Concolic Testing for High Test Coverage and Reduced Human Effort in Automotive Industry

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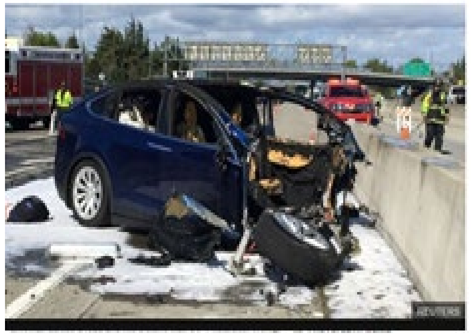
Manual Testing in Automotive Industry: - **Large Human Effort Required**

Manual Testing

- SW reliability is critical for cars

Toyota "Unintended Acceleration" has killed 89

Tesla fatal crash was on Autopilot



- Achieving high reliability requires **large human effort**

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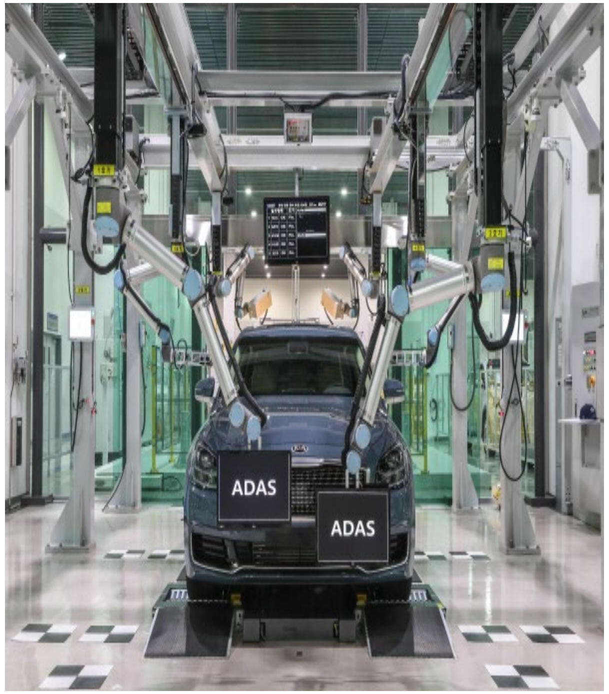
1MLoC / a car * 10 models ÷ 7KLoC/MM

= **120MYr** (for coverage testing)

Automated Testing can **Achieve High Reliability** and **Reduce Human Testing Effort**

Automated Testing



- Automated testing achieves **high reliability**

Achieving high code coverage

Detecting hidden bugs

- Automated testing can be **100x faster** than manual one

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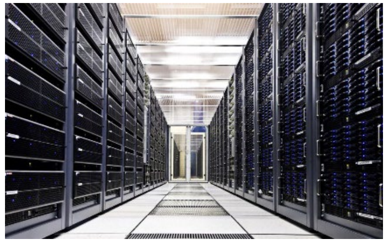


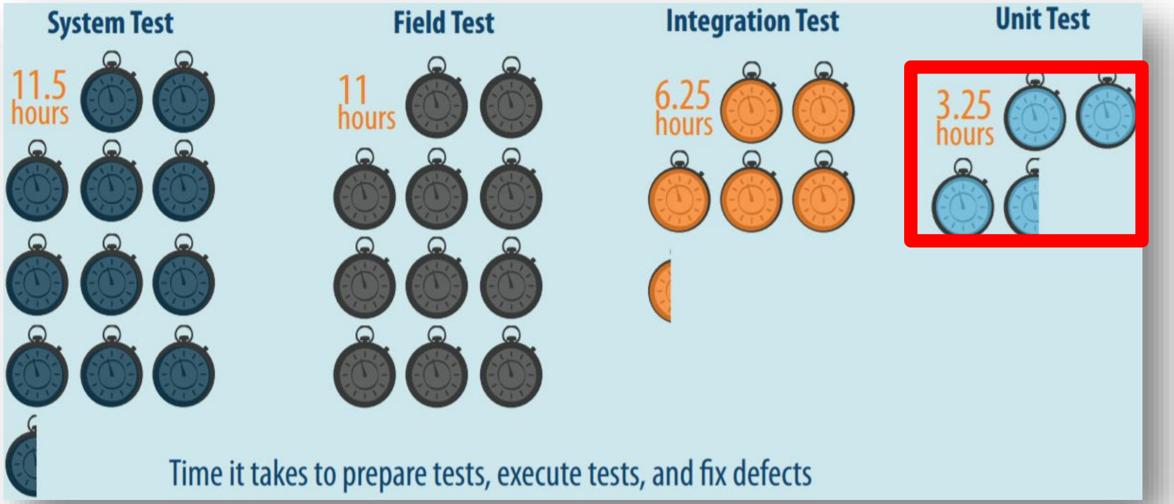
1MLoC/a car * 10 models ÷ **700KLoC/1CM**

= **1.2CYr** (**= 0.1M on 100 cloud cores**)

Benefits of Unit Testing

- **Bug correction cost: 7x cheaper** than system tests
  - $937 (unit test) vs $7,136 (system test)
- **Bug correction time: 3x faster** than system testing
  - 3.25 hours vs 11.5 hours

Source: B. Boehm and V. Basil, Software Defect Reduction Top 10 List, IEEE Computer, January 2001



Source: Capers Jones, Applied Software Measurement: Global Analysis of Productivity and Quality

Excerpted from the CONBRIO paper slides [Kim et al., ICSE18]

Importance of Automated **Unit Testing** In Automotive SW

System testing is **expensive** and **less effective**

- **Full vehicle HW** and **human drivers** are required
- Driving a car with **various physical environments** spends **a lot of time**
- **Hard-to-achieve high test coverage** due to low controllability

VS

Unit testing is **cheap** and **more effective**

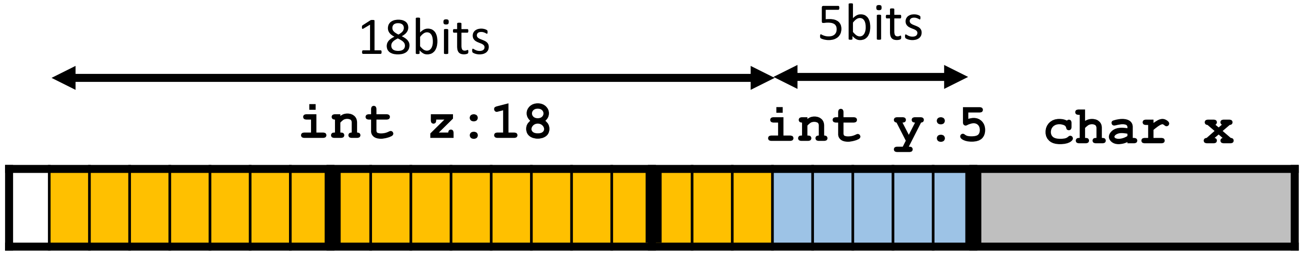
- Full vehicle HW and human drivers are **NOT necessary**
- No need to drive a car
- **Easy-to-achieve high coverage** due to high controllability

