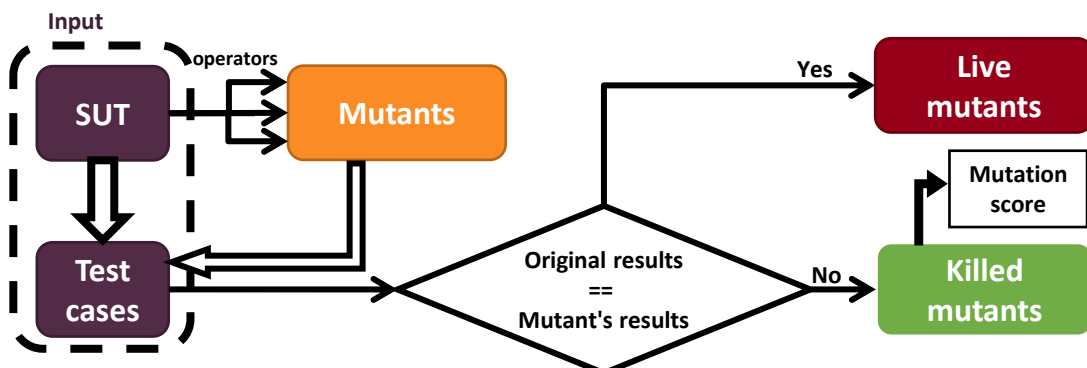


# USING MUTATION TESTING TO IMPROVE TEST EFFICIENCY IN EMBEDDED SYSTEMS



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## Mutation Testing



### State of the art

- Most efficient mutation operators identified
- Focus shifting from scalability to industrial adoption and test quality improvement
- Large scale case studies: Google [1], ESA [2]

- Uses slightly modified code variants – **mutants** – to simulate faults
- Measures **fault detection** ability of a test suite

[1] G. Petrović, M. Ivanković, G. Fraser and R. Just, "Practical Mutation Testing at Scale: A view from Google," in IEEE Transactions on Software Engineering, vol. 48, no. 10, pp. 3900-3912, 1 Oct. 2022, doi: 10.1109/TSE.2021.3107634

[2] O. Cornejo, F. Pastore and L. C. Briand, "Mutation Analysis for Cyber-Physical Systems: Scalable Solutions and Results in the Space Domain," in IEEE Transactions on Software Engineering, vol. 48, no. 10, pp. 3913-3939, 1 Oct. 2022, doi: 10.1109/TSE.2021.3107680

## Embedded software (C)

Lightweight mutation testing tool for railway software test environment

- Successfully introduced in industrial workflow
- Evaluation of tests generated to satisfy code coverage criteria: **SIL2 compliant test suites missing test cases**

Mutation results on automatically generated tests

| Operator set                           | # of mutants | Killed | Alive | Score   |
|----------------------------------------|--------------|--------|-------|---------|
| Increment invert                       | 0            | 0      | 0     |         |
| Mathematical                           | 23           | 9      | 14    | 39.13%  |
| Conditionals boundary                  | 2            | 2      | 0     | 100.00% |
| Conditionals negation                  | 26           | 20     | 6     | 76.92%  |
| Boolean invert                         | 0            | 0      | 0     |         |
| Return NULL                            | 61           | 38     | 23    | 62.30%  |
| Remove condition                       | 109          | 78     | 31    | 71.56%  |
| ALL                                    | 221          | 147    | 74    | 66.52%  |
| Return NULL without equivalent mutants | 38           | 38     | 0     | 100.00% |
| Corrected ALL                          | 198          | 147    | 36    | 74.22%  |

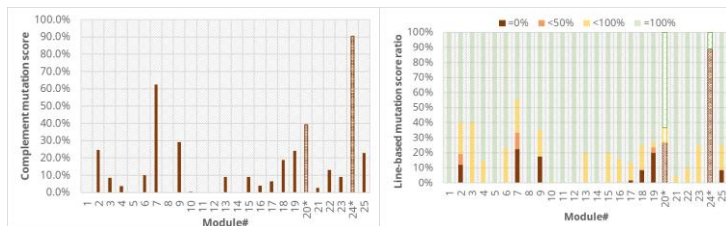
**Future work:** evaluating other industrial test generator tools

## PLC software (ST, FBD)

Case study in railway industry

- **Survey with developers** to identify SW testing challenges
- **New visualization and metrics** for mutation test results
- **Test generation** for live mutants

| line# code                                                                                                                                        | Score  | ABS | ACR | LCR | PCR | DOT | ALL |
|---------------------------------------------------------------------------------------------------------------------------------------------------|--------|-----|-----|-----|-----|-----|-----|
| 1.1 //SR316,SR1317                                                                                                                                |        |     |     |     |     |     |     |
| 1.2 IF (NOT Unit_Is_Type1) THEN State_Type1:=State_Type1.ZERO_STATE; END_IF                                                                       | 100.0% | 10  | 0   | 10  | 0   | 0   | 10  |
| 1.3 IF (Unit_Is_Type1 AND (State_Type1=State_Type1.ZERO_STATE)) THEN State_Type1:=State_Type1.SETUP_STATE; END_IF                                 | 100.0% | 10  | 0   | 10  | 0   | 0   | 10  |
| 1.4                                                                                                                                               |        |     |     |     |     |     |     |
| 1.5 //SR425,SR1429                                                                                                                                |        |     |     |     |     |     |     |
| 1.6 Type1_SetupDone:= (NOT(State_Type1=State_Type1.ZERO_STATE)) AND (NOT(State_Type1=State_Type1.SETUP_STATE));                                   | 100.0% | 10  | 0   | 10  | 0   | 0   | 10  |
| 1.7                                                                                                                                               |        |     |     |     |     |     |     |
| 1.8 Setup_State_Type1_On(On:= (State_Type1=State_Type1.SETUP_STATE) AND ComponentSetup_Done,TimeOnDelay:=T_ST_Type1_Unit_Setup,InitState:=FALSE); | 100.0% | 10  | 0   | 10  | 0   | 0   | 10  |
| 1.9                                                                                                                                               |        |     |     |     |     |     |     |
| 1.10 LockCond:=FALSE;                                                                                                                             |        |     |     |     |     |     |     |
| 1.11 IF (Setup_State_Type1_On.Out                                                                                                                 |        |     |     |     |     |     |     |
| 1.12 OR                                                                                                                                           |        |     |     |     |     |     |     |
| 1.13 ((NOT(State_Type1=State_Type1.ZERO_STATE)) AND (NOT(State_Type1=State_Type1.SETUP_STATE)) AND                                                | 100.0% | 10  | 0   | 10  | 0   | 0   | 10  |
| 1.14 ((CommandIn=OUT40) OR Sig1_from_Type2 OR Sig2_from_Type2 OR (NOT Orientation_Valid)))                                                        | 57.14% | 10  | 0   | 10  | 0   | 0   | 10  |
| 1.15 ) THEN                                                                                                                                       |        |     |     |     |     |     |     |
| 1.16 LockCond:=TRUE;                                                                                                                              |        |     |     |     |     |     |     |
| 1.17 END_IF                                                                                                                                       |        |     |     |     |     |     |     |



**Future work:** extended survey & transition to open-source code

[https://acta.uni-obuda.hu/Serban\\_Micskei\\_148.pdf](https://acta.uni-obuda.hu/Serban_Micskei_148.pdf)



<https://tdk.bme.hu/conference/VIK/2024/sessions/beagy/paper/Teszthatekonysag-javitasa-mutacios>



Critical Systems Research Group

