mbeddr
C the Difference. C the Future.

An extensible version of the C programming language for Embedded Programming

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C the Difference - C the Future

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LEAR CORPORATION SICK Sensor Intelligence. fortiss itemis

What if…

you could change languages like you can change programs?

A Test, written in essentially normal C

```
module WriteATestCase from cdesignpaper.unittest imports nothing {

  var int8_t failedTests;

  int32_t main(int32_t argc, int8_t*[ ] argv) {
    testMultiply();
    return failedTests;
  } main (function)

  void testMultiply() {
    if ( times2(21) != 42 ) { failedTests++; } if
  } testMultiply (function)

  int8_t times2(int8_t a) {
    return 2 * a;
  } times2 (function)
}
```

The same test, but now using additional language concepts from the unit test extension

```
module UnitTestDemo from cdesignpaper.unittest imports nothing {

  int32_t main(int32_t argc, int8_t*[ ] argv) {
    return test testMultiply;
  } main (function)

  exported test case testMultiply {
    assert(0) times2(21) == 42;
  } testMultiply(test case)

  int8_t times2(int8_t a) {
    return 2 * a;
  } times2 (function)
}
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```

Test Cases are a kind of void function, but with adapted syntax

- The same test, but now using additional language concepts from the unit test extension

```
module UnitTestDemo from cdesignpaper.unittest imports nothing {

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  } times2 (function)
}
```

Asset Statements check conditions; they are restricted to be used only in test cases.

- The same test, but now using additional language concepts from the unit test extension

```
module UnitTestDemo from cdesignpaper.unittest imports nothing {

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  } main (function)

  exported test case testMultiply {
    assert(0) times2(21) == 42;
  } testMultiply(test case)

