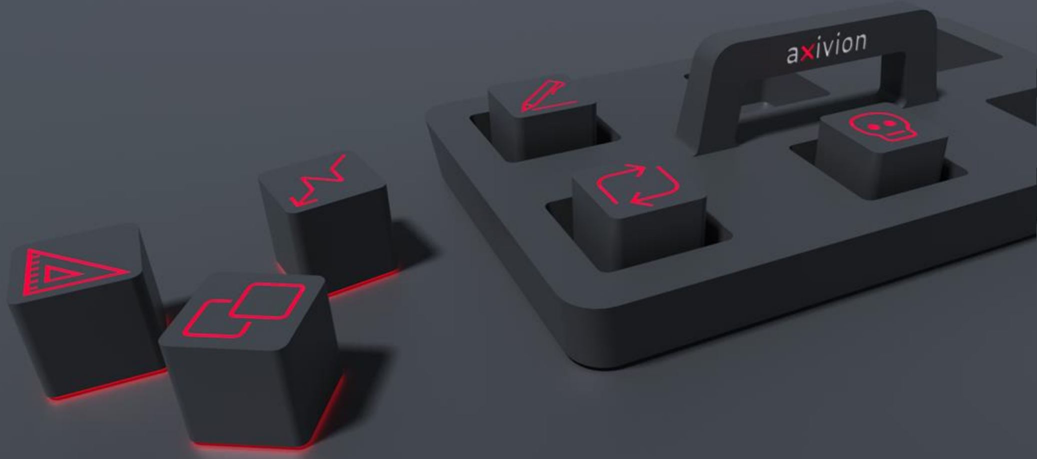
Testing, Model Checking and Static Analysis

Dream Team or Rivals?



Sebastian Krings

Axivion GmbH

axivion

stopping software erosion

> “Software is eating the world.”
>
> \- Marc Andreessen

Ever-increasing Dependence on Safety-Critical Software

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- Software used everywhere, from cars to trains to medical devices
- Software errors lead to damages, loss of equipment and have killed people
- Enormous financial losses due to software not even deemed safety-critical

We need to get software right.

Let’s see how.

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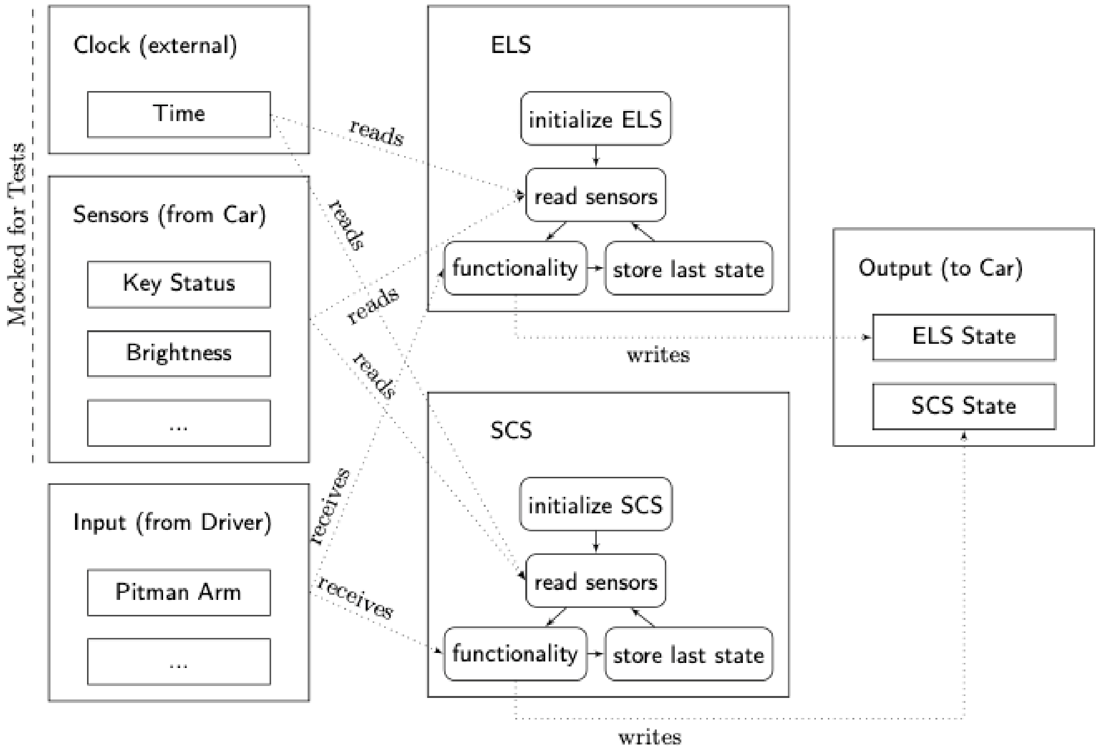
Case Study - Interacting Assistant Systems

