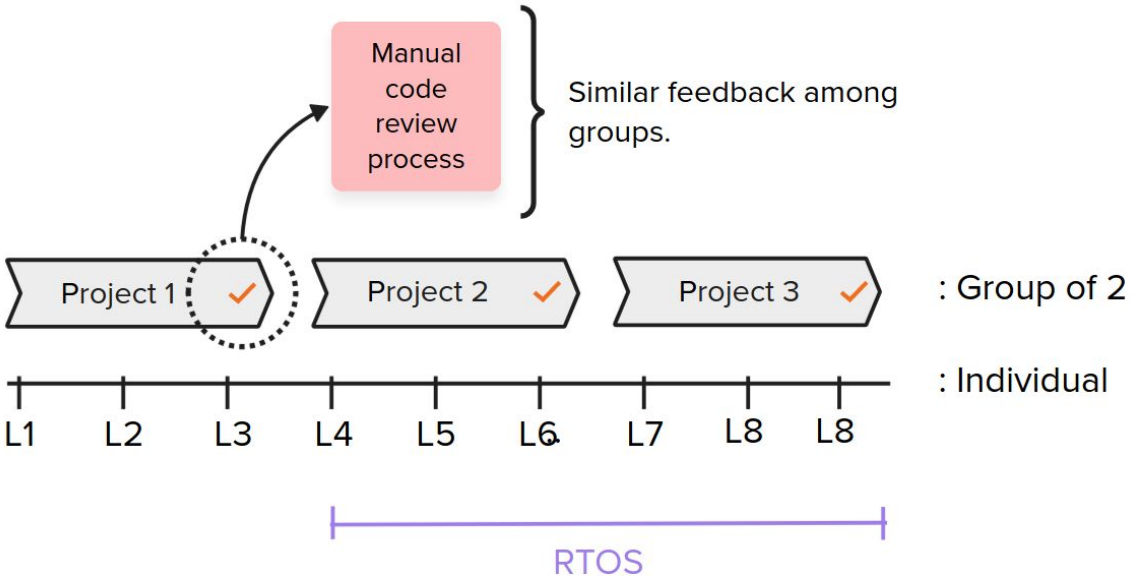
- Undergrad course
- Offered in the fifth semester of CE
- Firmware focus (C language)
- Hands-on

**Software ⟷ Design ⟷ Hardware**

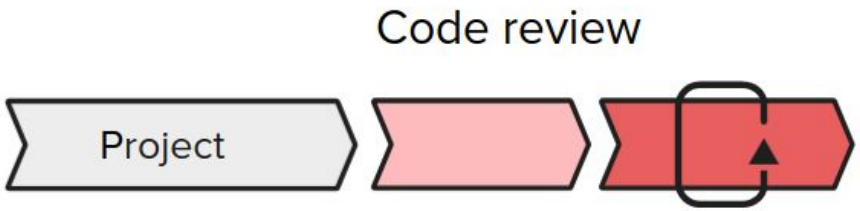
# Course details - Overview



# Course details - Code review



# Code review - Details




Students modify code and ask for validation

- github issues

| Type | Percentage |
|---|---|
| Code refactoring | 55% |
| **Rules violation** | **13%** |
| Code malfunction | 12% |
| Wrong rubric | 7% |
| Documentation | 5% |
| Solution questions | 5% |
| Complements | 3% |

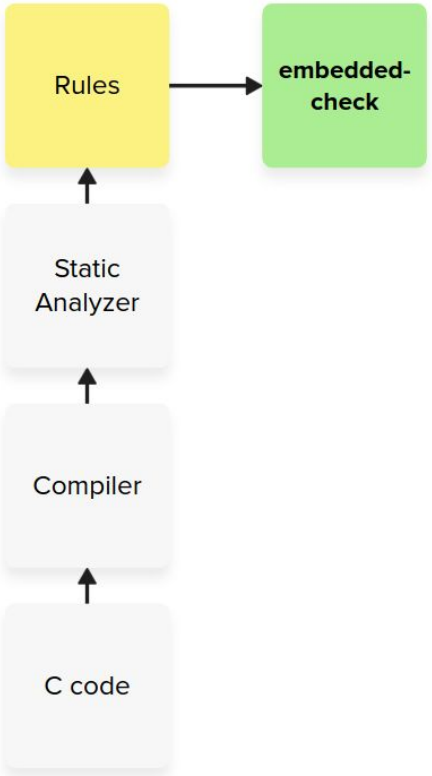
N = 96

3 semesters

2021 / 2022

# Rules

- Created based on faculty expertise
- Focus in firmware
- Three categories:
  - C Language (2 rules)
  - Embedded Systems (4 rules)
  - FreeRTOS (4 rules)
- Reflects **misconceptions**



