The Effect of Program and Model Structure on MC/DC Test Adequacy Coverage

ICSE '08: Proceedings of the 30th international conference on Software engineering

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31.03.2009

MC/DC as a coverage metric for testing

- MC/DC widely used in critical systems such as in avionics or military
- **Paper states MC/DC criteria can be “cheated” and heavily depends on code structure**

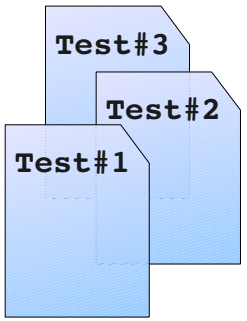
What is MC/DC?

Modified Condition/Decision Coverage

=> Source code metric for measuring the quality of a test suite

Condition Coverage + Decision Coverage + Each condition must independently affect the outcome of a decision

Test Suite



Implementation

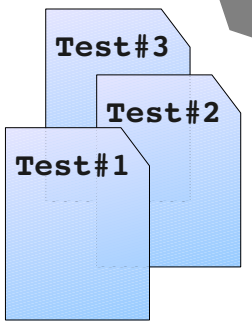
```
int myFunc (bool c1, bool c2, bool c3)
{
    bool d1 = c1 or c2;
    bool d2 = d1 and c3;
    if (d2)
        return 1;
    else
        return -1;
}
```

MC/DC example

```
int myFunc (bool c1, bool c2, bool c3)
{
    bool d1 = c1 or c2;
    bool d2 = d1 and c3;
    if (d2)
        return 1;
    else
        return -1;
}
```

c1	c2	d1 = c1 or c2
F	F	F
F	T	T
T	F	T
T	T	T

d1	c3	d2 = d1 and c3
F	F	F
F	T	F
T	F	F
T	T	T



Test Suite

Subset of all possible input tuples which satisfies MC/DC criteria

For Example: **{TFF, FTF, FFT, TTT}** // (c1 c2 c3)

Problems with MC/DC

Same program written in a different way (**d1** has been **inlined**)

```
int myFunc (bool c1, bool c2, bool c3)
{
    bool d2 = (c1 or c2) and c3;
    if (d)
        return 1;
    else
        return -1;
}
```

c1	c2	c3	d2 = (c1 or c2) and c3
F	F	F	F
F	F	T	F
F	T	F	F
F	T	T	T
T	F	F	F
T	F	T	T
T	T	F	F
T	T	T	T

Previous test suite does not satisfy MC/DC criteria anymore!

If correct expression should have been

```
bool d2 = (c1 and c2) and c3;
```

bug will not be revealed by current test suite!

Problem: A test suite satisfying MC/DC criteria would have detected fault, which shows that MC/DC coverage can be affected by program structure.

Case examples

Goal: show that test suite providing MC/DC over non-inlined version will achieve lower MC/DC over implementation that is inlined.

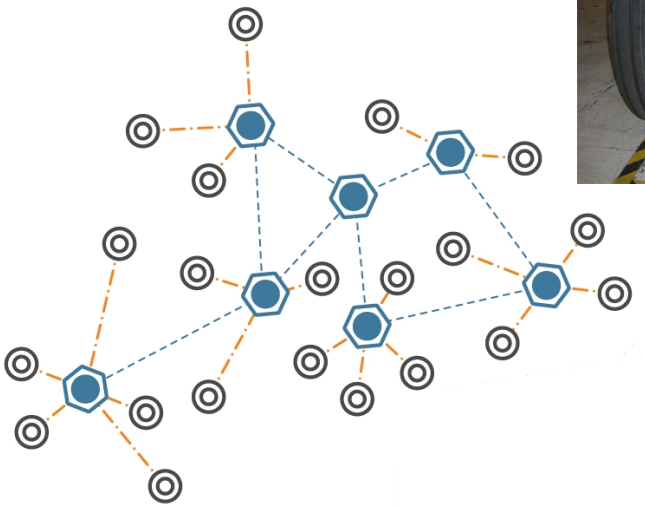
Case examples used in industry

- Aircraft Display Window Manager (3)
- Flight Guidance System (3)

