Realizing the Vision of Zero Software Defects

Systems & Software Technology Conference Tutorial

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Tutorial Agenda

- Complexity of Systems
  - Failures and their cause

- Implementation and Verification
  - Developing robust systems

- Model and Code Verification
  - Addressing design and code errors

- Practical Considerations
  - Implementing and verifying complex systems

- Additional Techniques for Improving Software Quality
  - Addressing standards and other considerations
Complexity of Systems

Failures and their cause
Complexity of Systems

- Modern automotive powertrain
  - 500 to 1,000 thousands lines of code (KLOC)

- Boeing 787 flight control system
  - 6,500 KLOC

- Software in spacecraft*
  - 3 to 1,700 KLOC

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*Automated Software Verification & Validation: An emerging approach for ground operations
Bell and Brat, NASA
Complex Systems Fail

- Ariane-5, expendable launch system
  - Overflow error
  - Resulted in destruction of the launch vehicle

- USS Yorktown, Ticonderoga class ship
  - Divide by zero error
  - Caused ship’s propulsion system to fail

- Therac-25, radiation therapy machine
  - Race condition and overflow error
  - Casualties due to overdosing of patients
## Cost of Failure – Aerospace Examples*

<table>
<thead>
<tr>
<th>System</th>
<th>Cost</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ariane 5 (1996)</td>
<td>$594M</td>
<td>Overflow software error</td>
</tr>
<tr>
<td>Delta III (1998)</td>
<td>$336M</td>
<td>SW did not account for normal roll oscillation</td>
</tr>
<tr>
<td>Titan IV B (1999)</td>
<td>$1.5B</td>
<td>Wrong decimal point in SW (const -0.19.. vs. -1.99..)</td>
</tr>
<tr>
<td>Mars Climate Orbiter (1999)</td>
<td>$524M</td>
<td>Wrong units</td>
</tr>
<tr>
<td>Zenit 3SL (2000)</td>
<td>$367M</td>
<td>Premature 2\textsuperscript{nd} stage shutdown</td>
</tr>
<tr>
<td>Messenger (2004)</td>
<td>$24M</td>
<td>SW test related delays resulting in data loss</td>
</tr>
</tbody>
</table>

*Automated Software Verification & Validation: An emerging approach for ground operations
Bell and Brat, NASA
Why Do Complex Systems Fail?*

- Insufficient specification
- Design errors
- Software coding errors
- Mechanical failure
- Deliberate interference
- Human errors

*Issues in Safety Assurance
Martyn Thomas, SafeComp 2003
Scope of Tutorial

- Insufficient specification
- Design errors
  - Software coding errors
- Mechanical failure
- Deliberate interference
- Human errors

Embedded Software
Design Errors

- Poorly designed software
  - That may or may not adhere to specifications

- Avoiding design errors
  - Not easy, issues may not be detected
  - With non-exhaustive testing or simulation methods

- Effects include
  - Software crashes
  - Unexpected software behavior
Design Error Examples

- Dead logic
- Unreachable states
- Deadlock conditions
- Non-deterministic behavior
- Exception conditions

- Overflow
- Divide by zero
- And lots more …
Software Code Errors

- Coding defects
  - Resulting in run-time errors

- What are run-time errors
  - Also known as “latent faults”
  - Rarely manifest and are infrequent

- Effects include
  - Software crashes
  - Unexpected software behavior
Run-Time Error Examples

- Non-initialized data
- Out of bound array access
- Null pointer dereference
- Incorrect computation
- Concurrent access to shared data

- Illegal type conversion
- Dead code
- Overflows
- Non-terminating loops
- And lots more …
The Vision of Zero Defect Software

- Is it possible?
- Yes, but with some caveats

- Is it applicable to all types of software?
- No, and that’s OK

- So when does it make sense to invest time, energy, and effort to create zero defect s/w …
Constraining the Problem

- When does software quality truly matter
  - Human lives at risk
  - Missions that cannot fail
  - Business operations that cannot suffer downtime

- Computer devices
  - High integrity embedded systems
  - Examples: flight control, braking systems, remote cellular base stations, …
Introduction to High Integrity Embedded Systems

- General embedded systems
  - Software world-wide increasing 10% to 20% per year
  - Embedded microprocessors account >98%

- High integrity systems found in
  - Aircraft, automobiles, medical devices
  - Safety and reliability are paramount