3 Technical Challenges for Automated Unit Testing

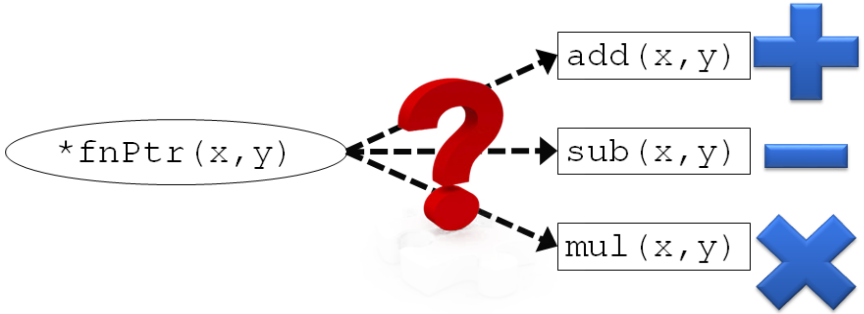
False alarms

Bit-fields

`struct S` : 4 Bytes

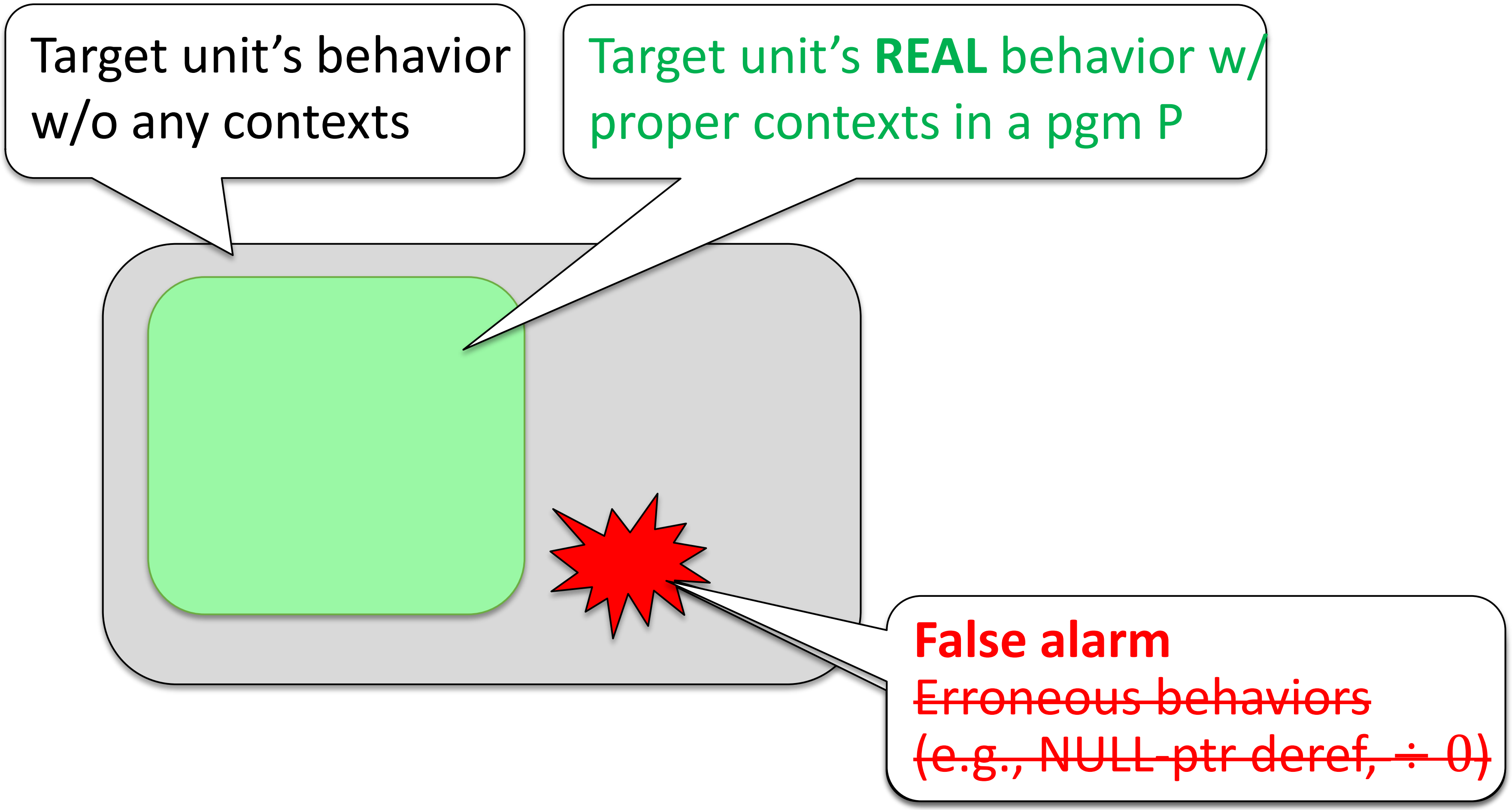


Function pointers



False Alarms due to Infeasible Unit Executions

- **False alarms** can be raised due to missing contexts



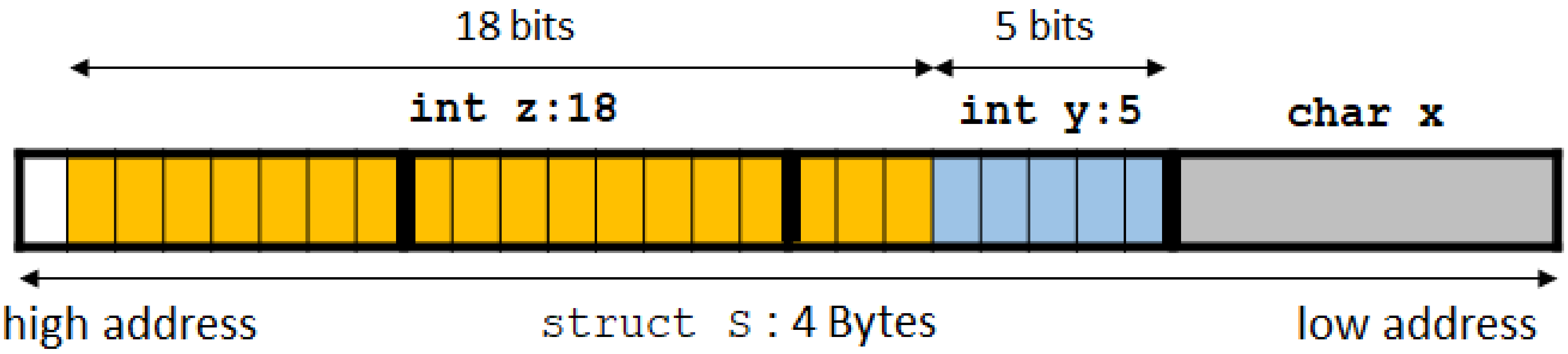
No Support of Symbolic Bit-fields

- Tracking symbolic expression for bit-fields is **NOT** possible
  - bit-fields are **NOT addressable (i.e., &(s.y) is not allowed)**

```
struct S{
   char x;
   int y:5;
   int z:18;};
```

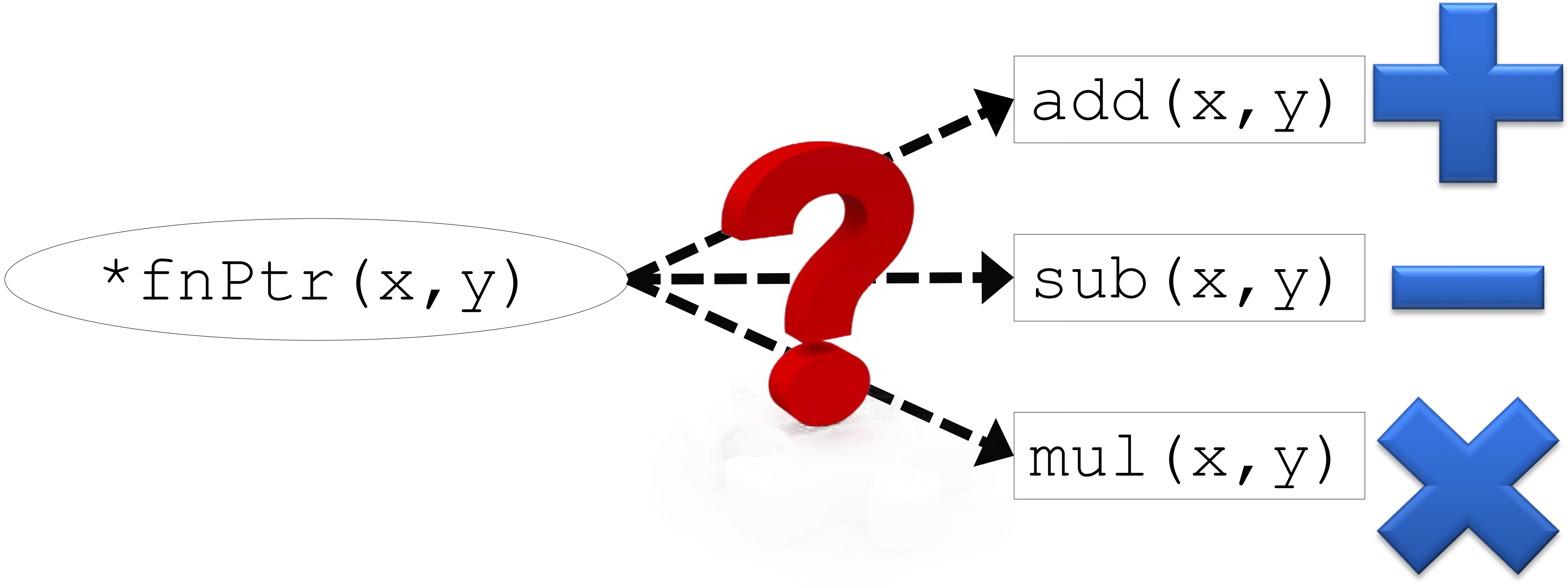
Symbolic Memory Map

Memory address (key)	Sym. Exp. (value)
&(S.x)	$S.x_0+3$
&(S.y) **NOT allowed**	**N/A**
&(S.z) **NOT allowed**	**N/A**