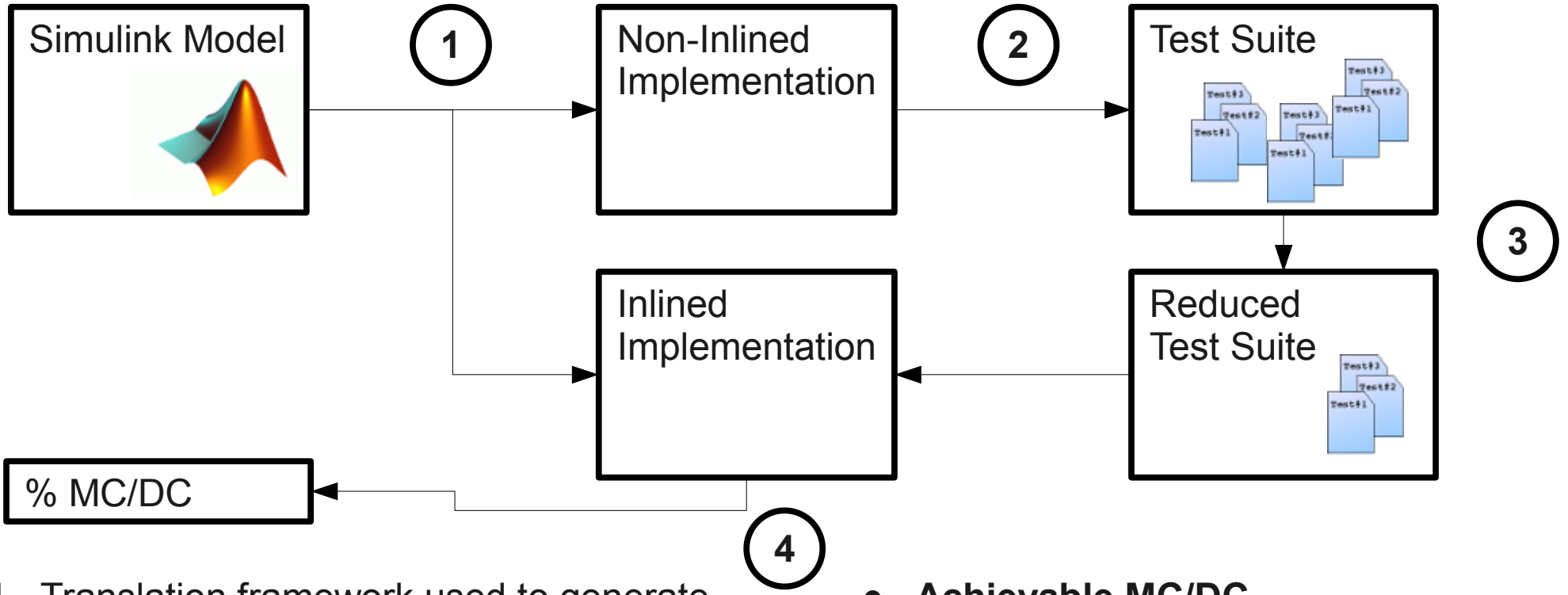
Toy examples

- Wheel Brake System
- Sensor Voting Example

Systems were available as Simulink Models



Experiment Setup



1 Translation framework used to generate different implementations

2 Test suite generated through NuSMV model checker

3 Obtain “minimal” test suite using a (naive) algorithm

4 Compare measured/achievable MC/DC

- **Achievable MC/DC**
  Complete coverage sometimes not possible (e.g. masking)
- **Measured MC/DC**
  Coverage provided by test suite

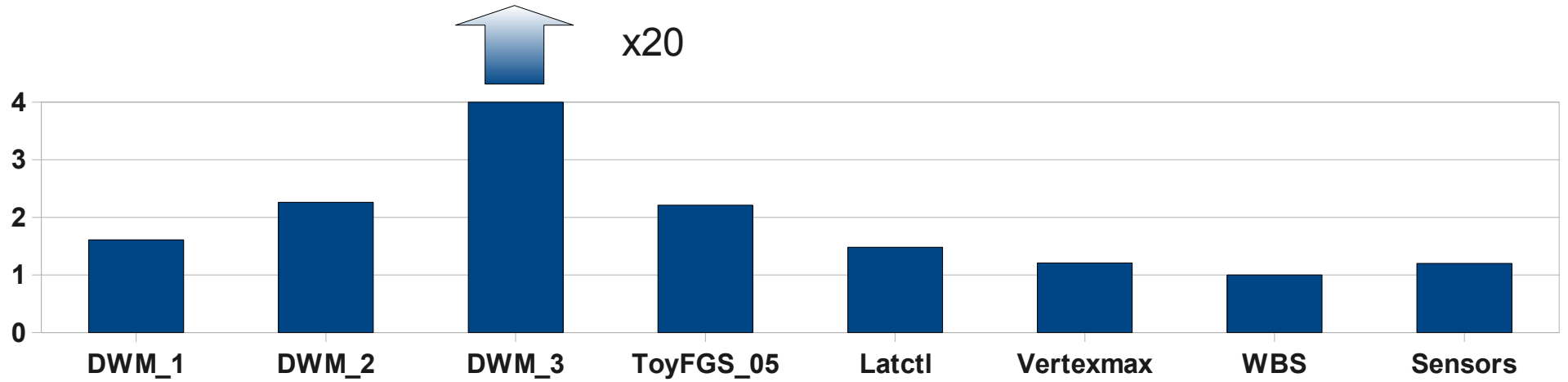
Size of Generated Test Suites

How many tests are needed for each implementation to achieve MC/DC?

