MC/DC Software Testing

Some Context & Definitions

What is a unit? This whole thing is a "unit"

Is this unit safety-critical? Yes

When should units be tested?

- Early in development, as fu
- During "unit testing" phase

What is a decision? This is a Decision

What is a condition? These are Conditions ☺

- This is when MC/DC is done

How are they tested?

- Run each unit with differing input-> verify result
- MC/DC: Exercise all meaningful paths for "coverage"

```
1  boolean function check_abort(boolean   off_course,
                                boolean     abort_commanded,
                                boolean valid_abort_command)
2   {
3     boolean result = false;   // true if aborting;
4     if (off_course OR
5         (abort_commanded AND valid_abort_command))
6     then
7        result = true;   // initiate abort sequence
8     else
9        result = false;  // don't abort, keep flying
10    return result;
11  }
```

Sample Code

Four MC/DC Rules

Why? To make sure it works right and all paths re covered

1. Each entry and exit point is invoked (lines 1 and 10 are tested)
2. Each decision takes every possible outcome (lines 7 and 9 are tested, abort (true) or don't abort (false))

3. Each condition in a decision takes every possible outcome
   - Conditions need to be tested for both TRUE and FALSE

4. Each condition in a decision is shown to independently affect the outcome
   - Why? This tests each condition ***only when it matters*** – when it effects outcome
   - Two primary types of MCDC[1] -- may choose either of these, or a combination of both
     - Unique-Cause
     - Masking

Examples follow

“Unique Cause” MC/DC Example

Truth Table

Test Case	Conditions (Input Variables)			Result of Decision (abort=1 not=0)
	Off-course	Abort Cmd	Valid Cmd	
1	0	0	0	0
2	0	0	1	0
3	0	1	0	0
4	0	1	1	1
5	1	0	0	1
6	1	0	1	1
7	1	1	0	1
8	1	1	1	1

4 Green Test Cases for MC/DC

All 8 Test Cases for MC/DC

```
 1 boolean function check_abort(boolean   off_course,
                                boolean     abort_commanded,
                                boolean valid_abort_command)
…
 4     if (off_course OR
 5         (abort_commanded AND valid_abort_command))
…
```

Sample Code

Call the function 4 times with these values: Unit Test Code

```
r = check_abort(1,0,1);  // test case 6, r = abort
r = check_abort(0,0,1);  // test case 2, r = no abort
r = check_abort(0,1,1);  // test case 4, r = abort
r = check_abort(0,1,0);  // test case 3, r = no abort
```

- “Unique Cause” MCDC
  - Only one condition in a decision is changed at a time, ***holding all others constant,*** while verifying change in result
- Example:
  - The function “check_abort” needs to be run with **pairs of test cases (6,2,4,3), in that order**
    - *Start with Cases 6 and 2, changing only “off_course” yields a different result, verifying independence of “off course”*
    - *Next use test 2 and 4, changing only “abort” yields a different result, verifying “abort”*
    - *Last, run cases 4 and 3, which only changes “valid” for a different result*
- N+1 tests are needed (N is the number of conditions in the decision), vs. 2^N for all permutations
  - This is the *minimum set of meaningful test cases*

“Masking” MC/DC Example

Truth Table

Test Case	Conditions (Input Variables)			Result of Decision (abort=1 not=0)
	Off-course	Abort Cmd	Valid Cmd	
1	0	0	X	0
2	0	0	X	0
3	0	1	0	0
4	0	1	1	1
5	1	X	X	1
6	1	X	X	1
7	1	X	X	1
8	1	X	X	1

X’s are “don’t care” values since left-to-right evaluation is stopped

```
 1 boolean function check_abort(boolean   off_course,
                                boolean     abort_commanded,
                                boolean valid_abort_command)
…
 4     if (off_course OR
 5        (abort_commanded AND valid_abort_command))
…
```

Sample Code

Unit Test Code

```
Call the function 4 times with these values:
r = check_abort(0,1,0);   // test case 3, r = no_abort
r = check_abort(0,1,1);   // test case 4, r = abort
r = check_abort(0,0,X);   // cases 1 or 2,r = no_abort
r = check_abort(1,X,X);   // cases 5,6,7,or 8, r=abort
```