No Support of Symbolic Function Pointers

› Hard-to-know which function a given func. ptr. points to

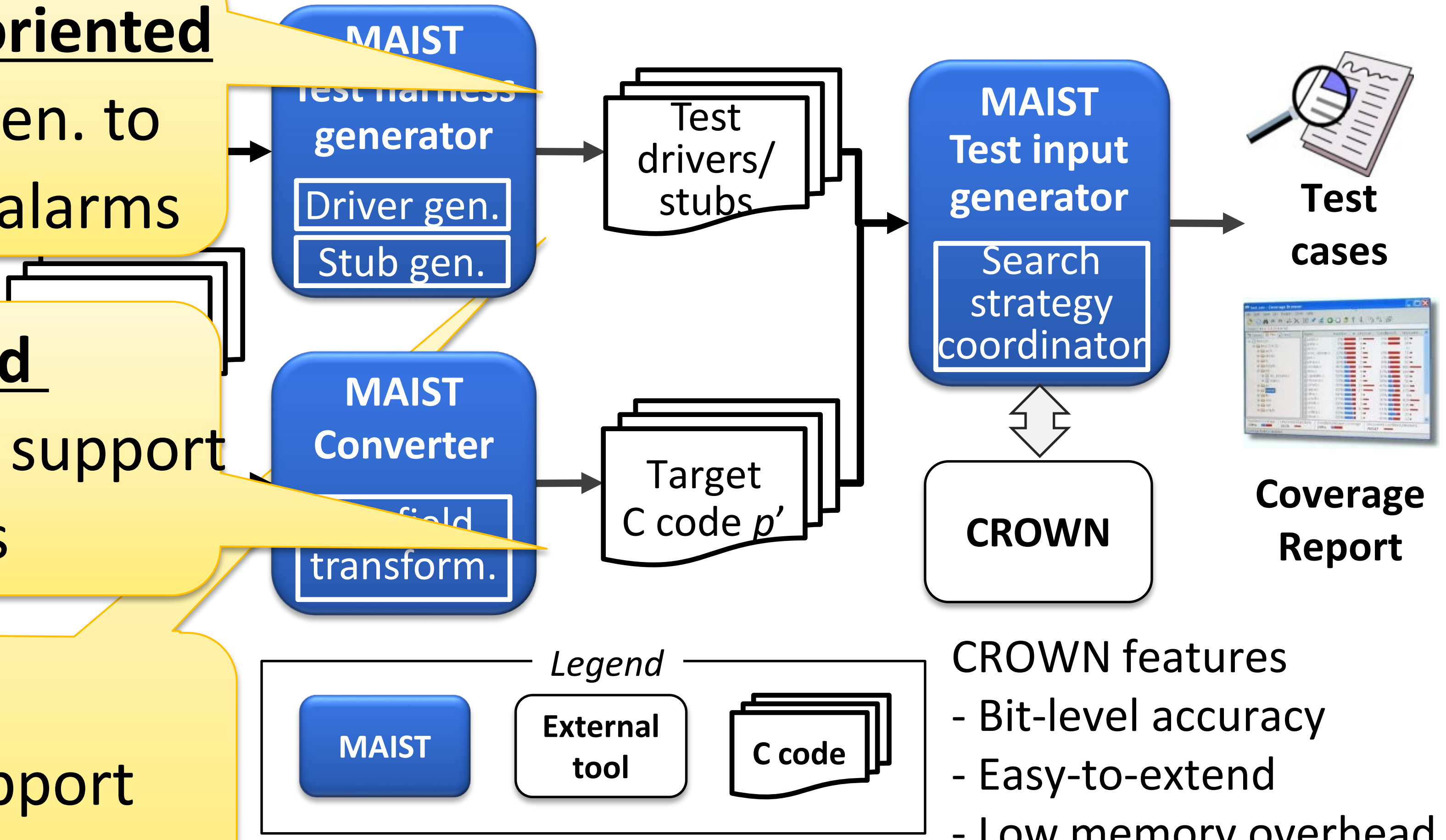


Overview of MAIST

Sol. 1: **<u>Task-oriented</u>** driver/stub gen. to reduce false alarms

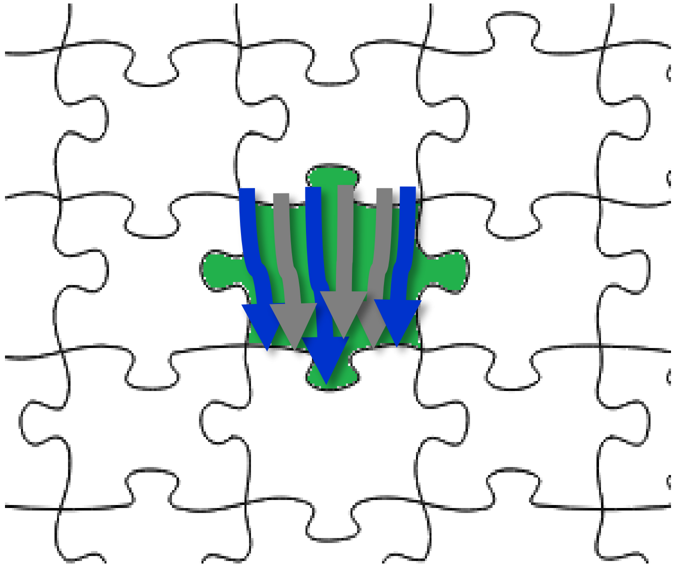
Sol. 2: **<u>Bit-field transform</u>**. to support sym. bit-fields

Sol. 3: Static analysis to support **<u>sym. function pointer</u>**

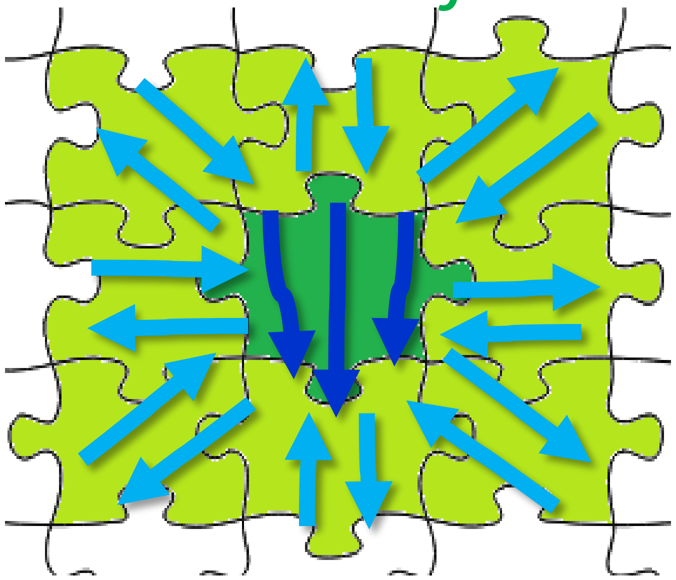


CROWN features
- Bit-level accuracy
- Easy-to-extend
- Low memory overhead
- Fast through lightweight instr.