- Software algorithms contain
  - Complex controls algorithms
  - Computations in fixed point and floating point
  - Logic, state based machine algorithms
  - Multi-threaded code execution
Challenges in High Integrity*

- Strong correlation between application size and the total number of defects
  - Estimated 30 defects per 1000 lines of code
  - 20% will be severe
  - Defects must be found and removed

- Time and resources allocated to finding and fixing software defects
  - Most expensive aspect of software development

* Embedded software: facts, figures, and future
  Ebert And Jones, IEEE Computer 2009
Implementation and Verification of Complex Systems

Implementing and Verifying Complex Embedded Software Systems
Software for an Engine Controller

Complex Algorithm

Aircraft Engine

Embedded Controller
Design Implementation and Verification

- System Requirements
- Software Requirements
- Software Design
- Coding
- Software Integration
- Hardware/Software Integration
- Vehicle Integration and Calibration
Design Implementation

System Requirements

Software Requirements

Software Design

Coding

RESEARCH

REQUIREMENTS

DESIGN

Environment Models

Mechanical

Electrical

Supervisory Logic

Control Algorithms

IMPLEMENTATION

Hand Code

Generated C/C++

Third Party Code

MCU

DSP
Design Implementation with Model Based Design (MBD)
Design & Code Error Manifestation

- **System Requirements**
- **Vehicle Integration and Calibration**
- **Software Requirements**
- **Hardware/Software Integration**
- **Software Design**
- **Software Integration**
- **Coding**

Errors can manifest here
Design & Code Error Detection

- System Requirements
- Software Requirements
- Software Design
- Coding
- Software Integration
- Hardware/Software Integration
- Vehicle Integration and Calibration

Errors can manifest here
Possible to miss error detection here
Model and Code Verification

Addressing design and code errors
Solving the Problem with Model and Code Verification

Model Verification

Detect and fix design errors

Robust Design

Code Verification

Detect and fix code errors

Robust Code
Design Error Detection in MBD

RESEARCH

REQUIREMENTS

DESIGN
- Environment Models
- Mechanical
- Electrical
- Supervisory Logic
- Control Algorithms

IMPLEMENTATION
- Hand Code
- Generated C/C++
- Third Party Code
  - MCU
  - DSP

INTEGRATION
Process of Design Error Detection in MBD

- Verify design at the model level (*model verification*)
  - Identify issues such as dead logic

- Exhaustively verify design
  - Using formal methods
Formal Methods

- Mathematical based techniques for
  - Specification, development and verification of software

- Proof based verification
  - Formally prove attributes of a system
  - Results are considered “sound”

- Example techniques
  - Model checking for exhaustive search for all states
  - Abstract interpretation for semantic analysis of programs
Introduction to Abstract Interpretation

- Formal methods based verification
  - Solution that can be applied to software programs

- What is Abstract Interpretation?
  - Consider the multiplication of three large integers

\[-4586 \times 34985 \times 2389 = ?\]
Application of Abstract Interpretation

- Abstract result of computation to sign domain
  - Could be positive or negative
  - Sign of the computation will be negative

- Determining sign
  - An application of Abstract Interpretation

- Technique enables precise knowledge of some properties
  - The sign, without having to multiply integers fully
  - Sign will never be positive for this computation

- Abstract Interpretation is **sound** and **exhaustively proves**
  - That sign of the operation will always be negative
  - And never positive
Verification Tools that Implement Model Checking and Abstract Interpretation

<table>
<thead>
<tr>
<th>Verification Tools</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ImProve</strong> for building high assurance embedded applications</td>
<td>Tom Hawkins</td>
</tr>
<tr>
<td><strong>UPPAAL</strong> for modeling, validation and verification of real-time systems</td>
<td>Aalborg University</td>
</tr>
<tr>
<td><strong>Stacktool</strong> for stack overflow checking of embedded software</td>
<td>University of Utah</td>
</tr>
<tr>
<td><strong>DAEDALUS</strong> for validating critical software</td>
<td>European IST Programme</td>
</tr>
<tr>
<td>And many others …</td>
<td>Search engines, Wikipedia, ….</td>
</tr>
</tbody>
</table>
In this tutorial …

- We use MathWorks verification tools to demonstrate examples of applying formal methods
- To demonstrate how one can attempt to achieve zero defect software
- Applicable to any tool or product that implements formal methods
Confirming sound design

- Design verification of a model
Verification of Handwritten Code
Typical Methods of Software Verification and Testing

- Code reviews
  - Fagan inspections to reduce coding errors
  - Process needs to be complemented with other methods

- Dynamic test
  - Validate that software meets requirements
  - Verify the execution flow of software, often on the target
When Are You Done?