- “Masking” MCDC – relies on computer “short circuiting” – evaluation stopping as soon as a decision can be made
  - The condition under test changes, ***but others can change*** as long as they will be “short circuited” (marked ”don’t care” in table)
  - Any tests including both (3 and 4), either (1 or 2), or any one of (5,6,7,8) meet the criteria
    - (3,4,1,5), (3,4,2,5), (3,4,1,6), (3,4,2,6), (3,4,1,7), (3,4,2,7), (3,4,1,8), (3,4,2,8)
- Example:
  - *Start with cases 3 and 4 which both must be run since there are no short circuits to verify “valid command”*
  - *Next run either (1 or 2) and 4 since the result changes in both of those cases, to verify “abort cmd”*
  - *Last, run one case from (5,6,7,8) which changes “valid” for a different result*
- This will require $2*\sqrt{N}$ tests, less than in the “unique cause” form of MC/DC

- Further Reading & References:

  - [1] AJohn J. Chilenski. “An Investigation of Three Forms of the Modified Condition/Decision Coverage (MCDC) Criterion. Technical Report”, DOT/FAA/AR-01/18, US. Department of Transportation, Federal Aviation Administration, April 2001.

  - Standards requiring MC/DC testing for Safety-Critical code:
    - Aircraft - DO-178B (Safety-critical Level A or B)
    - Automotive - ISO-26262 (ASIL D)
    - Nuclear - IEC-61508-3 (SIL 1-3)
    - Spacecraft - NASA NPR-7150.2 (Class A Safety-critical)

- Provide comments to where you’ve seen this or to lorraine.e.prokop@nasa.gov

- Related follow-on “software shorts”
  - “Using gcov for MC/DC Testing”

Backup for MCDC

MC/DC Software Testing One-Pager

MC/DC (Modified Condition/Decision Coverage) Rules:

1. Each entry and exit point is invoked (lines 1 and 9 are tested)
2. Each decision takes every possible outcome (lines 6 and 8 are tested, abort and null)
3. Each condition in a decision takes every possible outcome (off_course, abort, and valid are each tested for both TRUE and FALSE)
4. Each condition in a decision is shown to independently affect the outcome - Why? This tests each condition ***only when it matters*** – when it effects outcome

- Three (3) types of MCDC[1] -- Unique-Cause (N+1 tests), Masking (2*Sqrt(n) tests), and Unique-Cause+Masking (NPR7150.2 does not dictate which to use)
  - "Unique Cause" MCDC holds all variables constant and changes only one at a time testing for unique outcome
    - Example: Only rows 6,2,4,3 in table need be tested (*in that order*) and represent one possible *minimum set of meaningful test cases (i.e Starting with row 6, changing only "off_course" in Test 2 results in a different outcome, then test 4 changes only "abort" with a different outcome, then test #3 changes "valid" for a different outcome)*
  - "Masking" MCDC allows other conditions to change as long as only the condition of interest influences the outcome (See backup for performance)
    - Masking MCDC is implemented by "short-circuiting" in computer programs (i.e. stopping as soon as test criteria are met)
    - Example: Any 4 tests including one of (5,6,7,8), both (3 and 4), and either (1 or 2) meet the criteria. (i.e. (5,1,3,4), (6,2,3,4), (8,1,3,4), etc…)

Sample Code

```
 1  function check_abort()
 2  {
 3    if (off_course OR
 4       (abort_commanded AND valid_abort_command))
 5    then
 6       abort();    // initiate abort sequence
 7    else
 8       null;       // do nothing
 9    return;
10  }
```

Test Case	Off-course	Abort Cmd	Valid Cmd	Outcome
1	0	0	0 X	0
2	0	0	1 X	0
3	0	1	0	0
4	0	1	1	1
5	1	0 X	0 X	1
6	1	0 X	1 X	1
7	1	1 X	0 X	1
8	1	1 X	1 X	1

Possible Test Cases:

- 8 Cases for full Condition Combination Coverage (CCC)
- 4 Green Row Cases (6,4,2,3 in that order) for "unique cause" MC/DC
- **X's indicate "don't care"** for "masking" MC/DC

- Standards requiring MC/DC testing for Safety-Critical code
  - Aircraft - DO-178B (Safety-critical Level A or B)
  - Automotive - ISO-26262 (ASIL D)
  - Nuclear - IEC-61508-3 (SIL 1-3)
  - Spacecraft - NASA NPR-7150.2 (Class A Safety-critical)

[1] AJohn J. Chilenski. "An Investigation of Three Forms of the Modified Condition/Decision Coverage (MCDC) Criterion. Technical Report", DOT/FAA/AR-01/18, April 2001.

