Promoting ECSS Category B Software to Category A

Reaching the highest software quality in ECSS

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Do you REALLY know what software you are flying?

When your flight software was almost correct:

- Ariane-5 maiden flight was almost successful
- Mars Climate Orbiter was almost placed into Mars orbit
- Beresheet almost landed on Moon

Can you answer the following questions?

- What happens before `main()`?
- How many functions do you call without even knowing they exist?
- What's different between Host/Target/Optimizations compilations?

Don't Trust Your Toolchain!

You think your flight **software is qualified**, because you've used a **qualified operating system** and you have **qualified application software**?
NO! You will fly unqualified:

- standard C library functions (`memset`, ...)
- compiler library functions (`.udiv`, ...)
- linker introduced object code

Study Goals

To define a **methodology, guideline, and tooling** to promote ECSS Category B qualified software to **Category A** software.

To apply the assessment to real-life use-cases:

- LibmCS
- RTEMS 6

Main Tasks for Promoting Software to Category A

- Achievement of 100% MCDC structural coverage:
  - ▷ Can be achieved with open-source tools like GCov
  - ▷ NASA includes our approach in the Software Engineering and Assurance Handbook, NASA-HDBK-2203
- Verification of of compiler/toolchain-added object code:
  - ▷ Identifying hidden calls to library functions
  - ▷ Assessing different branching structure in (optimized) object code
  - ▷ Can also be achieved with open-source tools

Lessons Learned

- We conducted interviews to learn current Category A software challenges, involving ESA ESTEC Software and PA experts.
- The second completed European Category A software is based on wrong assumptions and flawed methods:
  - ▷ Atomic logical decision to avoid MCDC coverage, loosing the potential of MCDC error detection
  - ▷ Blind application of methods to trace object code to source code with wrong disassembly interpretation

Acknowledgements

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Availability and Contact

- MCDC Checker on GitLab:
  `https://gitlab.com/gtd-gmbh/mcdc-checker/mcdc-checker`
- GTD GmbH Information and Support:
  `https://gtd-gmbh.de/`
  `gtd@gtd-gmbh.de`

Tool 1 — MCDC Checker

Unoptimized object code implements decisions as BDDs, which coverage happens to be equivalent to MCDC when tree-like.

Our MCDC-Checker:

- walks the abstract syntax tree of your C/C++ source code
- checks each decision BDD whether it is tree-like
- proposes a reordering if that results in a tree-like BDD
- MCDC coverage can then be assessed by using GCov as usual

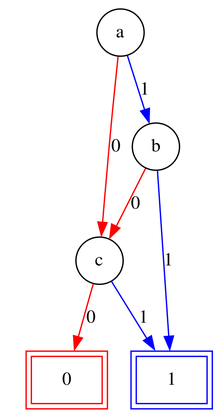


Figure: (a and b) or c

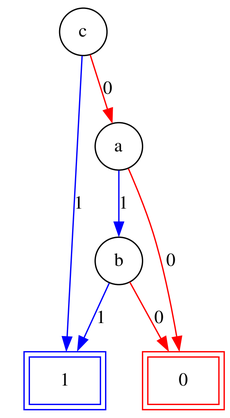


Figure: c or (a and b)

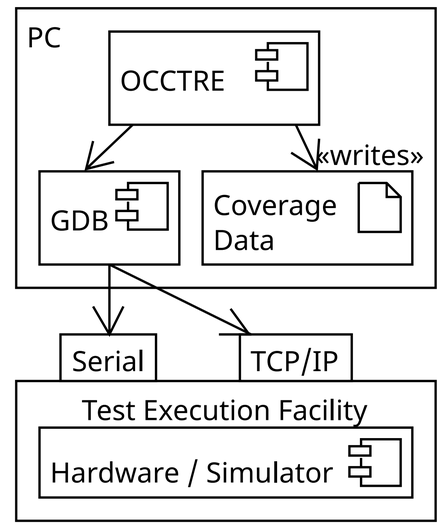
Tool 2 — ELF Checker

- Compares debug, stripped and binary versions of your application software
  ⇒ Instructions and data are equivalent
- Checks that sections from the debug version are correctly embedded into the flashable binary (correct address and content)
- Lists length, alignment, type and flags of all sections
- Shows location and alignment of all sections in the flashable binary