# C Language

```c
#include <asf.h>

/**
 * freq: Frequecia em Hz
 * time: Tempo em ms que o tom deve ser gerado
 */
void tone(int freq, int time){
    double periodo_s = (double) 1 / freq;
    int periodo_us = periodo_s * 1e6;

    int n_de_iter = time / (periodo_s * 1000);
    int cont = 0;
    while(cont < n_de_iter) {
        if (!but_pause_flag) {
            pio_set(BUZZER_PIO, BUZZER_PIO_IDX_MASK);
            delay_us(periodo_us / 2);
            pio_clear(BUZZER_PIO, BUZZER_PIO_IDX_MASK);
            delay_us(periodo_us / 2);
            cont++;
        }
    }
}

// Recebe freq em hz e toca essa freq pelo tempo
// definido em TIME_BUZER_TEST (padrao 5s = 5000ms)
void buzzer_test(int freq) {
    double periodo_s = (double) 1 / freq;
    int periodo_us = periodo_s * 1e6;
    int n_iter = TIME_BUZZER_TEST / (periodo_s * 1000);

    for (int i = 0; i < n_iter; i++) {
        pio_set(BUZZER_PIO, BUZZER_PIO_IDX_MASK);
        delay_us(periodo_us / 2);
        pio_clear(BUZZER_PIO, BUZZER_PIO_IDX_MASK);
        delay_us(periodo_us / 2);
    }
}

// ...
// ...
```

foo.h

# C Language

NO (or wrong) include guard

C code in head file

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        delay_us(periodo_us / 2);
    }
}

// ...
// ...
```

foo.h

# Embedded Systems

```
char btn_flag;
volatile int freq;

// Hardware callBack (ISR)
void but_pause_callback()
{
    while (!btn_flag) {}
    btn_flag = 1;
    update_oled_display();
}

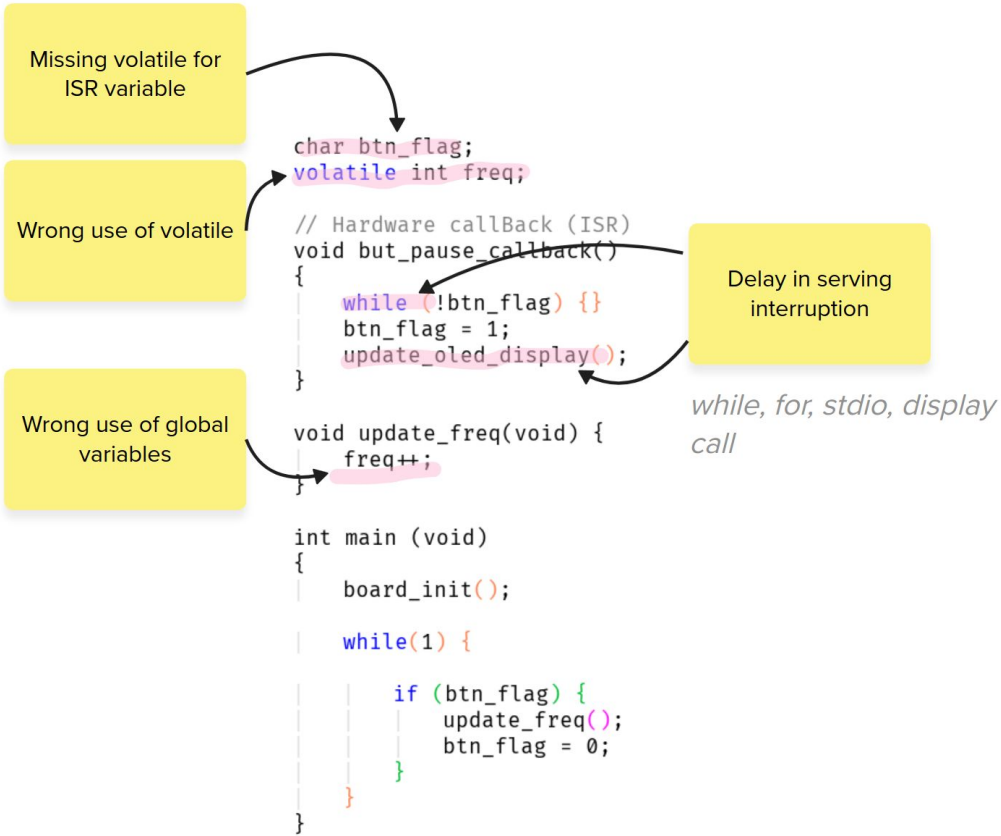
void update_freq(void) {
    freq++;
}

int main (void)
{
    board_init();