MC/DC Software Training

Introduction Notes:

- *Who I am*

- *First in a series of software shorts on topics in software*

- *What is MC/DC? Modified Decision/Coverage testing – sounds sorta "questionable"*

    - *Way of testing the minimum set of all meaningful logic paths through the code*
        - *Not all logical paths through the code, but only the paths that effect the outcome*

- *Why do it?*
    - *Aside from it being required for safety critical code in space and aircraft, automotive, nuclear industries – it just makes sense!*
    - *Not to kill someone*

    How to do it?
    - *I will go over -*
        - *What is a unit*
        - *What are the rules of MC/DC*
        - *Provide simple examples of both forms of MC/DC*
            - *And a warning – I will show some short code – do not fear! I will step through it!*

- Hope this was helpful
- Provide comments to where you've seen this or to lorraine.e.prokop@nasa.gov
- Related follow-on "software shorts"
  - " "Using gcov for MC/DC Testing"
- Have a nice day!

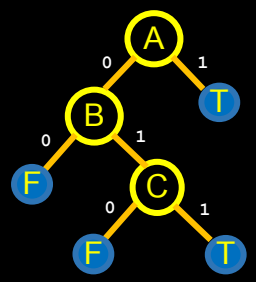
“Using gcov for MC/DC” One-Pager

- GCOV - Open-source tool used with gnu c compiler (gcc) to perform unit test code coverage analysis
  - Performs Object Branch Coverage (OBC) through generation of Binary Decision Diagrams (BDD) – see example
  - Object Branch Coverage had been proven[1] to be equivalent to MCDC if OBC contains all “tree-like” decisions
  - Does not identify *all* permutations to achieve Condition Combination Coverage (CCC) (which is a good thing, limiting tests to only those meaningful)
- Can gcov be used to meet MCDC criteria?
  - Yes, but some extra work must be done to ensure all decisions are “tree-like” (i.e. no graphs) – see example
    - All non-tree-like decisions can be converted to tree-like decisions[1]
      - Non tree-like decisions have been shown to be a VERY small percentage of overall decisions in several large code bases (<1% [4], “few” [2])
    - gcov performs “unique-cause+short-circuit” MC/DC, “short-circuit” being the implementation-equivalent to the “masking” form of MC/DC
    - The “taken at least once” statistic must be driven to 100% to achieve MC/DC coverage against all tree-like decisions
    - Open source tools are available to identify non-tree-like decisions
      - https://www.open-do.org/projects/couverture/, https://gitlab.com/gtd-gmbh/mcdc-checker/mcdc-checker

Sample BDD’s

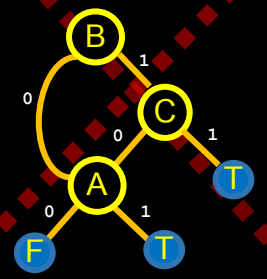
Tree-like ← rewrite — **Non-Tree-like**

`A or (B and C)`



- 6 branches/edges
- 4 tests needed to cover 4 leaves

`(B and C)or A`



- 6 branches/edges
- 3 tests needed to cover 3 leaves

```
GOV results running 3 tests: #3-010, 4=011 6=101; ABC)
Taken at least once:83.33% of 6   Taken at least once:100.00% of 6
```

- Guidelines
  - Must turn off all optimization; run gcc with the following switches
    - `gcc -O0 -fprofile-arcs -ftest-coverage`
  - Run “`gcov -b`” on output and drive “taken at least once” to 100%
  - Periodically or in CI
    - Run tool to identify non-tree-like branches
    - Rewrite all non-tree-like to be tree-like
    - Write additional unit tests to achieve 100% “taken at least once”

References:

- [1] Comar, Guitton, Hainque, and Quinot. “Formalization and Comparison of MCDC and Object Branch Coverage”, Embedded Real Time Software and Systems Conference, Feb 2012.
- [2] Thomas Wucher, Andoni Arregui. “MC/DC for Space: A new Approach to Ensure MC/DC Structural Coverage with Exclusively Open Source Tools”, ESA Software Product Assurance Workshop 2021.
- [3] AJohn J. Chilenski. “An Investigation of Three Forms of the Modified Condition/Decision Coverage (MCDC) Criterion. Technical Report”, DOT/FAA/AR-01/18, US. Department of Transportation, Federal Aviation Administration, April 2001.
- [4] Bordin, et.al. “Object and Source Coverage for Critical Applications with the COUVERTURE Open Analysis Framework”, Embedded Real Time Software and Systems Conference, May 2010.