	Address	Length	Alignment	Address	Length	Alignment		Offset	Length	Alignment	
.comment	0x00000000	0x00000063	0x01	0x00000000	0x00000063	0x01	SHT_PROGBITS, MERGE, STRINGS	-	-	-	-
.debug_abbrev	0x00000000	0x000245C4	0x01	-	-	-	SHT_PROGBITS, -	-	-	-	-
.debug_aranges	0x00000000	0x00002930	0x08	-	-	-	SHT_PROGBITS, -	-	-	-	-
.debug_frame	0x00000000	0x00004554	0x04	-	-	-	SHT_PROGBITS, -	-	-	-	-
.debug_info	0x00000000	0x001143EC	0x01	-	-	-	SHT_PROGBITS, -	-	-	-	-
.debug_line	0x00000000	0x0004855E	0x01	-	-	-	SHT_PROGBITS, -	-	-	-	-
.debug_loc	0x00000000	0x00065F51	0x01	-	-	-	SHT_PROGBITS, -	-	-	-	-
.debug_ranges	0x00000000	0x00016970	0x01	-	-	-	SHT_PROGBITS, -	-	-	-	-
.debug_str	0x00000000	0x0000E75E	0x01	-	-	-	SHT_PROGBITS, MERGE, STRINGS	-	-	-	-
.gnu.attributes	0x00000000	0x00000010	0x01	0x00000000	0x00000010	0x01	SHT_GNU_ATTRIBUTES	-	-	-	-
.shstrtab	0x00000000	0x000000C3	0x01	0x00000000	0x0000004D	0x01	SHT_STRTAB	-	-	-	Data mismatch
.strtab	0x00000000	0x00005211	0x01	-	-	-	SHT_STRTAB	-	-	-	-
.symtab	0x00000000	0x00007440	0x04	-	-	-	SHT_SYMTAB	-	-	-	-
.text	0x00000000	0x000285C0	0x20	0x00000000	0x000285C0	0x20	SHT_PROGBITS	ALLOC, EXECINSTR	0x00000000	0x000285C0	0x20	Data mismatch
.rtemsroset	0x000285C0	0x00000060	0x08	0x000295C0	0x00000060	0x08	SHT_PROGBITS	ALLOC	0x000285C0	0x00000060	0x08	Addr mismatch
padding	-	-	-	-	-	-	-	-	0x00028620	0x00000020	-	Not Zero
.rtemsstack	0x00028640	0x00002000	0x40	0x00028640	0x00002000	0x40	SHT_NOBITS	ALLOC, WRITE	0x00028640	0x00002000	0x40	Flags mismatch
.data	0x0002A640	0x00003C80	0x08	0x0002A640	0x00003C80	0x08	SHT_PROGBITS	ALLOC, WRITE	0x0002A640	0x00003C80	0x08	Type mismatch
.bss	0x0002E2C0	0x00410C30	0x40	0x0002E2C0	0x00410C30	0x40	SHT_NOBITS	ALLOC, WRITE	-	-	-	-
padding	-	-	-	-	-	-	-	-	0x0002E2C0	0x00000060	-	Not Zero

Tool 3 — OCCTRE (Record Object Code Coverage)

- Executes the software image/binary step by step and records instruction information
- GDB based
- Generates processable object code coverage data like CSV, JSON or Markdown
- Highly configurable (platforms, facilities, disassemblers)
- Highly scriptable (python interface)



Address	Label(+off)	Instruction (hex)	Instruction	Opcode	Executed	Branch taken	Code File
0x0000f1a0	boot_card+0	9d e3 bf a0	save %sp, -96, %sp	save	1	set()	bsps/shared/start/bootcard.c:42
0x0000f1a4	boot_card+4	91 d0 20 09	ta 9	ta	1	{'0x0000f1a8'}	cpukit/score/cpu/sparc/include/rtems/score/sparc.h:429
0x0000f1a8	boot_card+8	03 00 00 61	sethi %hi(0x18400), %g1	sethi	1	set()	bsps/shared/start/bootcard.c:53
0x0000f1ac	boot_card+12	7f ff f9 d3	call 0xd8f8 <rtems_initialize>	call	1	set()	bsps/shared/start/bootcard.c:55
0x0000f1b0	boot_card+16	f0 20 62 70	st %i0, [%g1 + 0x270]	st	1	set()	bsps/shared/start/bootcard.c:55
0x0000d8f8	rtems_initialize_executive+0	9d e3 bf a0	save %sp, -96, %sp	save	1	set()	cpukit/sapi/src/exinit.c:130
0x0000d8fc	rtems_initialize_executive+4	3b 00 00 42	sethi %hi(0x10800), %i5	sethi	1	set()	cpukit/include/rtems/linkersets.h:151
0x0000d900	rtems_initialize_executive+8	39 00 00 42	sethi %hi(0x10800), %i4	sethi	1	set()	cpukit/sapi/src/exinit.c:134
0x0000d904	rtems_initialize_executive+12	ba 17 61 10	or %i5, 0x110, %i5	or	1	set()	cpukit/include/rtems/linkersets.h:152

Tool 4 — asm2cfg (Analyze Object Code Coverage)

- Generates the basic-block structure of investigated function
- Reads in object code coverage data (e.g. produced by OCCTRE)
- Generates human readable diagrams for missing test cases
- Highly configurable (platforms, facilities, disassemblers)
- Highly scriptable (python interface)