System	Controls	Reads	Development
Adaptive Exterior Light System (ELS)	Head- and taillights • Brightness • Illumination distance • Curve lighting	• Driver input via actuators • Sensors for Speed, etc.	• To be developed in C • Following the MISRA C 2012 coding guidelines • Obviously highly safety critical
Speed Control System (SCS)	Speed of vehicle • Acceleration • Deceleration • Emergency breaks		

Component Diagram

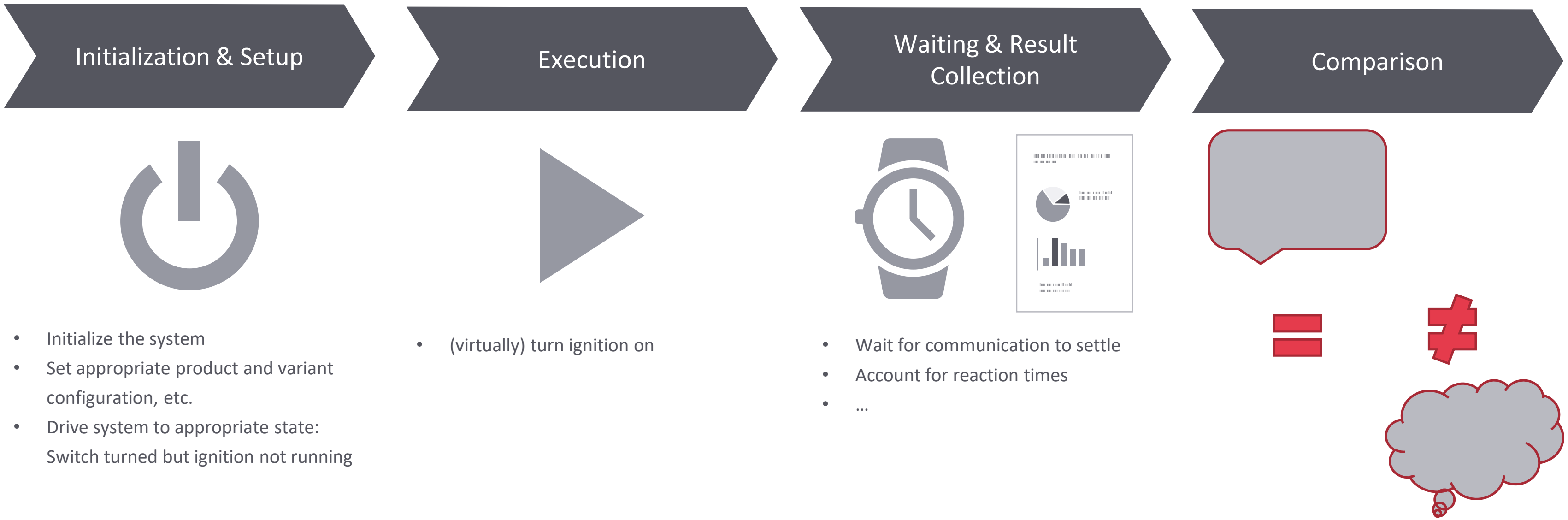


Testing - Overview

- Broadly speaking: make the system under test execute a certain scenario and check if we like the outcome
- Many different kinds and ideas
    - White-, black- and grey-box testing
    - Unit, integration and system testing
    - Sanity- and smoke-testing
    - Manual and automated testing
    - Hardware-in-the-loop and mocking
    - ….

Testing - Example

Requirement: If the ignition is ‘On’ and the light rotary switch is in the position ‘On’, then low beam headlights are activated.



Initialization & Setup

- Initialize the system
- Set appropriate product and variant configuration, etc.
- Drive system to appropriate state: Switch turned but ignition not running

Execution

- (virtually) turn ignition on

Waiting & Result Collection

- Wait for communication to settle
- Account for reaction times
- …

Comparison

Testing - Conclusions and Remarks

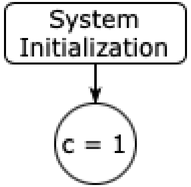
- Requirement is only partially tested
  - We have switch first, ignition second
  - But we are missing ignition first, switch second
- Needed to mock away the sensors
- No hope to ever test exhaustively
- Add some coverage metric
  - Statement, condition, MC/DC, …

Model Checking - Overview

- Broadly speaking: explore all states the system might be in, check an invariant property for each
- Many different kinds and ideas:
  - Abstraction level
  - Explicit or symbolic states
- Consider expressiveness of underlying logic, i.e., what is the invariant allowed to talk about
  - State only
  - Path on which a state was reached
  - Past or future states

Model Checking - State Spaces

```
extern int some_value();
int main {
       int c = 1;
       c += some_value();
       ...
}
```