Unit Testing *f* without Contexts of *f*



Unit Testing *f* with Contexts of *f*



Without Contexts of *f*

Pros: fast exploration of target unit execution paths

Cons: infeasible target unit executions

With Contexts of *f*

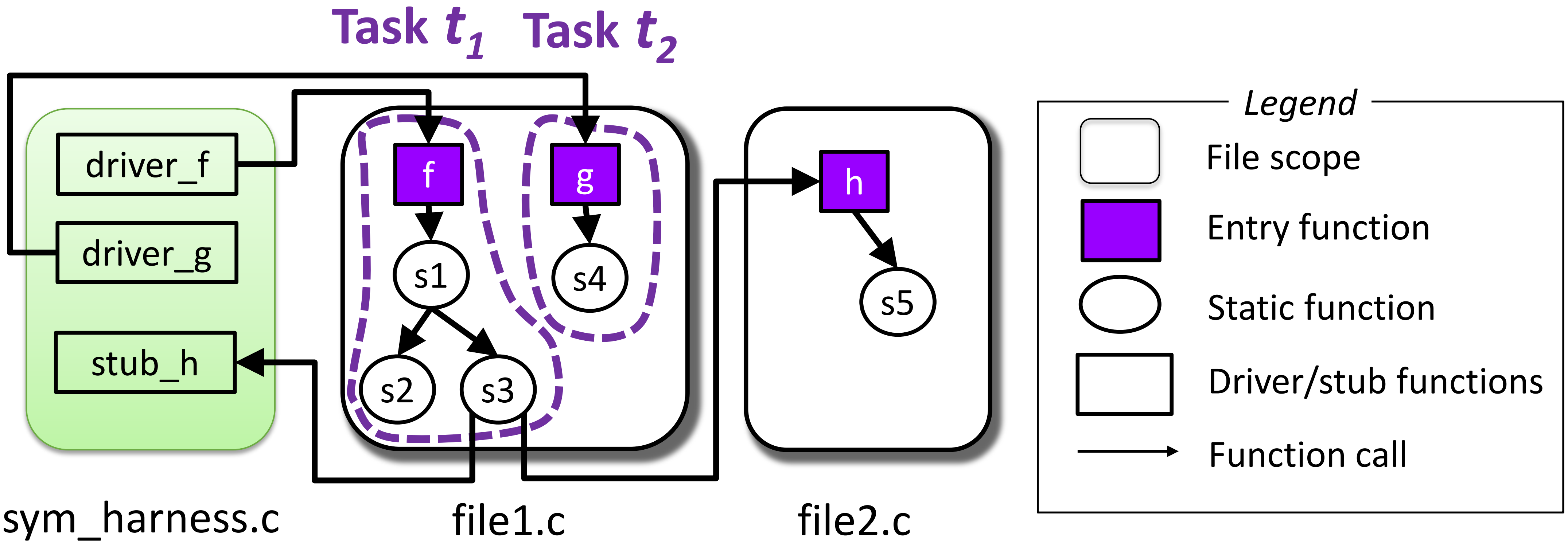
Pros: reduced infeasible target unit executions

Cons: slow exploration of target unit execution due to large cost of exploring context functions

Excerpted from the CONBRIO paper slides [Kim et al., ICSE18]

Task-oriented Unit-test Driver/Stubs Generation

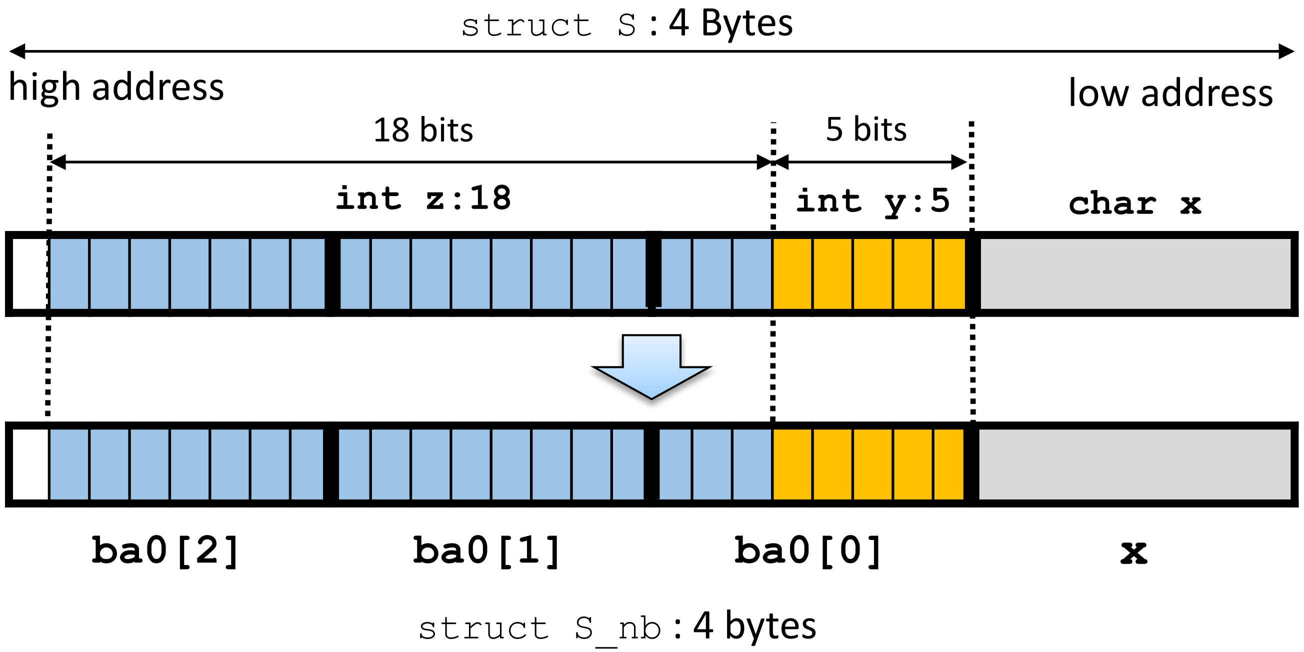
- A ***Task*** is a mostly **minimal independent unit**



Bit-field Transformation

```
struct S{
  char x;
  int y:5;
  int z:18;};
```

```
struct S_nb{
  char x;
  unsigned char ba0[3];
} ;
```



Original program *p*	Transformed program *p'*
`n=S.z+1;`	`n=(((S_nb.ba0[2]&127)<<16) | (S_nb.ba0[1]<<8) | S_nb.ba0[0])>>5 +1;`

`S.z=S.x+3;`	`S_nb . ba0 [2]= ((((S_nb.x+3) <<5) > >(2*8)) &127)| (S_nb .ba0 [2]&128);`
	
	`S_nb . ba0 [1]= (((S_nb.x+3) <<5) > >(1*8)) &255;`
	
	`S_nb . ba0 [0]= (((S_nb.x+3) <<5) &224) | ( S_nb .ba0 [0]&31);`

Symbolic Function Pointer Support

Step 1: Identifying candidate functions using static analysis

```
target.c
 1:int (*fnPtr)(int,int);
 2:int add(int,int) {…}
 3:int sub(int,int) {…}
 3:int mul(int,int) {…}
 4:void f() {…
 5:  fnPtr=add;}
 6:int g(){…
 7:  fnPtr=sub;}
 7:int h(){…
 8:  fnPtr=mul;}
 8:void do_chk(int
 9:…
10: int ret=fnPtr(x,y);
11: …}
```

Function pointer input

Candidate1: add()

Candidate2: sub()

Candidate3: mul()

Step 2: Set *fnPtr as one of the candidates using a symbolic var sym_choice

```
harness_target.c
 1:void drv_do_chk(){
 2: …
 3:   SYM_int(sym_choice);
 4:   switch(sym_choice){
 5:   case 0:
 6:     fnPtr=add;
 7:     break;
 8:   case 1:
 9:     fnPtr=sub;
10:     break;
11:   case 2:
12:     fnPtr=mul;
13:   default: break;}
14:   SYM_int(p1);
15:   do_chk(p1);}
```