- Dijkstra
  - “Program testing can be used to show the presence of bugs, but never to show their absence”

- Hailpern
  - “Given that we cannot really show there are no more errors in the program, when do we stop testing?”
Find the Run-Time Error in `new_position()`

```c
int new_position(int sensor_pos1, int sensor_pos2) {
    int actuator_position;
    int x, y, tmp_pos, magnitude;

    actuator_position = 2; /* default */
    tmp_pos = 0; /* values */
    magnitude = sensor_pos1 / 100;
    y = magnitude + 5;
    x = actuator_position;

    while (actuator_position < 10) {
        actuator_position++;
        tmp_pos += sensor_pos2 / 100;
        y += 3;
    }

    if ((3*magnitude + 100) > 43) {
        magnitude++;
        x = actuator_position;
        actuator_position = x / (x - y);
    }

    return actuator_position + tmp_pos; /* new value */
}
```
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    actuator_position = x / (x - y);

    return actuator_position + tmp_pos; /* new value */
}
```
Consider the operation: \( \frac{x}{(x - y)} \)

Potential run-time errors
- Variables \( x \) and \( y \) may not be initialized
- An overflow on subtraction
- If \( x == y \), then a divide by zero will occur

How to prove that run-time errors do or do not exist?
Code Review of `new_position()`

```c
int new_position(int sensor_pos1, int sensor_pos2)
{
    int actuator_position;
    int x, y, tmp_pos, magnitude;

    actuator_position = 2; /* default */
    tmp_pos = 0;            /* values */
    magnitude = sensor_pos1 / 100;
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    }

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    {
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        x = actuator_position;
        actuator_position = x / (x - y);
    }

    return actuator_position + tmp_pos; /* new value */
}
```
Code Review of *new_position()*

```c
int new_position(int sensor_pos1, int sensor_pos2) {
    int actuator_position;
    int x, y, tmp_pos, magnitude;

    actuator_position = 2; /* default */
    tmp_pos = 0;        /* values */
    magnitude = sensor_pos1 / 100;
    y = magnitude << 5;
    x = actuator_position;

    while (actuator_position < 10) {
        actuator_position++;
        tmp_pos += sensor_pos2 / 100;
        y += 3;
    }

    if ((3*magnitude + 100) > 43) {
        magnitude++;
        x = actuator_position;
        actuator_position = x / (x - y);
    }

    return actuator_position + tmp_pos; /* new value */
}
```

Variables may not be initialized

Overflow potential
Code Review of `new_position()`

```c
int new_position(int sensor_pos1, int sensor_pos2) {
    int actuator_position;
    int x, y, tmp_pos, magnitude;

    actuator_position = 2; /* default */
    tmp_pos = 0;       /* values */
    magnitude = sensor_pos1 / 100;
    y = magnitude % 5;
    x = actuator_position;

    while (actuator_position < 10) {
        actuator_position++;
        tmp_pos += sensor_pos2 / 100;
        y += 3;
    }

    if ((3*magnitude + 100) > 43) {
        magnitude++;
        x = actuator_position;
        actuator_position = x / (x - y);
    }

    return actuator_position + tmp_pos; /* new value */
}
```

- Variables may not be initialized
- Overflow potential
- Division by zero potential
Code Review and Dynamic Test

- Code review results
  - Initially identified potential divide by zero condition
  - Deeper review shows potential overflow and initialization issues

- Next step is to Test
  - Validate that code written to meet requirements
  - Verify that the code is robust and will not fail
Requirements Specification

- Compute new position of control arm based on 2 position sensors
- Implement algorithm as modeled in the Simulink modeling environment
- Return value of new position shall be within $\pm 2^{28}$
Dynamic Test with a Test-Harness

```c
/* **************************************************************************
 * test harness to validate function new_position()
 *--------------------------------------------------------------------------*/

main (void) {
    int x, i, j;

    /*--------------------------------------------------------------------------
    * Requirement spec states that: -2^28 < result < 2^28
    * Inputs to function: can be full range (signed 32 bit target)
    *--------------------------------------------------------------------------/