Model Checking - State Spaces

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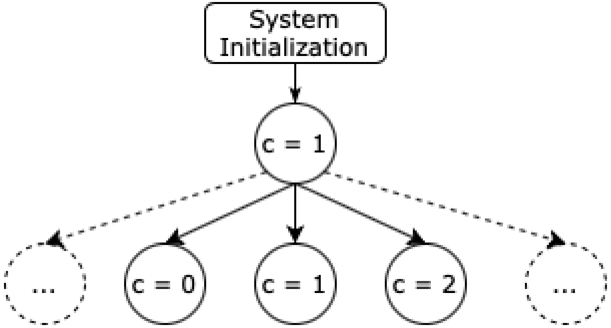

Model Checking - Example

- Requirement: Whenever the low or high beam headlights are activated, the tail lights are activated, too.
- Translate into invariant
- Check using CBMC (for instance)

```
assert(implies(state.lowBeamLeft > 0,
               state.tailLampLeft > 0 &&
               state.tailLampRight > 0));
```

Model Checking - Example - Resulting Output

```
State 59 file light/light-impl.c line 242 function light_do_step thread 0
----------------------------------------------------
 ks=/*enum*/NoKeyInserted (00000000000000000000000000000000)

State 63 file light/light-impl.c line 242 function light_do_step thread 0
----------------------------------------------------
 ks=/*enum*/KeyInIgnitionOnPosition (00000000000000000000000000000010)

State 65 file light/light-impl.c line 244 function light_do_step thread 0
----------------------------------------------------
 engine_on=FALSE (00000000)

State 69 file light/light-impl.c line 244 function light_do_step thread 0
----------------------------------------------------
 engine_on=TRUE (00000001)
```

Model Checking - Results

- Combinatorial explosion!
- Checking industrial-scale systems often infeasible
- But checking the whole system is not needed to discover errors
- Techniques to increase applicability:
  - Symbolic techniques
  - Symmetry detection and avoidance
  - …

Static Analysis - Overview

- Broadly speaking: avoid code execution, try to infer properties from the source code
- Many different techniques under one umbrella:
    - Style checking or linting
    - Data flow and pointer-based analyses
    - Abstract interpretation
    - Symbolic techniques
    - ….
- Comes at a price: over- and under-approximations and resulting false positives / negatives

Static Analysis - Axivion - Issue List Example

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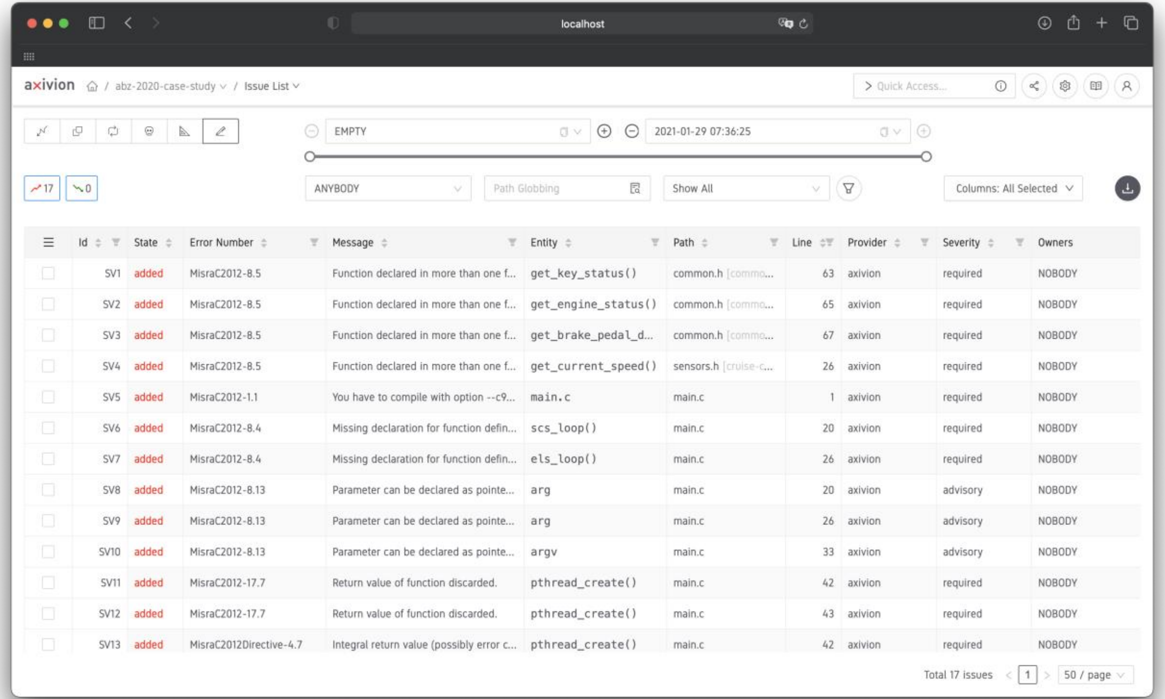