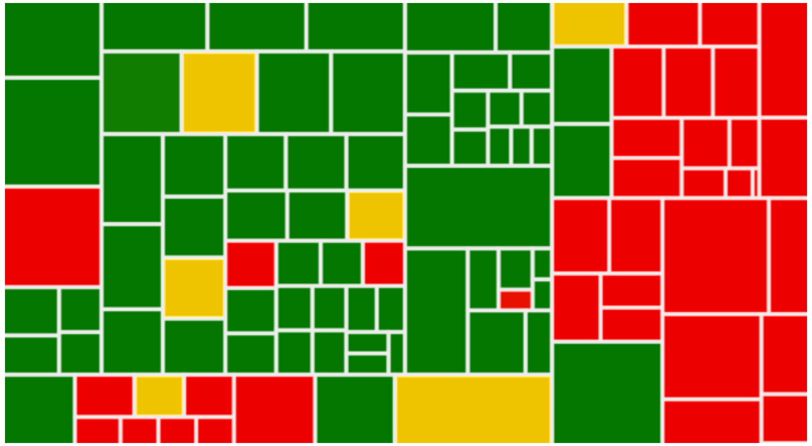
Set *fnPtr as add() if sym_choice==0

Set *fnPtr as sub() if sym_choice==1

Set *fnPtr as mul() if sym_choice==2

Research Questions

› RQ1-2: Overall benefit of MAIST

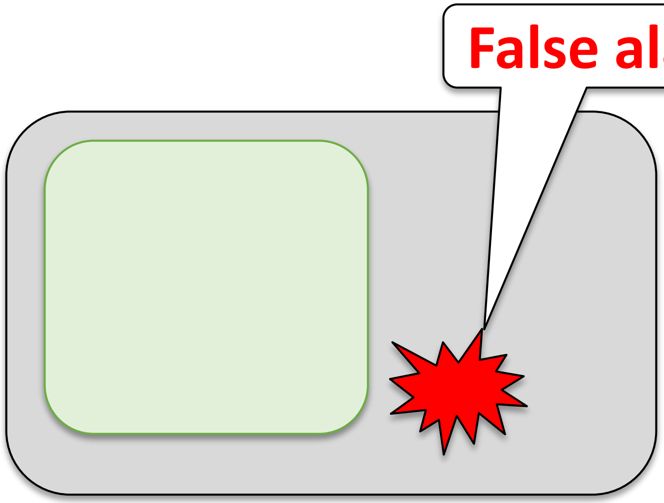


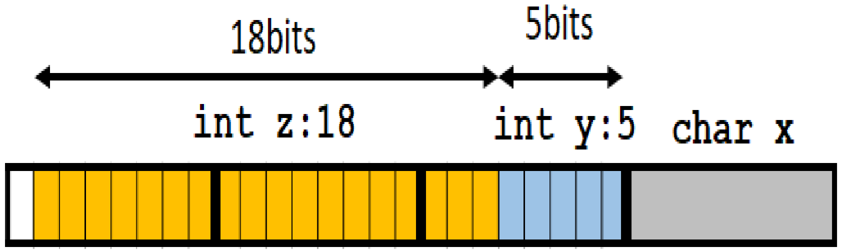
RQ1: **How much**
test coverage
does MAIST achieve?

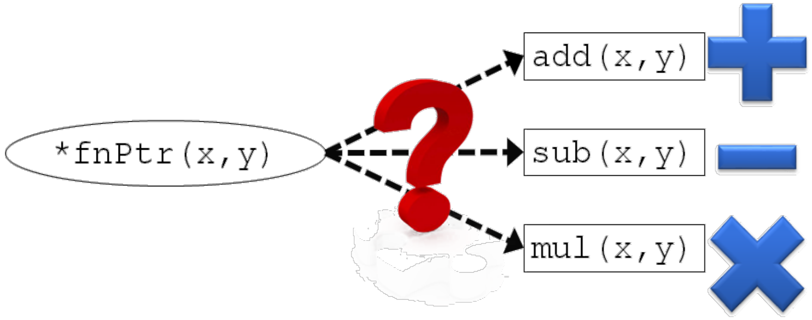
RQ2: **How much**
human test effort
does MAIST reduce?

Research Questions

› RQ3-5: Effectiveness of MAIST for addressing the technical difficulties







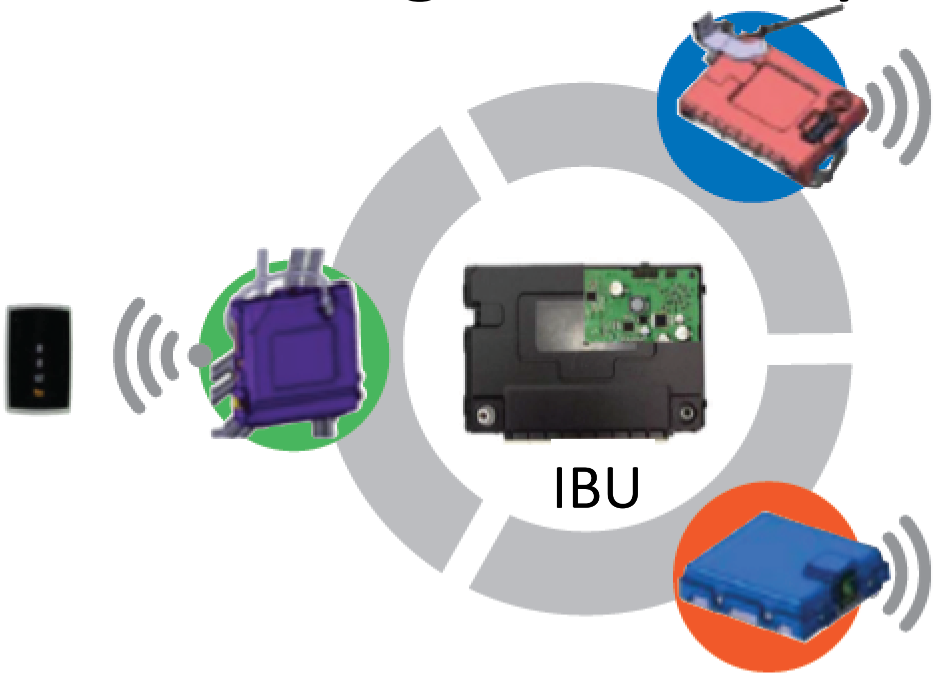
RQ3: **Effect of Task-oriented test Gen.**

RQ4: **Effect of Sym. bit-fields**

RQ5: **Effect of Sym. Func. Ptr.**

Overview of Target SW: Integrated Body Unit

- Smart Key (SMK)
  - Remote door lock/unlock
  - Button start



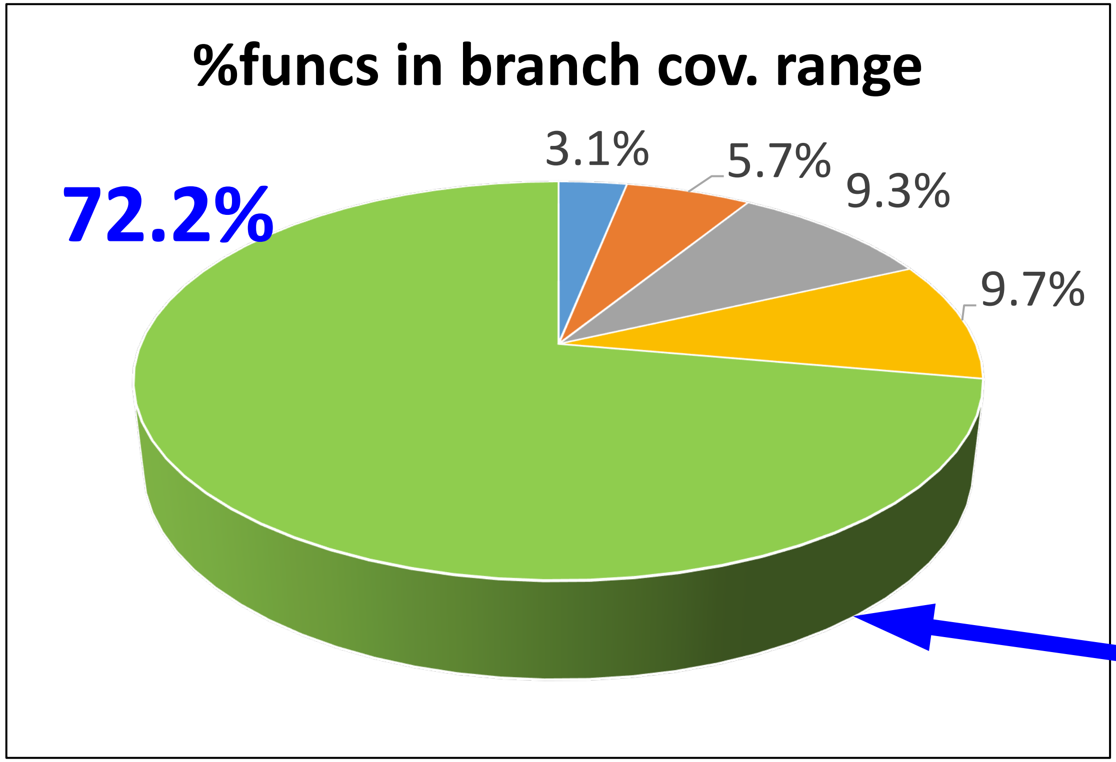
- Body Control Module (BCM)
  - Wiper, door control
  - Burglar alarm
- Tire Pressure Monitor (TPM)
  - Tire pressure sensing