    while(1) {

        if (btn_flag) {
            update_freq();
            btn_flag = 0;
        }
    }
}
```

# Embedded Systems



# RTOS (FreeRTOS)

```c
volatile char btn_flag;

// Hardware callBack (ISR)
void btn_pause_callback()
{
    btn_flag = 1;
}

void timer_irs(){
    xSemaphoreGive(xSemaphore, 0);
}

void task_1(void){
    int timer = 0;
    while(1) {
        if (xSemaphoreTake(xSemaphore, 0)) {
            timer++;
            xQueueSendFromISR(xQueue, &timer, 0);
        }
    }

}

void task_2(void){
    while(1) {
        if (btn_flag) {
            delay_ms(100);
            update_oled_display();
            btn_flag = 0;
        }
    }
}
```

# RTOS (FreeRTOS)

Wrong use of global variables

Missing **FromISR**

Wrong use of **FromISR**

*Shall use RTOS resources such as Queue and Semaphores*

```
volatile char btn_flag;

// Hardware callBack (ISR)
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    btn_flag = 1;
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        }
    }
}
```
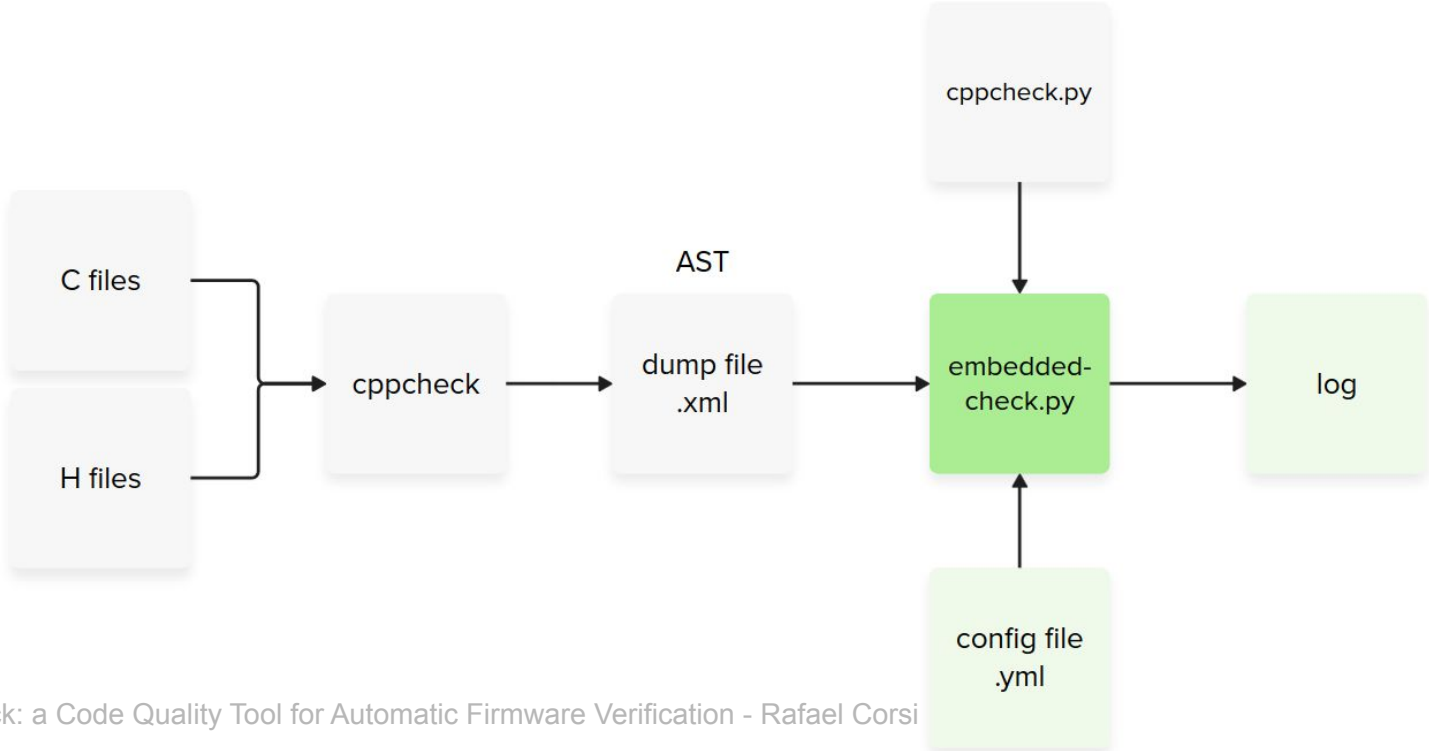

Shall use RTOS delay not software delays

# embedded-check

- A static analyser tool capable of verifying all rules



# embedded-check

Easy to extend

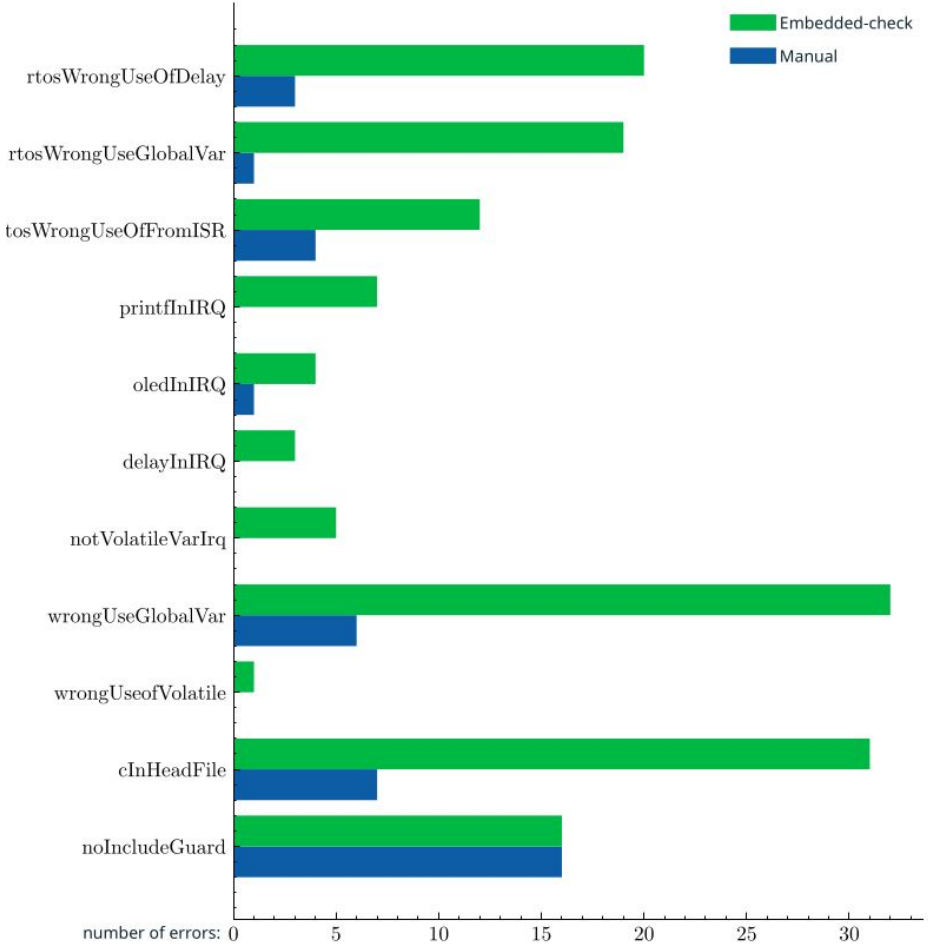
```python
def rule_1_3(self):
    """
    Rule 1_3: Do not use volatile where is not need
    """

    erro = 0
    var_erro_list_id = []

    for ass in self.code.all_vars_with_ass:
        if ass['variable'].Id in var_erro_list_id:
            continue