    /*--------------------------------------------------------------------------
    * Exhaustive testing not possible, so lets check for -100 to 100
    * and a few other spot checks
    *--------------------------------------------------------------------------/

    /*--------------------------------------------------------------------------
    * Try -100..100 x -100..100 */
    for (i = -100; i < 101; i++) {
        for (j = -100; j < 101; j++) {
            x = new_position(i, j);
            if ((x > -268435456) && (x < 268435456)) {
                printf ("PASS: i=%d, j=%d, x=%d\n", i, j, x);
            }
        }
    }
```
Exhaustive Testing of \textit{new\_position()}

- Both inputs are signed int32
  - Full range inputs: $-2^{31} - 1 \ldots +2^{31} - 1$
  - All combinations of two inputs: $4.61 \times 10^{18}$ test-cases

- Test time on a Windows host machine
  - 2.2GHz T7500 Intel processor
  - 4 million test-cases took 9.284 seconds
  - Exhaustive testing time: \textbf{339,413 years}

Exhaustive Testing is Impossible
How to Increase Confidence?

- Could do more spot testing
  - But it is still not exhaustive

- Add defensive code (if $x \neq y \ldots$)
  - This will protect against divide by zero!
  - But adds more code and execution overhead
  - What about other potential errors like overflow?

- Wish that the code will not fail
  - Is that a good strategy …

- What about static code analysis tools?
  - Compiler warnings and more sophisticated tools
Introduction to Static Code Analysis

- Scanning source code to automate software verification
- Range from *unsound* methods to *sound* techniques
Introduction to Static Code Analysis

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Introduction to Static Code Analysis

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**Compiler warnings**
- Incompatible type detection, etc.

**Bug finding**
- Pattern matching, heuristics, data/control flow

**Formal methods**
- Sound proof based techniques, applied to source code
Compiler Warning Example

```c
void Arg_f(float *y);
void Arg_f(float *y)
{
    *y=12.0;
}

void WrongArg(void)
{
    volatile int r=0;
    Arg_f(&r);
    r = 1/(1-r);
}
```
Compiler Warning Example

```c
void Arg_f(float *y);
void Arg_f(float *y)
{
    *y = 12.0;
}
void WrongArg(void)
{
    volatile int r = 0;
    Arg_f(&r);
    r = 1/(r-r);
}
```

```bash
$ gcc -c -Wall src.c
src.c: In function `WrongArg':
src.c:12: warning: passing arg 1 of `Arg_f' from incompatible pointer type
$ 
```
Compiler Warnings for `new_position()`

```c
int new_position(int sensor_pos1, int sensor_pos2)
{
    int actuator_position;
    int x, y, tmp_pos, magnitude;

    actuator_position = 2; /* default */
    tmp_pos = 0,        /* values */
    magnitude = sensor_pos1 / 100;
    y = magnitude + 5;
    x = actuator_position;

    while (actuator_position < 10)
```
Compiler Warnings for `new_position()`

```c
int new_position(int sensor_pos1, int sensor_pos2)
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    tmp_pos = 0,         /* values */
    magnitude = sensor_pos1 / 100;
    y = magnitude + 5;
    x = actuator_position;

    while (actuator_position < 10)
```

```
$ gcc -c -Wall where_are_errors.c
$ `
Splint
Annotation-Assisted Lightweight Static Checking
Inexpensive Program Analysis Group
University of Virginia, Department of Computer Science

Splint is a tool for statically checking C programs for security vulnerabilities and coding mistakes. With minimal effort, Splint can be used as a better lint. If additional effort is invested adding annotations to programs, Splint can perform stronger checking than can be done by any standard lint.
Static Analysis with Splint (splint.org)

Splint - Secure Programming Lint
Download - Documentation - Manual - Links

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Annotation-Assisted Lightweight Static Checking
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Splint is a tool for statically checking C programs for security vulnerabilities and coding mistakes. With minimal effort, Splint can be used as a better lint. If additional effort is invested adding annotations to programs, Splint can perform stronger checking than can be done by any standard lint.

```bash
$ splint -strict where_are_errors.c
Splint 3.1.1 --- 09 Aug 2007

where_are_errors.c:1:5: Function new_position declared but not used
   A function is declared but not used. Use /*@unused*/ in front of function
define to suppress message. (Use -fcnuse to inhibit warning)
where_are_errors.c:25:1: Definition of new_position
where_are_errors.c:1:5: Function new_position exported but not declared in
   header file
   A declaration is exported, but does not appear in a header file. (Use
   -exporthdr to inhibit warning)
where_are_errors.c:25:1: Definition of new_position

Finished checking --- 2 code warnings
```