  int8_t times2(int8_t a) {
    return 2 * a;
  } times2 (function)
}
```

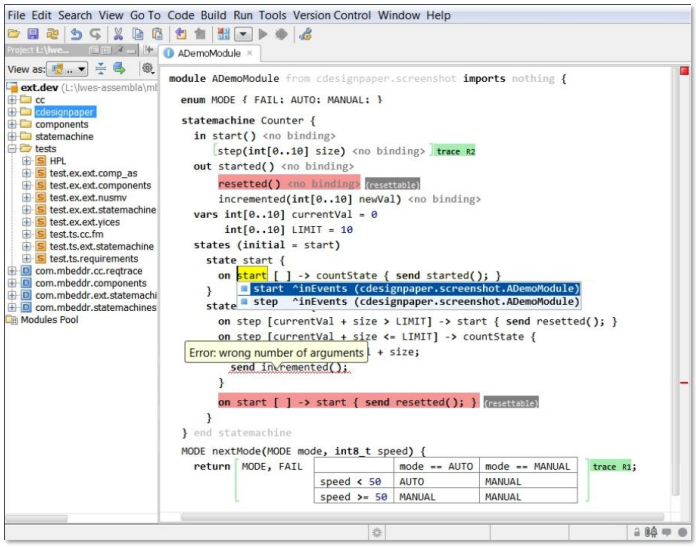
A special expression that executes tests, and evaluates to the number of failed tests (which is then returned to the OS here)

- The unit testing extensions are implemented in separate language module.
- The constructs become available to programmers only if they import the respective language module into their program
- This keeps the overall language clean --- a precondition for building extensions targetting different audiences.

mbeddr C Approach

An extensible C with support for formal methods, requirements and PLE.

IDE for Everything



A debugger for all of that

- The Debugger debugs the code on the level of the extensions!
- When defining new language concepts, language developers also specify how these concepts should be debugged.

SDK for building your own Language Extensions!

- This SDK is essentially MPS ☺, plus some custom documentation.

IDE for Everything

JetBrains
MPS
Open Source
Language Workbench

- Apache 2.0
- Available at http://jetbrains.com/mps

Challenges

in embedded software development

Abstraction without Runtime Cost

- Abstractions are important to write maintainable and analyzable software; however,
- Abstractions should not incur runtime overhead (or at least as little as possible)

C considered unsafe

- void pointers are evil
- standards like MISRA-C prohibit certain constructs from being used in many organizations

Program Annotations

- Things like physical units, value ranges, or access patterns to data structures are often defined outside the code program in some kind of XML
- The C type checker doesn't know about them, a separate checker is used --- cumbersome!

Static Checks and Verification

- Model Checking, SAT solving etc. are important to „proof" the correctness of programs, however,