axivion / abz-2020-case-study / Issue List

EMPTY

2021-01-29 07:36:25

ANYBODY

Path Globbing

Show All

	Id	State	Error Number	Message	Entity	Path	Line	Provider	Severity	Owners
☐	SV1	added	MisraC2012-8.5	Function declared in more than one f...	`get_key_status()`	common.h [commo...	63	axivion	required	NOBODY
☐	SV2	added	MisraC2012-8.5	Function declared in more than one f...	`get_engine_status()`	common.h [commo...	65	axivion	required	NOBODY
☐	SV3	added	MisraC2012-8.5	Function declared in more than one f...	`get_brake_pedal_d...`	common.h [commo...	67	axivion	required	NOBODY
☐	SV4	added	MisraC2012-8.5	Function declared in more than one f...	`get_current_speed()`	sensors.h [cruise-c...	26	axivion	required	NOBODY
☐	SV5	added	MisraC2012-1.1	You have to compile with option --c9...	`main.c`	main.c	1	axivion	required	NOBODY
☐	SV6	added	MisraC2012-8.4	Missing declaration for function defin...	`scs_loop()`	main.c	20	axivion	required	NOBODY
☐	SV7	added	MisraC2012-8.4	Missing declaration for function defin...	`els_loop()`	main.c	26	axivion	required	NOBODY
☐	SV8	added	MisraC2012-8.13	Parameter can be declared as pointe...	`arg`	main.c	20	axivion	advisory	NOBODY
☐	SV9	added	MisraC2012-8.13	Parameter can be declared as pointe...	`arg`	main.c	26	axivion	advisory	NOBODY
☐	SV10	added	MisraC2012-8.13	Parameter can be declared as pointe...	`argv`	main.c	33	axivion	advisory	NOBODY
☐	SV11	added	MisraC2012-17.7	Return value of function discarded.	`pthread_create()`	main.c	42	axivion	required	NOBODY
☐	SV12	added	MisraC2012-17.7	Return value of function discarded.	`pthread_create()`	main.c	43	axivion	required	NOBODY
☐	SV13	added	MisraC2012Directive-4.7	Integral return value (possibly error c...	`pthread_create()`	main.c	42	axivion	required	NOBODY

Total 17 issues < 1 > 50 / page

Static Analysis - Axivion - Issue Details Example

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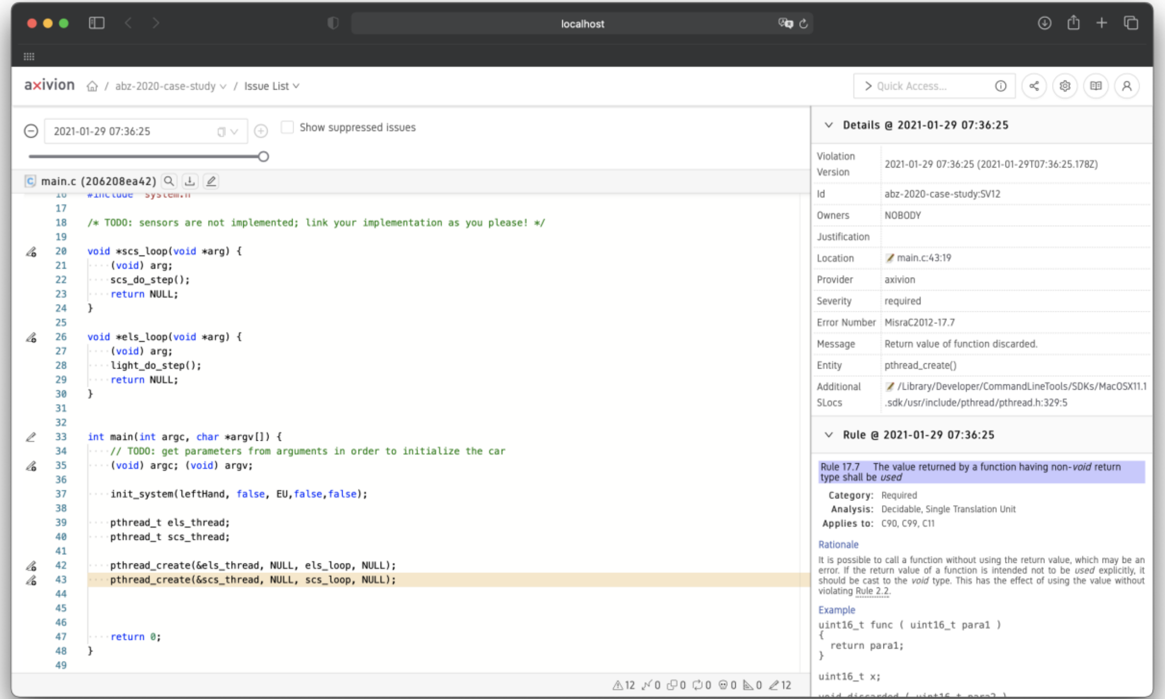

```
17
18  /* TODO: sensors are not implemented; link your implementation as you please! */
19
20  void *scs_loop(void *arg) {
21      (void) arg;
22      scs_do_step();
23      return NULL;
24  }
25
26  void *els_loop(void *arg) {
27      (void) arg;
28      light_do_step();
29      return NULL;
30  }
31
32
33  int main(int argc, char *argv[]) {
34      // TODO: get parameters from arguments in order to initialize the car
35      (void) argc; (void) argv;
36
37      init_system(leftHand, false, EU,false,false);
38
39      pthread_t els_thread;
40      pthread_t scs_thread;
41
42      pthread_create(&els_thread, NULL, els_loop, NULL);
43      pthread_create(&scs_thread, NULL, scs_loop, NULL);
44
45
46
47      return 0;
48  }
49
```