Secure Programming Lint
Specifications Lint
First Aid for Programmers

http://splint.org/
## Verification Results on `new_position()`

### Required Checks

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comments</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code Review</td>
<td>Identified potential non-initialized variables, overflows, and divide by zero</td>
<td>Further examination required</td>
</tr>
<tr>
<td>Dynamic Test</td>
<td>Test to requirements</td>
<td>Pass</td>
</tr>
</tbody>
</table>

### Additional Confidence Checks

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comments</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compiler warnings</td>
<td>None</td>
<td>No issues</td>
</tr>
<tr>
<td>Static Code Analysis</td>
<td>Splint with –strict</td>
<td>No issues</td>
</tr>
<tr>
<td>Formal methods</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Formal Methods Based Static Code Analysis

- Detects and proves the absence of certain run-time errors
- Operates at source code level
static void pointer_arithmetic (void) {
    int array[100];
    int *p = array;
    int i;

    for (i = 0; i < 100; i++) {
        *p = 0;
        p++;
    }

    if (get_bus_status() > 0) {
        if (get_oil_pressure() > 0) {
            *p = 5;
        } else {
            i++;
        }
    }

    i = get_bus_status();

    if (i >= 0) {
        *(p - i) = 10;
    }
}
Returning to our Example \texttt{new\_position()}

```c
int new_position(int sensor_pos1, int sensor_pos2)
{
    int actuator_position;
    int x, y, tmp_pos, magnitude;

    actuator_position = 2; /* default */
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    while (actuator_position < 10)
    {
        actuator_position++;
        tmp_pos += sensor_pos2 / 100;
        y += 3;
    }

    if ((3*magnitude + 100) > 43)
    {
        magnitude++;
        x = actuator_position;
    }

    actuator_position = x / (x - y);
}

return actuator_position + tmp_pos; /* new value */
```
Polyspace Results on `new_position()`

- Verification results for `new_position()`
- Results for `new_position()` with added protection
How to Prove $x! \Rightarrow y$ for $x/(x-y)$
How to Prove $x! \Rightarrow y$ for $x/ (x- y)$
How to Prove $x! \Rightarrow y$ for $x/(x-y)$

With Abstract Interpretation

- No code execution
- No test-cases
- Exhaustive!
- Proven!
Advantages and Disadvantages

- **Advantages**
  - Deep formal methods based code verification
  - Can formally prove that code is defect free and formally prove absolute existence of a defect
  - Sound technique … identifies all potential failure points

- **Disadvantages**
  - Compute intensive, will take time to run
  - In practice limited to projects with <1 MLOC
  - If results are viewed conservatively, all potential defects must be reviewed
Verifying Complex Handwritten Code

- Identifying run-time errors (reds)
- Dead code (grays)
- Understanding potentially failing code (oranges)
- Analysis of multithreaded coded
Range Violation Detection

- Some applications assume certain variable range
  - E.g. angle in degrees must be between 0 and 359
  - May simplify simulation and test

- What happens if range is violated?

- How to detect range violations exhaustively?
Range Violation Detection

- Range violation detection
Practical Considerations of Implementing and Verifying Complex Systems

Context of automatic code generation from Model Based Design (MBD) and the reality of mixed model and code environments
Verification of a System

**RESEARCH**

**REQUIREMENTS**

**DESIGN**
- Environment Models
- Mechanical
- Electrical
- Supervisory Logic
- Control Algorithms

**IMPLEMENTATION**
- Hand Code
- Generated C/C++
- Third Party Code
  - MCU
  - DSP

**INTEGRATION**
Returning to our Engine Controller

Complex Algorithm

*Model + Code*

Aircraft Engine

Embedded Controller

Code
Automatic Code Generation from Model

- S-Function
- Custom Code
- Legacy Code
- Subsystem ...
- Model Reference ...
- Storage Classes
- Legacy Data

Generated code from model
Automatic Code Generation from Model

- Generated code consists of
  - Subsystems and model references

- Often includes handwritten code
  - S-Functions and legacy code
  - Individually, small in size (100s LOC)
  - May be automatically repeated many times within generated code
Automatic Code Generation from Model