- it is expensive to do on C code since C's abstractions are too low-level

Product Lines and Requirement Traces

- Trace links from code (or other implementation artifacts) back to requirements must be supported
- Product Line Variability must be handled in a more maintainable way than #ifdefs

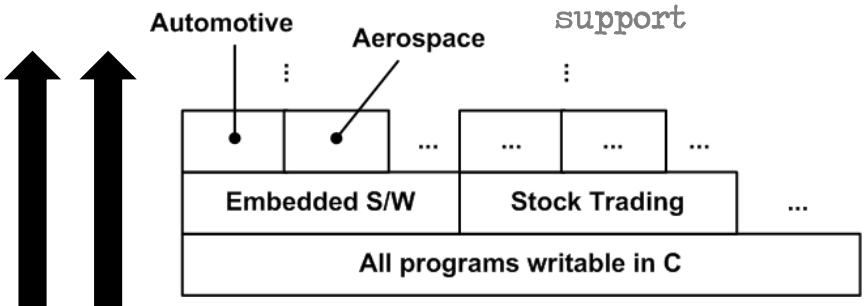
Separate, hard to integrate Tools

- Modeling tools don't integrate well with each other, or with manually written code
- Modeling tools aren't really extensible, making them hard to adapt to specific domains

mbeddr C Solution Philosophy

Extension

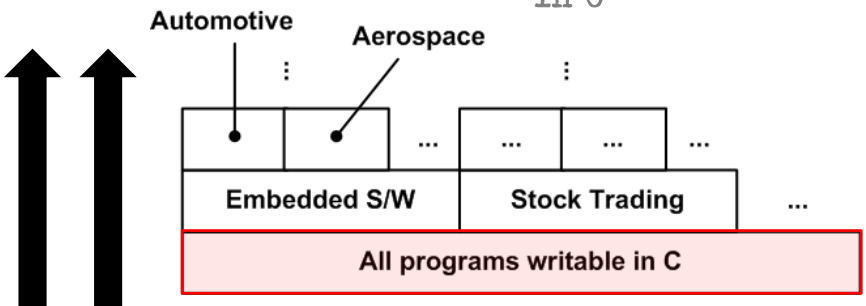
- Domains can be seen as specializations of others. Each may require specialized language support



more specialized domains
more specialized languages

Extension

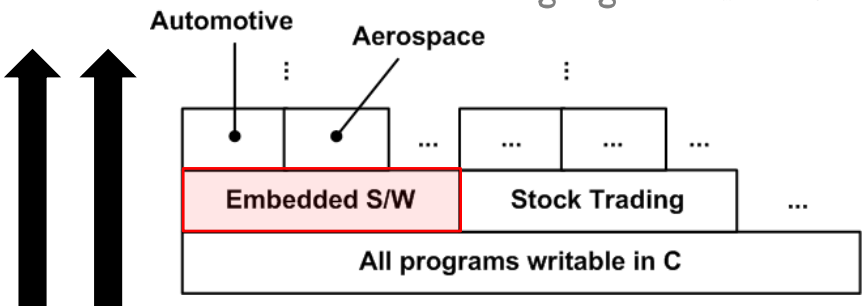
- There is a general domain the encompasses all programs writable in C



more specialized domains
more specialized languages

Extension

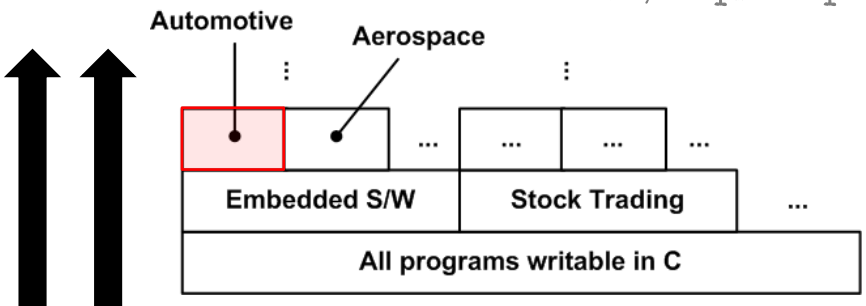
- Embedded software is a specialzation of C --- requiring special language abstractions



more specialized domains
more specialized languages

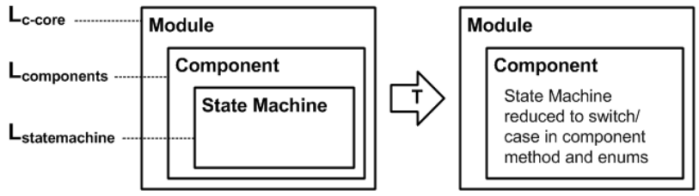
Extension

- Automotive or Aerospace are subsequent specializations … ad infinitum, in principle.

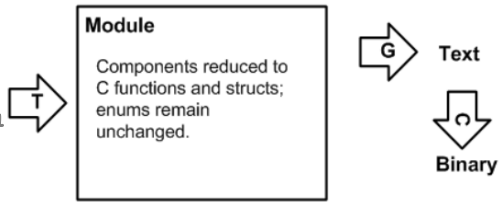


more specialized domains
more specialized languages

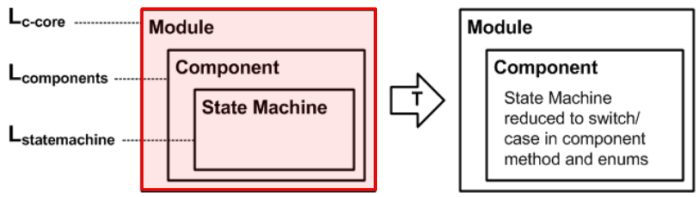
Incremental Trafo



- Assume we have a module which contains a components which in turn contains a state machine. How is this compiled?



Incremental Trafo



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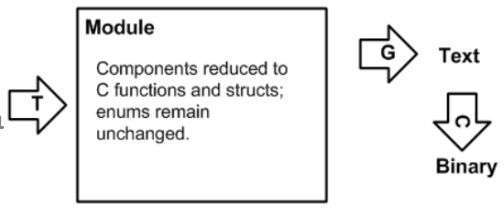
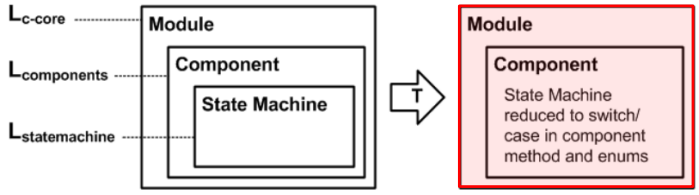
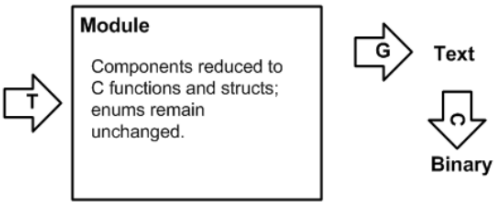


Incremental Trafo



- In the first step, the state machine is reduced to a component operation that contains e.g. the usual switch/ case way of implementing a SM