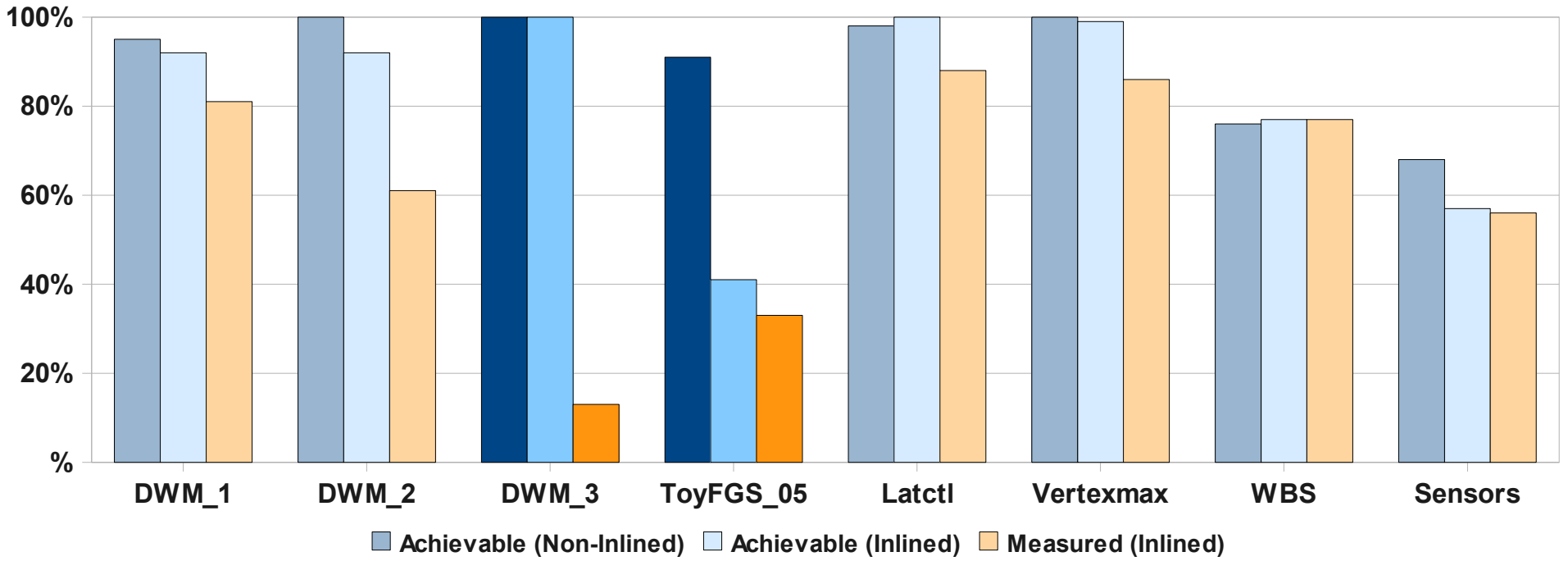
	Non-Inlined		Inlined	
	Full	**Reduced**	**Full**	**Reduced**
DWM_1	180	18	121	29
DWM_2	299	39	946	88
DWM_3	2522	**23**	2697	**463**
ToyFGS_05	4445	75	1909	166
Latctl	315	52	205	77
Vertexmax	1415	235	1464	285
WBS	271	10	125	10
Sensors	103	10	189	12

DWM_3 requires 20 times more tests to cover inlined version!

=> Mostly Boolean logic, leading to complex expressions in the inlined implementation



Achieved Coverage (MC/DC)



- Generated test suite for non-inlined version of DWM_3 achieves very low MC/DC on inlined implementation (13%)
- Interesting: ToyFGS_05 has a much lower achievable MC/DC in inlined version => many DNF expressions containing redundancy causing strong masking effect
- Inadequacy ranging from 13% to 86%, statistically supported on a 5% significance level (including industrial examples only)

Conclusions

MC/DC is indeed highly sensitive to structure of implementation!

- **Suggestions**
  - Different coverage metric that takes masking into account (independent of code structure)
  - Apply coverage on model domain instead of code domain
- **Problems with experiments**
  - Small number of examples
  - Test suite reduction too naive
- **Personally**
  - Removing toy examples from statistics is questionable
  - Effectiveness of MC/DC?