- Generated code consists of
  - Subsystems and model references

- Often includes handwritten code
  - S-Functions and legacy code
  - Individually, small in size (100s LOC)
  - May be automatically repeated many times within generated code

- Robustness issues to consider
  - Handwritten code fails, or causes generated code to fail
  - Generated code may cause handwritten code to fail (*Interface related failures*)
  - Handwritten code is not visible to modeling tools
Integration of Generated Code
Integration of Generated Code

- S-Function
- Custom Code
- Legacy Code
- Model Reference

Generated code from model

Embedded Software

- Generated Code
- Handwritten Code
- Third Party Code
- Obj. Code (libraries)
Integration of Generated Code

- Code integration
  - Generated code stitched together with handwritten code
  - All components integrated with handwritten code
Integration of Generated Code

- Code integration
  - Generated code stitched together with handwritten code
  - All components integrated with handwritten code

- Robustness issues to consider
  - Design error in the generated code
  - Runtime error in handwritten or 3rd party code
  - How do you ensure the entire system is robust?
  - How to verify generated code at interface level?
Verification of Mixed Model and Code

- Checking handwritten code in the models
- Verifying the generated code
- Verifying integrated code
Additional Techniques for Improving Software Quality

Getting near to zero defect goal
Enforce Code Standards

- C is a very flexible language
  - `char **********ptr;` is valid syntax
  - You can also write code without comments

- Are these good practices?
  - In general, NO

- Important to follow some code standards
  - Examples: MISRA C/C++, JSF++
Using Code Standards

- **Example standards**
  - MISRA (Motor Industry Software Reliability Association), developed for automotive, but used outside in other industries
  - JSF++ (Joint Strike Fighter Air Vehicle C++)

- **Facilitate**
  - Code safety, portability and reliability

- **Code rules**
  - Some required, others advisories
  - Various categories, such as style, environment, and run-time
Example MISRA Rules

- **Required**
  - All object and function identifiers shall be declared before use
  - The right hand side of a "&&" or "||" operator shall not contain side effect
  - The statement forming the body of an "if", "else if", "else", "while", "do ... while", or "for" statement shall always be enclosed in braces

- **Advisory**
  - Should not directly use basic types such as char, int, float etc.
  - All declarations at file scope should be static where possible
  - Tests of a value against zero should be made explicit, unless the operand is effectively Boolean
Applying Coding Standards

- Application of MISRA C coding standards
- Measuring the improvement in quality
Enabling Software Quality

- Ideal goal, create software with zero defects

- In reality, must have a quality mandate
  - Internally or required externally
  - To meet specific software quality objectives

- Define a quality model with objectives
  - Enables a prescriptive solution to achieve quality
Runtime Defects in Software

- Software will contain runtime defects
  - Cannot eliminate all defects in one step

- Incremental processes are needed
  - Different quality objectives and levels

- Ex. quality model with objectives
  - Six levels, s/w quality objectives (SQO)
  - For intermediate development and verification stages
Incremental Steps to Achieve Quality

All Runtime Defects in Your Software
Incremental Steps to Achieve Quality

- Eliminate some runtime defects
  - By quantifying code verification results
    - Red, Gray, Orange
    - MISRA Rules
    - Code complexity metrics

Some Runtime Defects May Still Remain
Incremental Steps to Achieve Quality
Software Quality Objectives #1

SQO1
- Meet specific code complexity thresholds
- Compliant to defined 1st MISRA-2004 rules subset

- First level has limited scope
  - Subsequent levels increase scope
  - Runtime defects may still remain in code

Some Runtime Defects May Still Remain
Incremental Steps to Achieve Quality

SQO1
- Meet specific code complexity thresholds
- Compliant to defined 1st MISRA-2004 rules subset

SQO2
- No systematic run-time errors (i.e. no reds)
- No unintentional non-terminating constructs

- Second level increases scope
  - More runtime defects eliminated
  - But, runtime defects may still remain

- For an intermediate delivery
  - Subsequent levels will improve quality

Some Runtime Defects May Still Remain
Incremental Steps to Achieve Quality

SQO1
- Meet specific code complexity thresholds
- Compliant to defined 1st MISRA-2004 rules subset

SQO2
- No systematic run-time errors (i.e. no reds)
- No unintentional non-terminating constructs

SQO3
- No unreachable branches (i.e. no dead code)