        # exclue ISR access vars
        if ass['variable'].Id in self.code.isr_global_vars_id:
            continue

        if ass['variable'].isExtern:
            continue

        if ass["variable"].isVolatile:
            var_name = ass["variable"].nameToken.str
            func_name = ass["className"]
            self.print_rule_violation(
                'rule_1_3',
                f"variable {var_name} in function {func_name}",
            )
            var_erro_list_id.append(ass['variable'].Id)
            erro = erro + 1
    return erro
```

# Does it works?

- No manual errors missed by embedded-check

- Detected issues 2.6x more than manual (150 vs. 42)

- Manual detected 28% repos with errors X 86% automatic



# How about the labs?

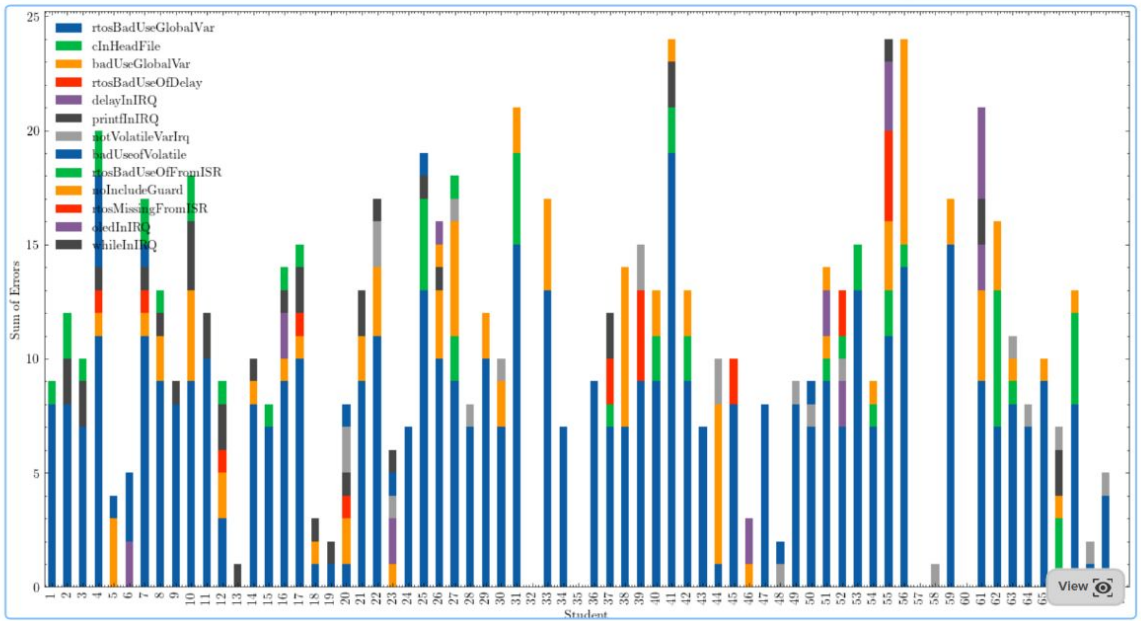
Did not receive any code feedback!

1250 detected errors

54.4% Embedded Systems

45.5% RTOS

11.9 violations per student (std=0.7)



# Common Errors

| Rule | Projects (%) (N=150) | Labs (%) (N=1250) |
|---|---|---|
| rtosWrongUseOfDelay | 15.4 | 7.0 |
| rtosWrongUseGlobalVar | 13.1 | 55.4 |
| rtosWrongUseOfFromISR | 5.0 | 2.2 |
| rtosMissingFromISR | 0.0 | 0.2 |
| printfInIRS | 2.6 | 6.5 |
| oledInIRS | 2.6 | 1.4 |
| delayInIRS | 4.4 | 4.8 |
| whileInIRS | 0.0 | 0.2 |
| notVolatileVarIRS | 1.6 | 2.2 |
| wrongUseGlobalVar | 21.4 | 9.4 |
| wrongUseVolatile | 1.3 | 4.2 |
| cInHeadFile | 19.8 | 6.2 |
| noIncludeGuard | 12.8 | 0.4 |

# Conclusions

The tool can replace manual feedback for checking the rules and it is easy to extend and can be use in different scenarios:

- **Post-Submission Analysis:** Identifies prevalent errors and assesses curriculum changes.
- **Manual Code Review Assistance:** Supports and improves efficiency in manual reviews.
- **Continuous Integration:** Ensures consistent code quality in CI systems for submissions.

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