Details @ 2021-01-29 07:36:25

Violation Version	2021-01-29 07:36:25 (2021-01-29T07:36:25.178Z)
Id	abz-2020-case-study:SV12
Owners	NOBODY
Justification	
Location	main.c:43:19
Provider	axivion
Severity	required
Error Number	MisraC2012-17.7
Message	Return value of function discarded.
Entity	pthread_create()
Additional SLocs	/Library/Developer/CommandLineTools/SDKs/MacOSX11.1.sdk/usr/include/pthread/pthread.h:329:5

Rule @ 2021-01-29 07:36:25

Rule 17.7 The value returned by a function having non-*void* return type shall be *used*

Category: Required
Analysis: Decidable, Single Translation Unit
Applies to: C90, C99, C11

Rationale

It is possible to call a function without using the return value, which may be an error. If the return value of a function is intended not to be *used* explicitly, it should be cast to the *void* type. This has the effect of using the value without violating Rule 2.2.

Example

```
uint16_t func ( uint16_t para1 )
{
  return para1;
}

uint16_t x;
```

Static Analysis for Functional Requirements?

- Not an out-of-the-box experience
- Needs customization and analyses tailored to the use case
- But can be realized on top of existing analysis frameworks
- Could be done for requirements such as ‘’After engine start, there is no previous desired speed. The valid values for desired speed are from 1 km/h to 200 km/h.”

Static Analysis - Results

- Very helpful to ensure MISRA C2012 is adhered to
- Very helpful to uncover programming errors and security issues
  - Null pointer dereferences
  - Division by zero
  - Bad practices
  - …
- Many things can be checked out of the box without tweaking
- Can sometimes be used for functional requirements, but that involves customizations

Formal Proof and Deductive Verification

- Broadly speaking: show correctness of system with mathematical rigor
- Translate system into some mathematical / logical representation
- Use (semi-)automatic or manual proof techniques to proof properties
- Very high effort and skill needed

Formal Proof is Possible!

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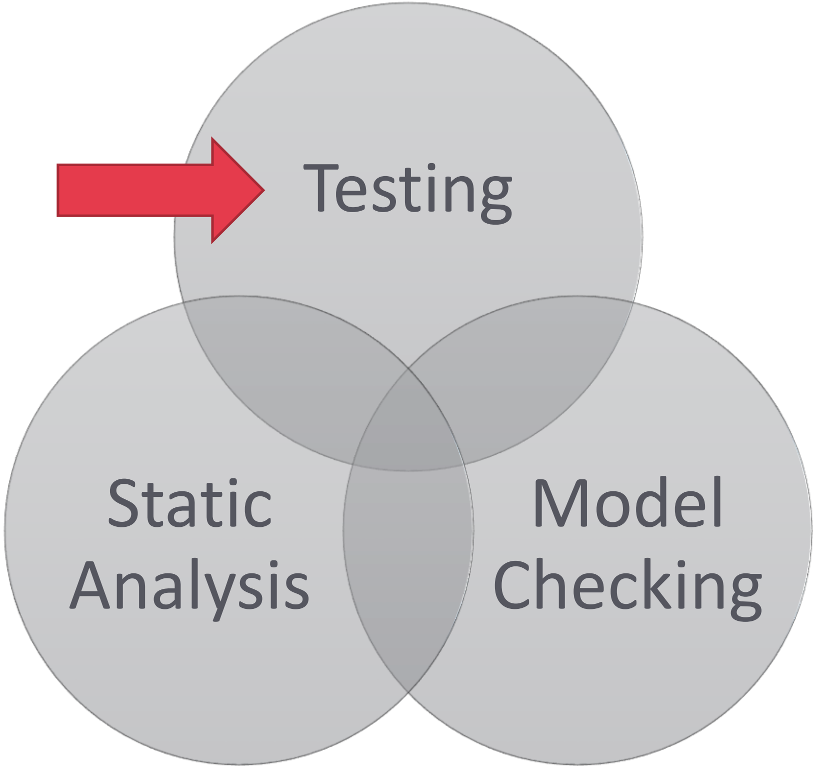
Combining Techniques