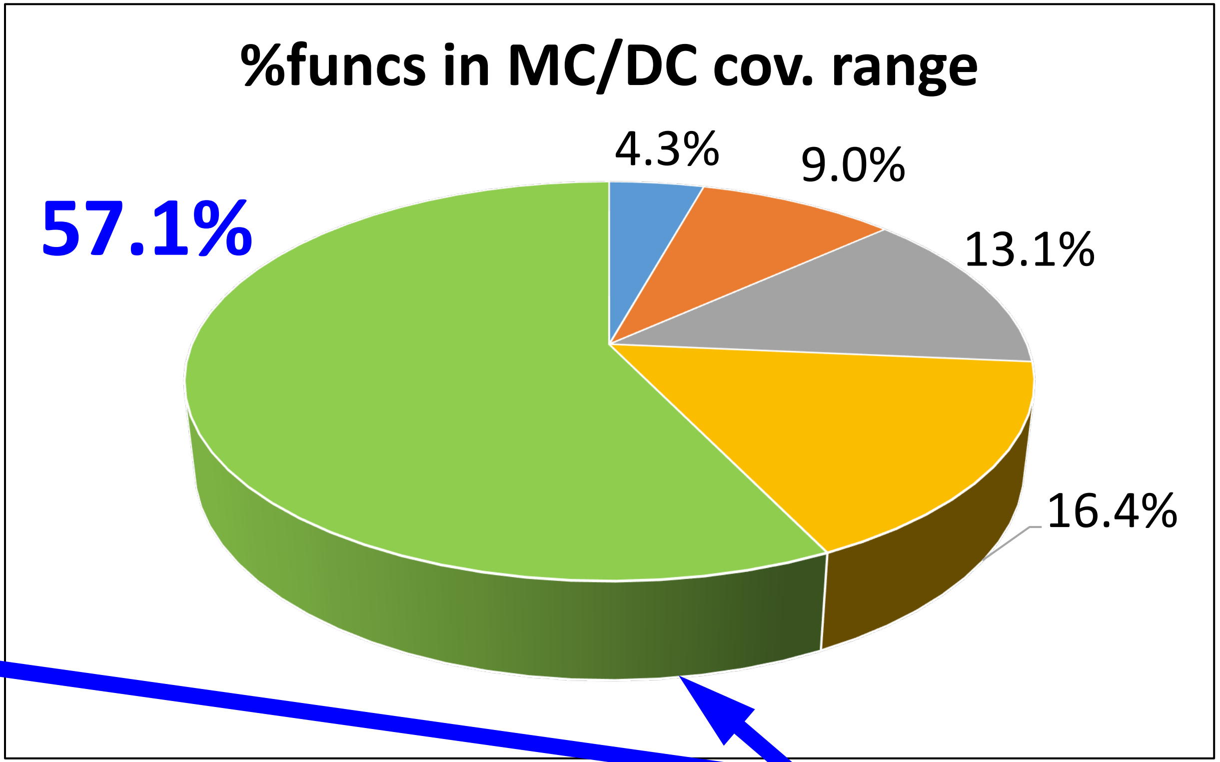
Module	#files	#tasks	#functions	LoC	Avg. CC per func.
BCM	27	143	656	53,690	4.3
SMK	198	554	2,521	135,877	5.8
TPMS	29	68	302	16,951	4.1
Total	**254**	**767**	**3,479**	**206,518**	**4.9**

RQ1:MAIST Achieved **90.5% Branch** and **77.8% MC/DC Cov.**

100% branch cov. of 72.2% of funcs

100% MC/DC cov. of 57.1% of funcs

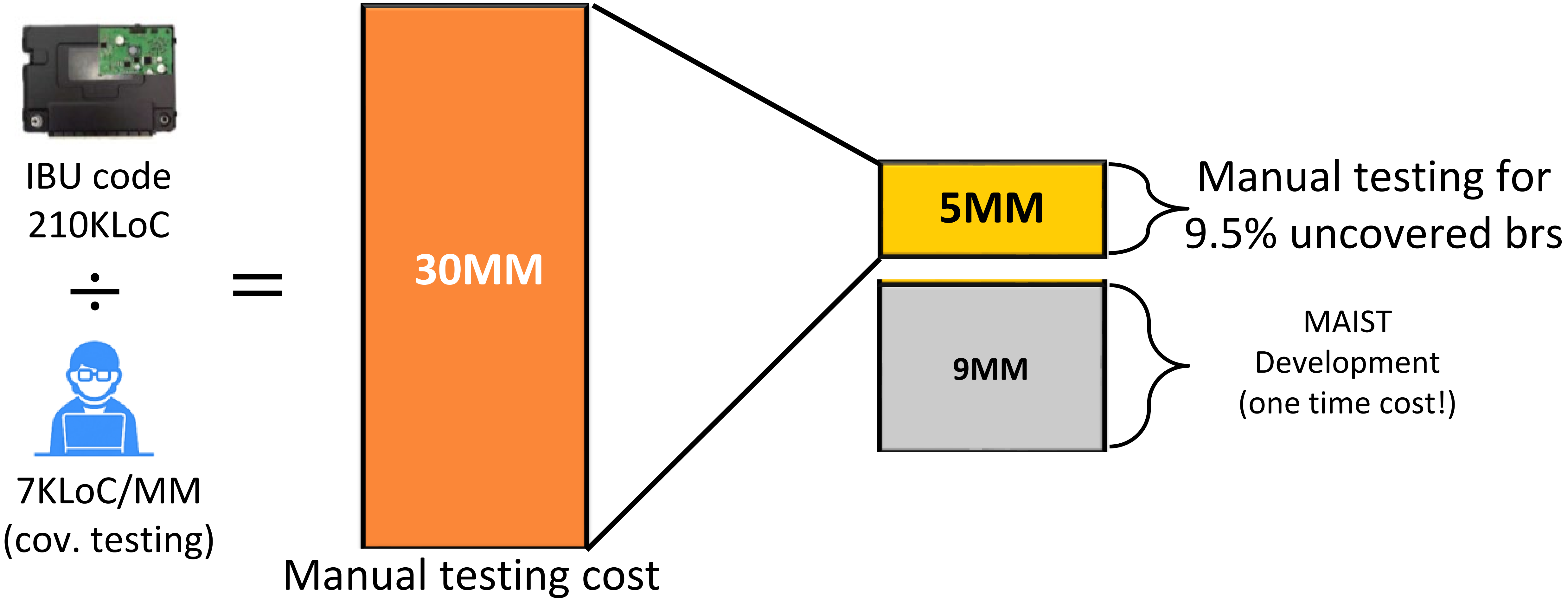




[20%,40%) [40%,60%) [60%,80%) [80%,100%) 100%

* Running 20 hours on 12 CPU cores (3.0GHz)