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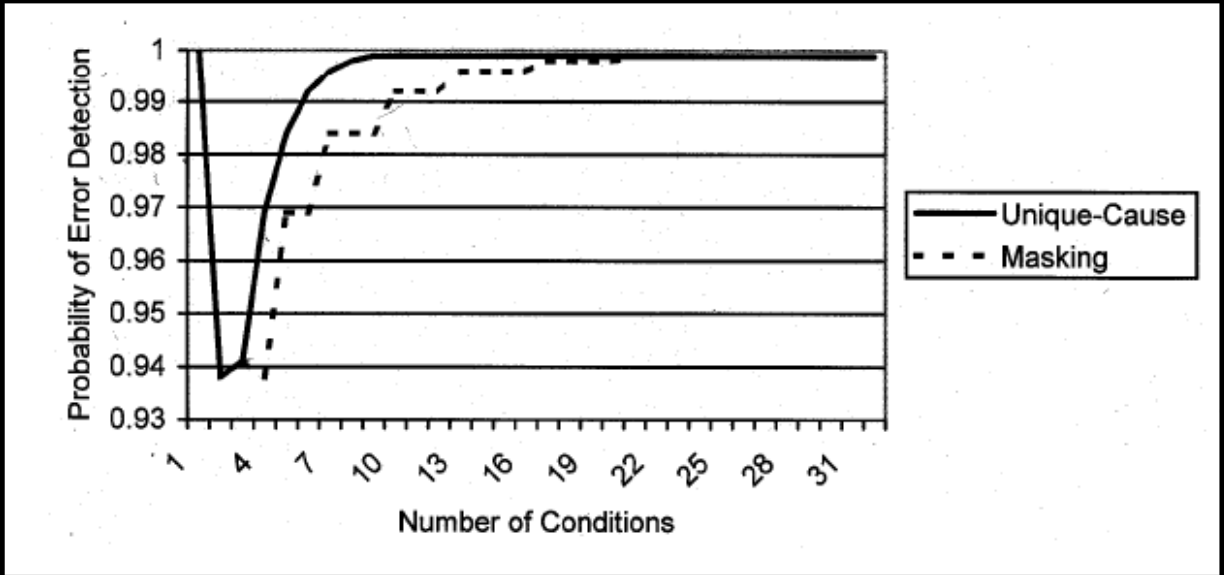
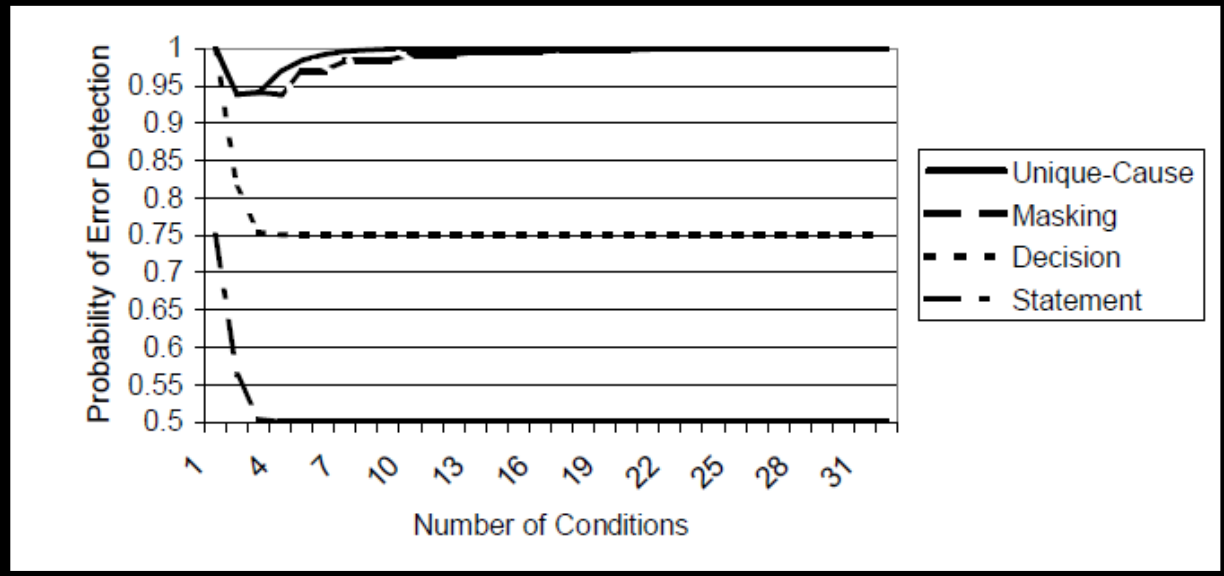
Backup

Effectiveness of Masking vs. Unique-cause MCDC



Effectiveness of MCDC types vs. other coverages



Reference: AJohn J. Chilenski. "An Investigation of Three Forms of the Modified Condition/Decision Coverage (MCDC) Criterion. Technical Report", DOT/FAA/AR-01/18, US. Department of Transportation, Federal Aviation Administration, April 2001.