Testing

Static Analysis

Model Checking

Combining Techniques

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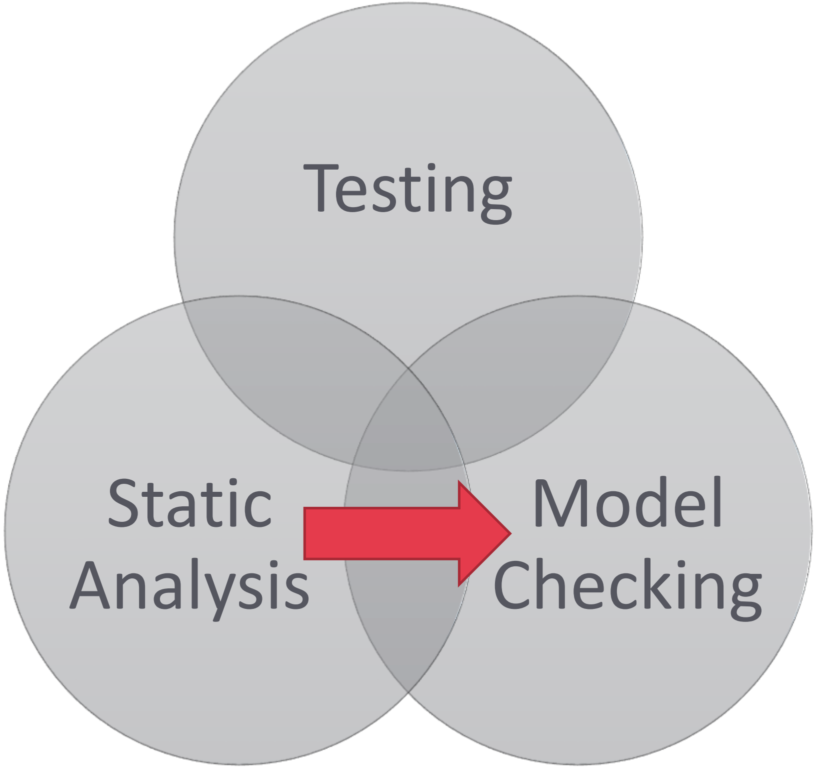
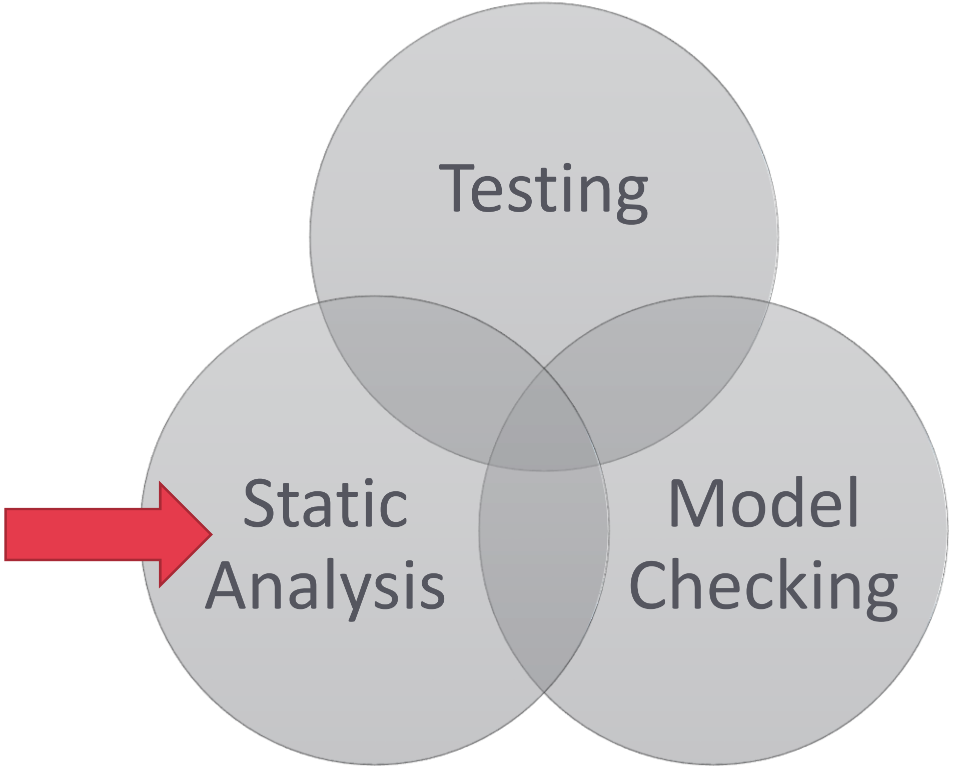