RQ2. MAIST Reduced Testing Cost from 30MM to 5MM (↓83.3%)

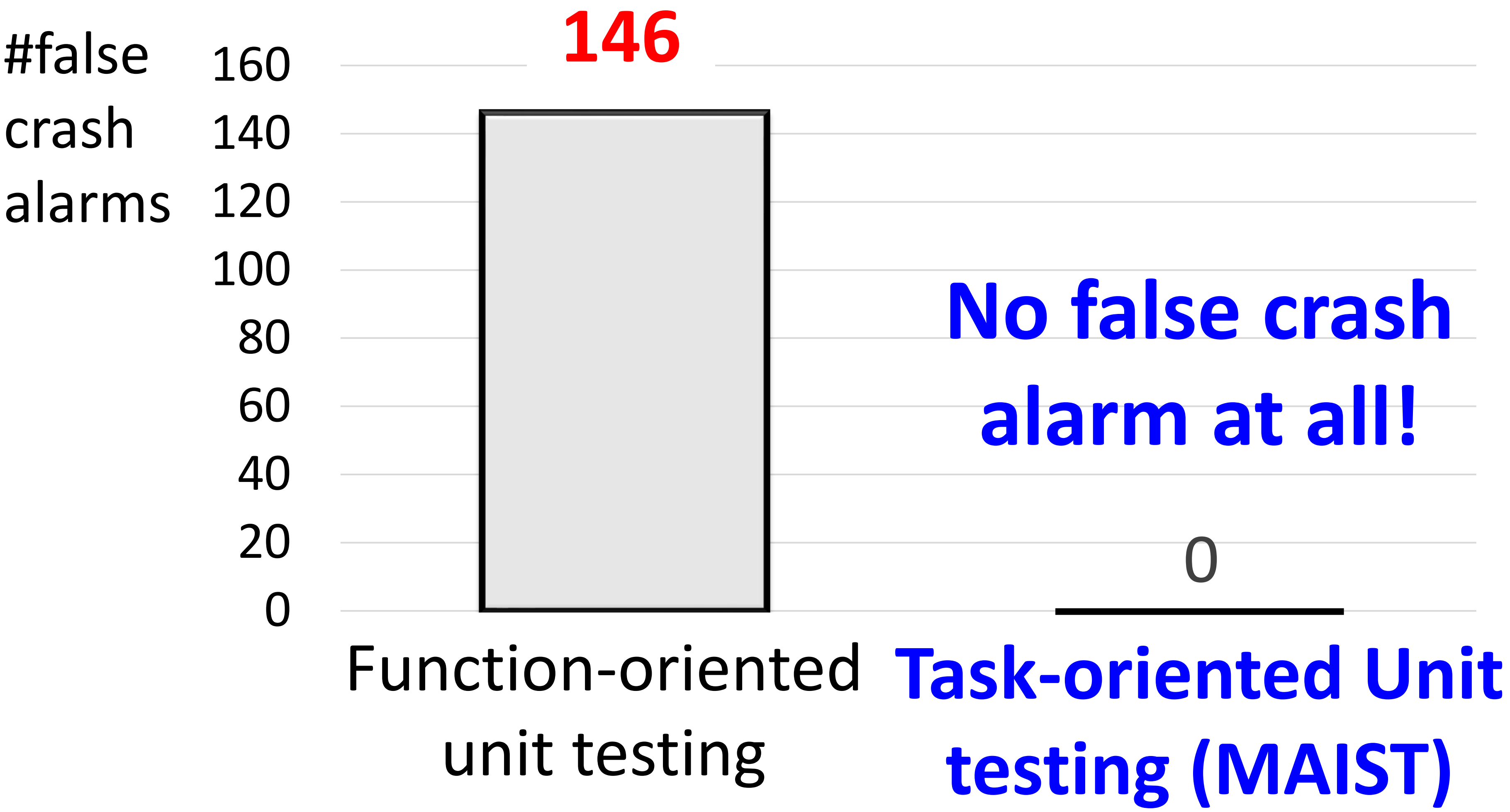


RQ2: Analysis of the Uncovered Branches

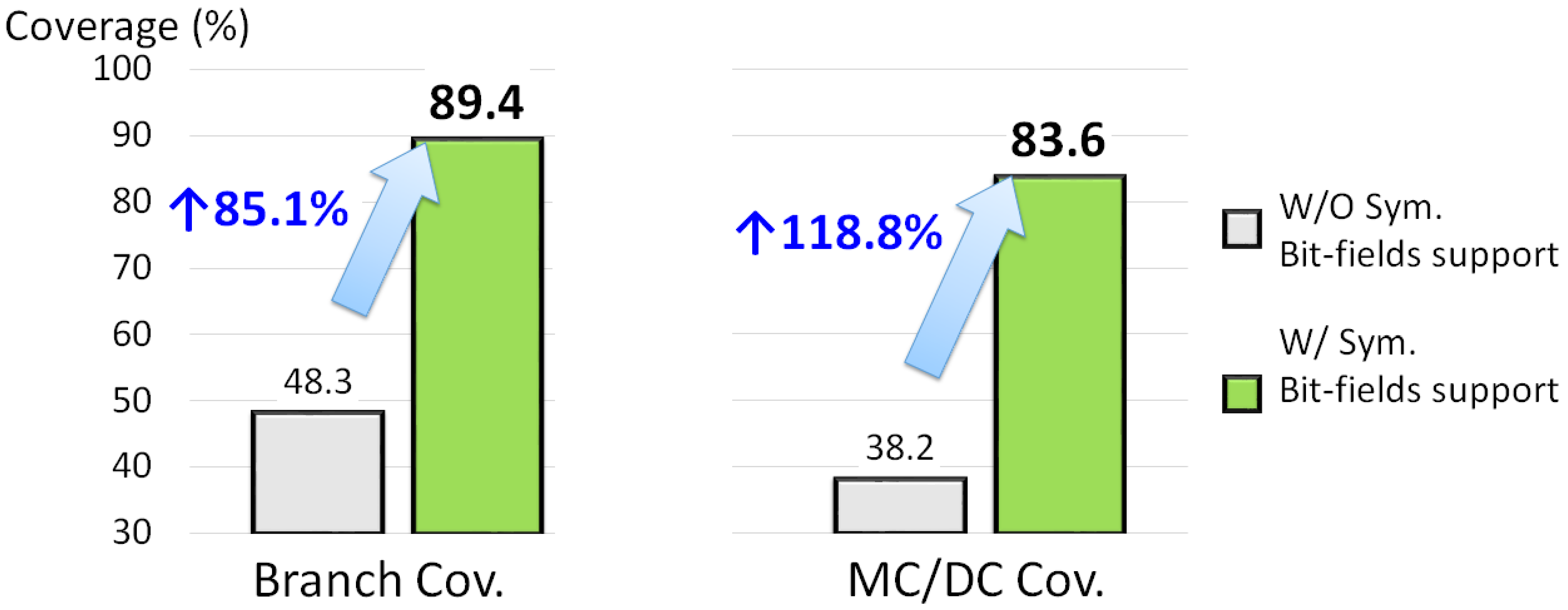
- **Imprecise stub** is the main cause of uncovered branches
  - Manually analyze 33 BCM functions having <60% br. Cov.