Some Runtime Defects May Still Remain
Incremental Steps to Achieve Quality

**SQO1**
- Meet specific code complexity thresholds
- Compliant to defined 1st MISRA-2004 rules subset

**SQO2**
- No systematic run-time errors (i.e. no reds)
- No unintentional non-terminating constructs

**SQO3**
- No unreachable branches (i.e. no dead code)

**SQO4**
- Achieve 1st subset of non-systematic run-time errors (i.e. specified percentage of orange)

Some Runtime Defects May Still Remain
Incremental Steps to Achieve Quality

**SQO1**
- Meet specific code complexity thresholds
- Compliant to defined 1st MISRA-2004 rules subset

**SQO2**
- No systematic run-time errors (i.e. no reds)
- No unintentional non-terminating constructs

**SQO3**
- No unreachable branches (i.e. no dead code)

**SQO4**
- Achieve 1st subset of non-systematic run-time errors (i.e. specified percentage of orange)

**SQO5**
- Compliant to defined 2nd MISRA-2004 rules subset
- Achieve 2nd subset of non-systematic run-time errors
Incremental Steps to Achieve Quality

**SQO1**
- Meet specific code complexity thresholds
- Compliant to defined 1st MISRA-2004 rules subset

**SQO2**
- No systematic run-time errors (i.e. no reds)
- No unintentional non-terminating constructs

**SQO3**
- No unreachable branches (i.e. no dead code)

**SQO4**
- Achieve 1st subset of non-systematic run-time errors (i.e. specified percentage of orange)

**SQO5**
- Compliant to defined 2nd MISRA-2004 rules subset
- Achieve 2nd subset of non-systematic run-time errors

**SQO6**
- Achieve 3rd subset of non-systematic run-time errors
DO-178B Certification Credit with Verification Tools

- Partial credit for the following:
  - Table A-5
    - Ref. Section: 6.3.4b, 6.3.4c, 6.3.4d, 6.3.4f
  - Table A-6
    - Ref. Section: 6.4.2.1, 6.4.2.2, 6.4.3

- Next slide explain 6.3.4.b and 6.3.4.f
Certification Credit for 6.3.4.b

- **Objective**
  - Compliance with the software architecture
  - The objective is to ensure that the Source Code matches the data flow and control flow defined in the software architecture

- **How tools can be used**
  - The data flow
    - Prove adherence to this aspect of the standard, as it automatically builds global data dictionary and identification of shared data reading and writing accesses

- **Artifacts**
  - Data dictionary, concurrent access graph, etc.
Certification Credit 6.3.4.f

- **Objective**
  - Determine the consistency of the Source Code, including stack usage, fixed point arithmetic overflow and resolution, resource contention, worst-case execution timing, exception handling, use of uninitialized variables or constants, unused variables or constants, and data corruption due to task or interrupt conflicts.

- **Code verification helps to identify**
  - Exhaustively: Fixed point arithmetic overflows, use of uninitialized variables and constants, etc.
  - Partially: Unused variables and constants

- **Artifacts**
  - Color coding to identify quality of code
  - Report generation for artifact purpose
Conclusion

Summary of tutorial
Adopting New Processes

Short Term

- Detect and fix design and code errors
  - Unreachable states, dead logic, etc.
  - Fix code level run-time errors

- Simplify code review process
  - Take verification results to code review

- Develop better test-cases
  - Improve coverage analysis
  - Understand impact of variable ranges
Adopting New Processes

*Long Term*

- Make verification a part of your quality improvement process
  - Monitor quality and status

- Leverage verification for certification
  - Maybe possible to skip some processes
  - E.g. show code does not contain divide by zeros
Conclusion

- Complexity of systems
  - Learn from past failures

- Model and code verification
  - Address design and code with error detection and proof
  - Use model verification to detect and fix design errors
  - Use code verification to detect and fix coding errors

- Practical considerations
  - Improve robustness in mixed model and code environments

- Additional techniques for improving software quality
  - Coding standards such as MISRA and JSF
  - Certification standards such as DO-178B
  - Achieving quality goals with software quality objectives
Acronyms

- DSP – Digital Signal Processor
- JSF – Joint Strike Fighter
- KLOC – Thousands (K) of Lines of Code
- LOC – Lines of Code
- MBD – Model Based Design
- MCU – Micro Control Unit
- MISRA – Motor Industry Software Reliability Association
- MLOC – Millions of Lines of Code
- SW – Software
- SQO – Software Quality Objectives