Combining Techniques



Testing

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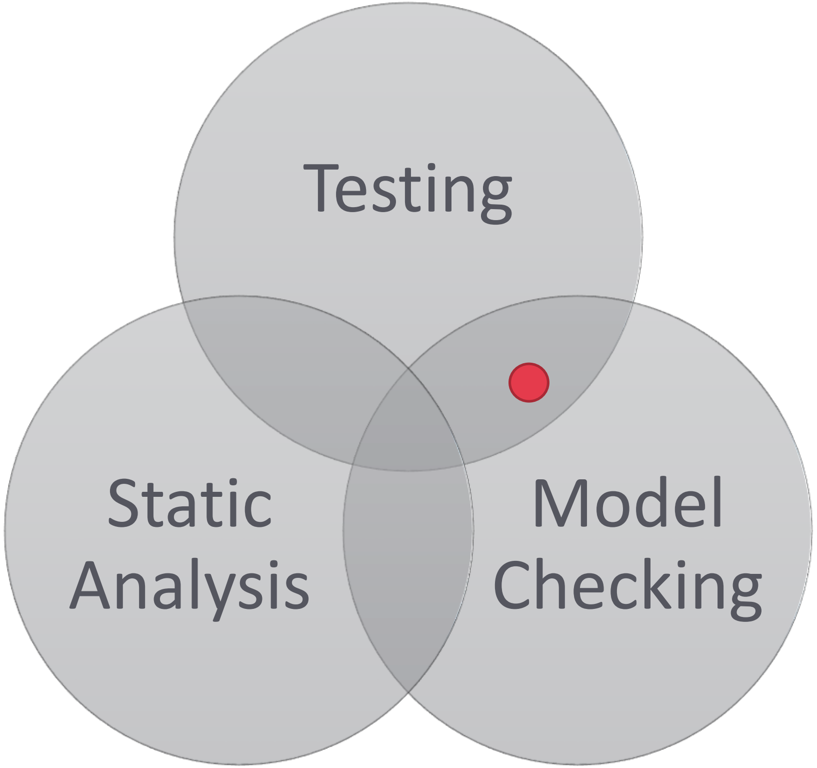
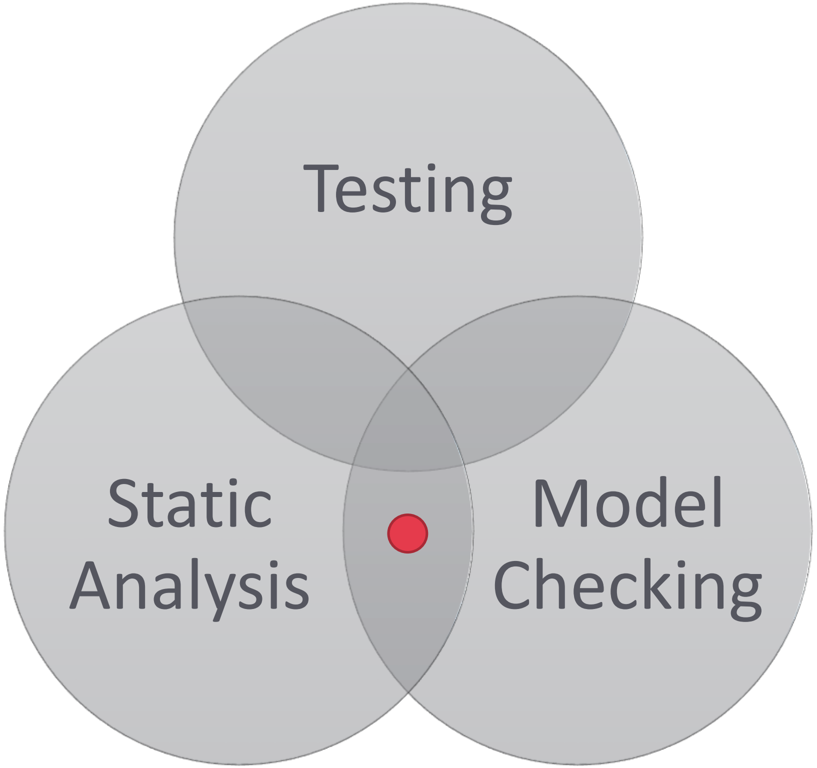
Combining Techniques



Combining Techniques



Combining Techniques

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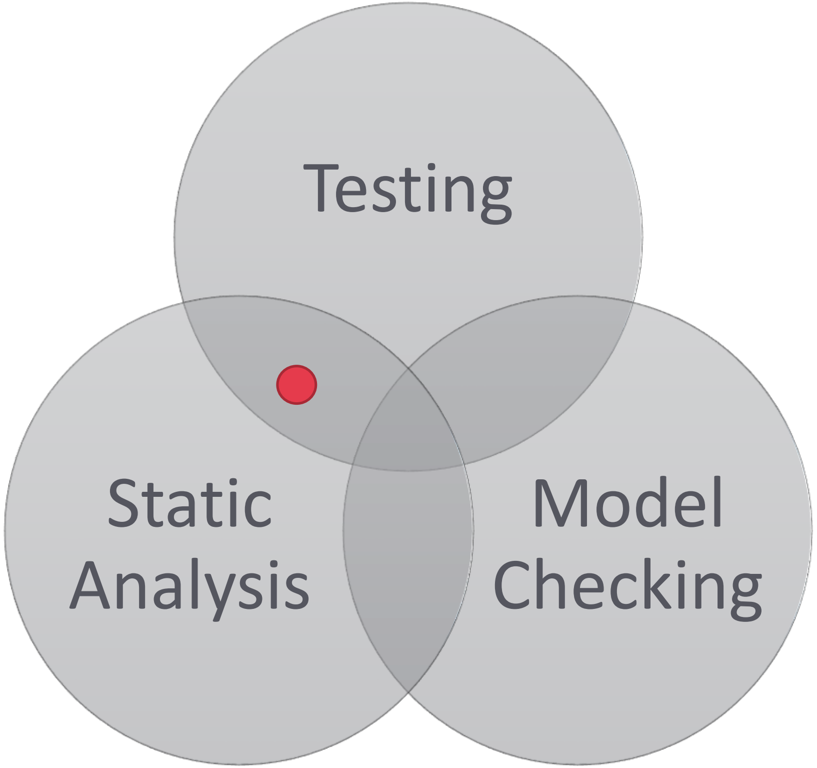