Reasons	#uncovered brs	Ratio (%)
Imprecise stub	43	41.7
Path explosion	21	20.4
Static local variable	21	20.4
Imprecise driver	10	9.7
Unreachable branches	8	7.8
Total	**103**	**100**

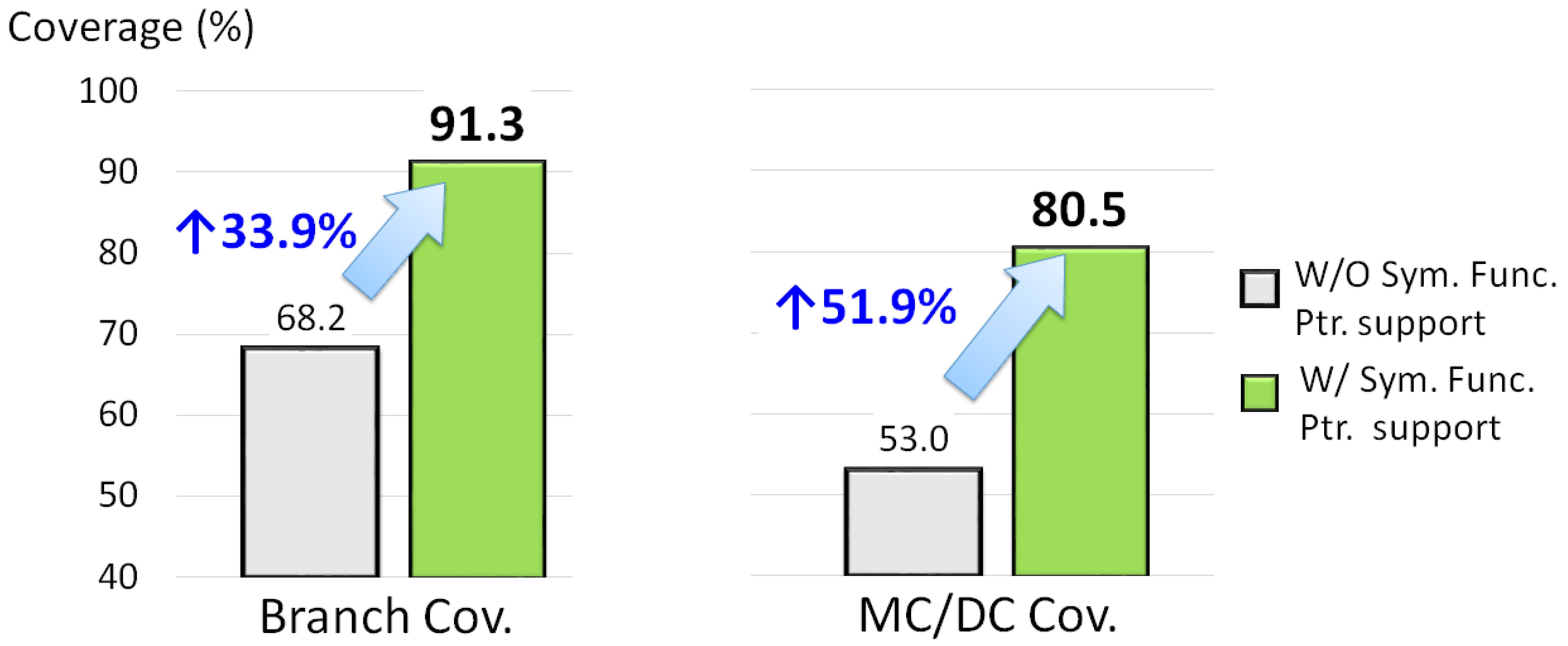
RQ3: **No false crash alarms** by Task-oriented driver/stub generation



RQ4: **Symbolic Bit-fields Support** Highly Increases Test Coverage



RQ5: **Sym. Function Pointer Support** Increases Test Coverage



Conclusion

Manual Testing in Automotive Industry:
- **Large Human Effort Required**

Manual Testing

- SW reliability is critical for cars

Toyota "Unintended Acceleration" has killed 89

Tesla fatal crash was on Autopilot

- Achieving high reliability requires **large human effort**

1MLoC / a car * 10 models ÷ 7KLoC/MM
= **120MYr** (for coverage testing)

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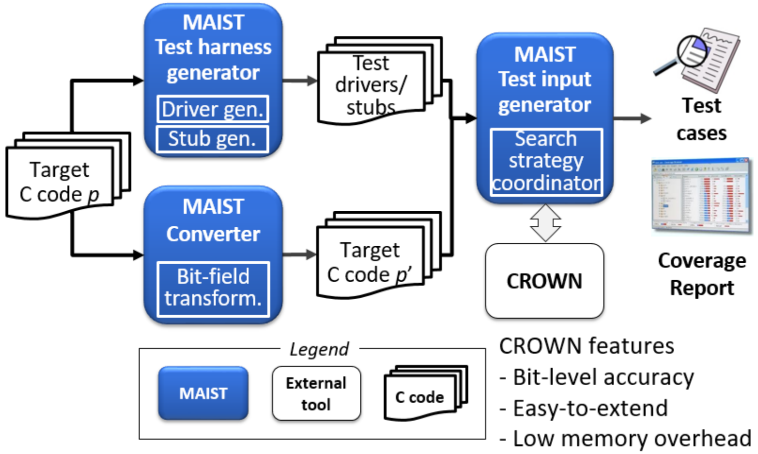

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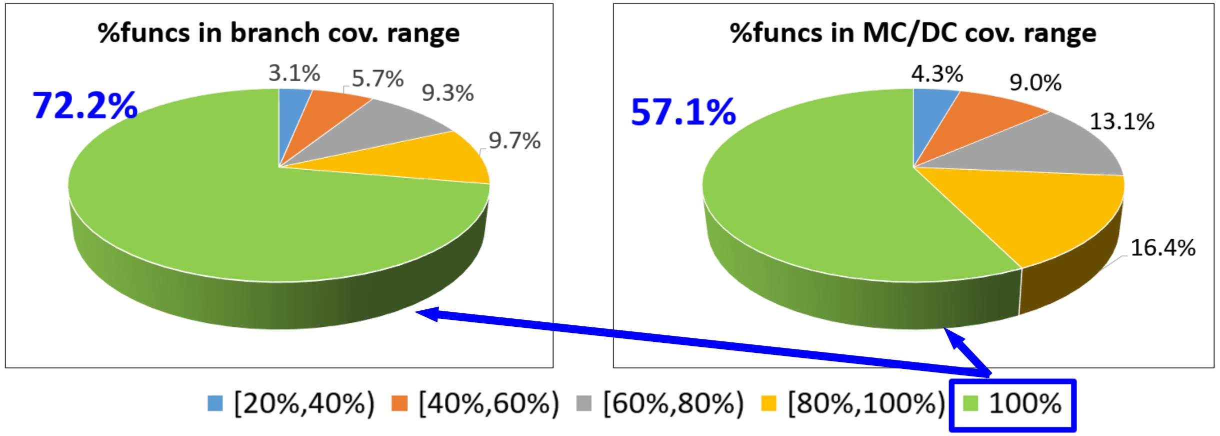
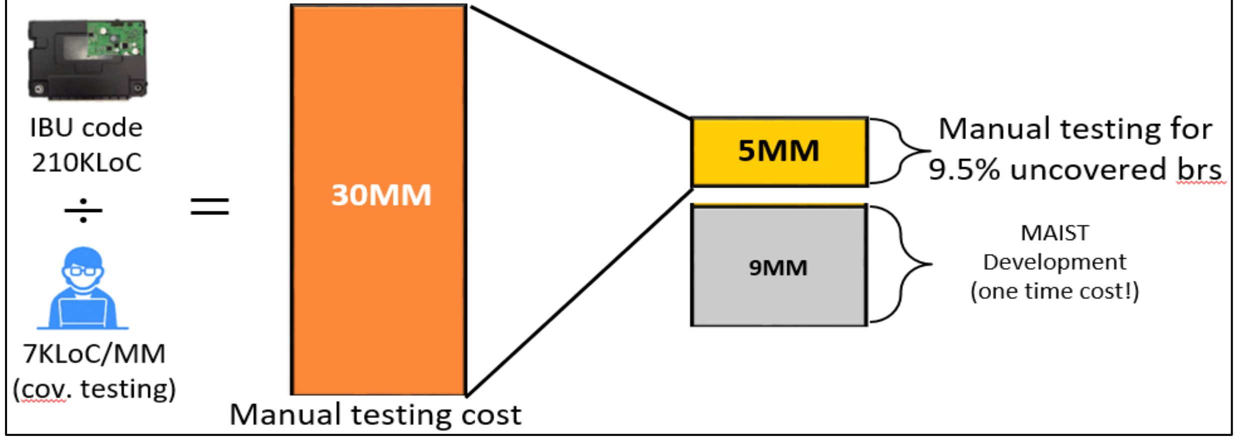


RQ2. MAIST Reduced Testing Cost from **30MM** to **5MM (↓83.3%)**



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