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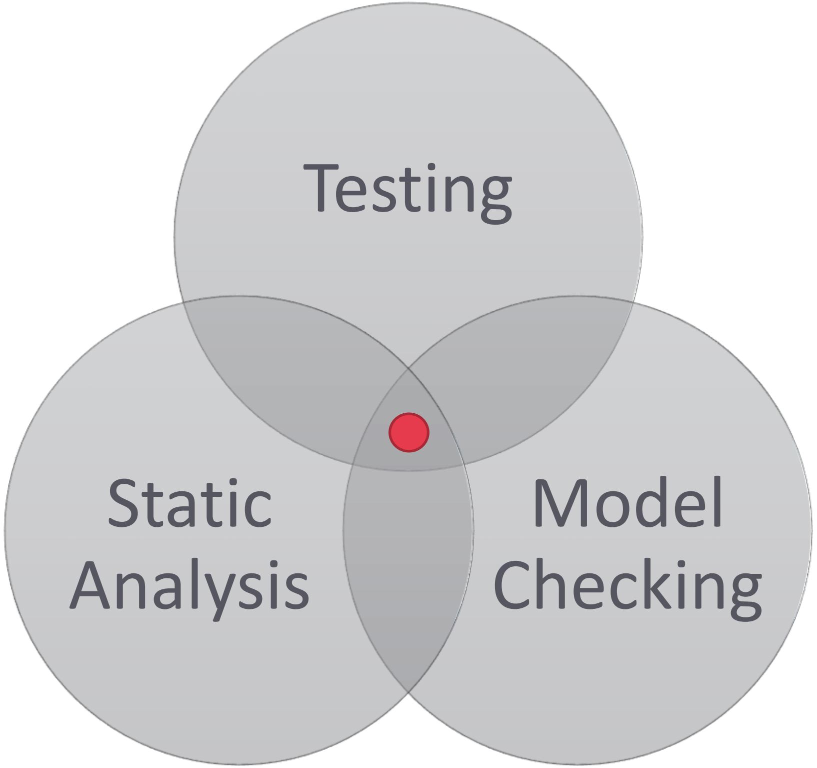

Conclusions

- Use whatever you can to ensure safety and security
- Techniques alone are useful …
- … but upcoming combinations might be even better.

Stay tuned for what we come up with!

Thank you for your attention!

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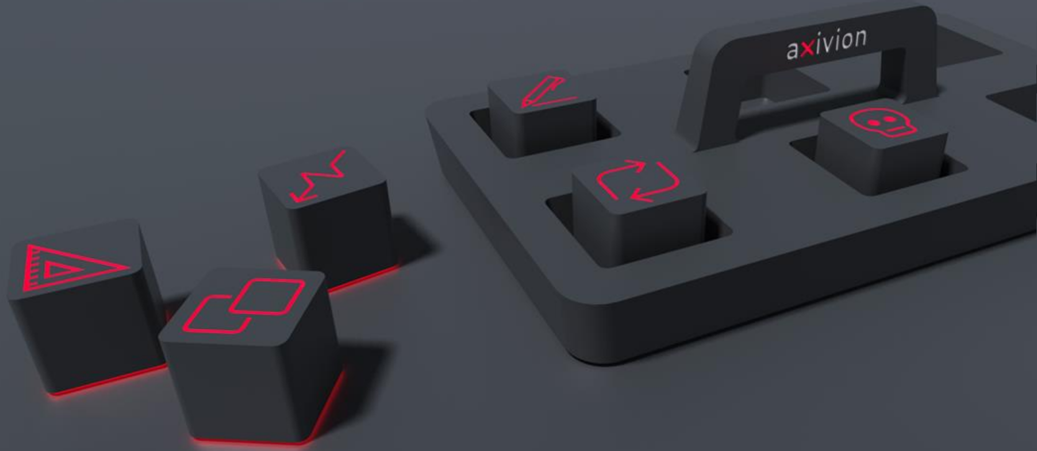

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