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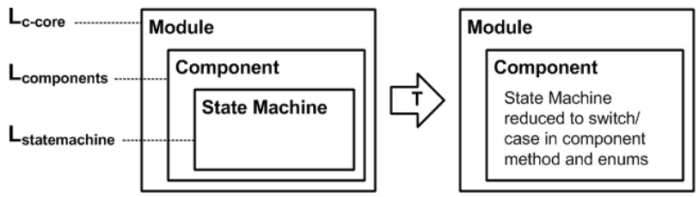
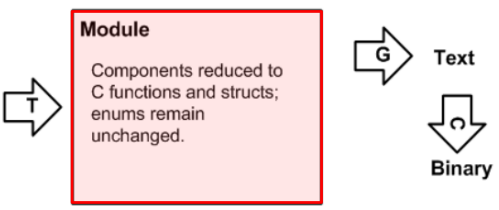


- In the next step, the component is reduced to a bunch of normal C methods; the contains switch /case statement just remains unchanged.



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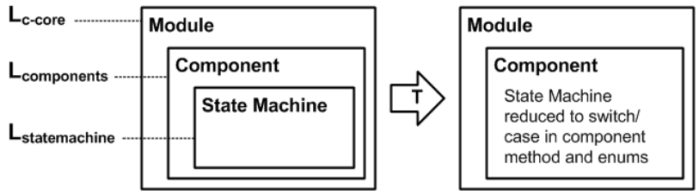
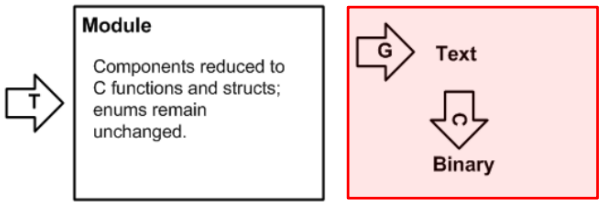
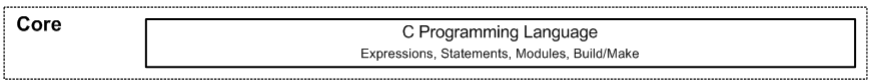


- Finally, we generate text from the C program and feed it into a regular compiler, such as GCC. mbeddr uses incremental reduction!



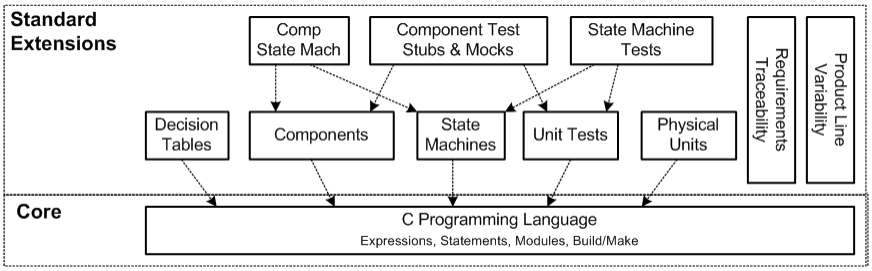
Language Extension

- The core contains all of C plus a couple of utilities such as namespaces, closures, real boolean types and integration with make.
- A few changes have been made relative to standard C --- these are clearly explained in the docs.
- It is designed to be extensible by users, e.g. it is simple to provide an integration with a custom build infrastructure



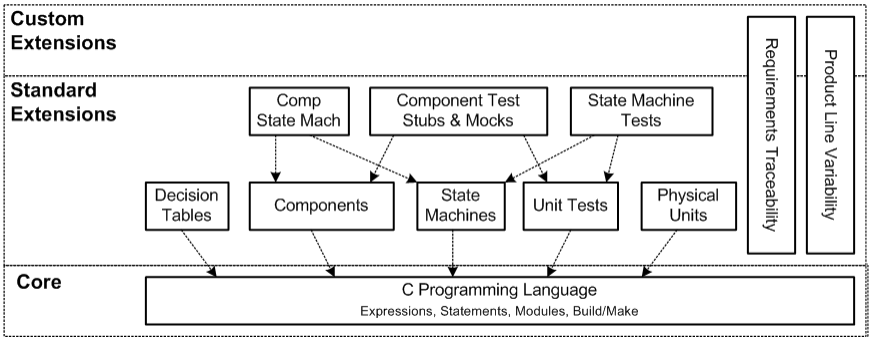
Language Extension

- These standard extensions are intended to be useful by many embedded software proejects. Most of them will become Open Source during 2012



Language Extension

- The SDK lets users build their own language extensions in a modular way -- without changing the existing languages, and independent of other extensions.



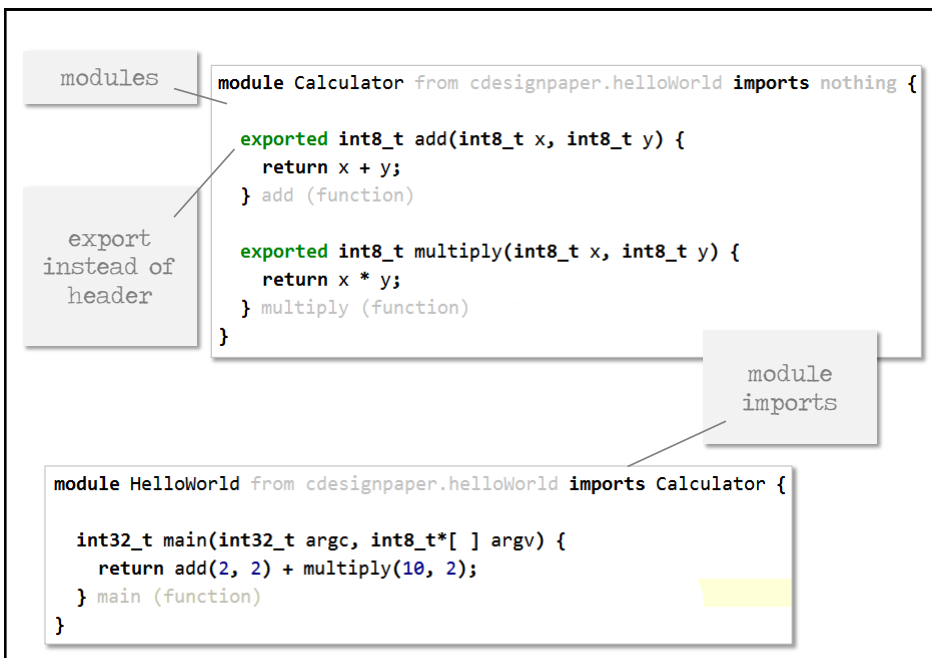
Subset of Available Extensions

All of C (cleaned-up)

- no preprocessor (better replacements!), modules/namespaces, unit tests, C99 primitive types required, booleans, binary literals, function references, closures

```
module Calculator from cdesignpaper.helloWorld imports nothing {

  exported int8_t add(int8_t x, int8_t y) {
    return x + y;
  } add (function)

  exported int8_t multiply(int8_t x, int8_t y) {
    return x * y;
  } multiply (function)
}
```

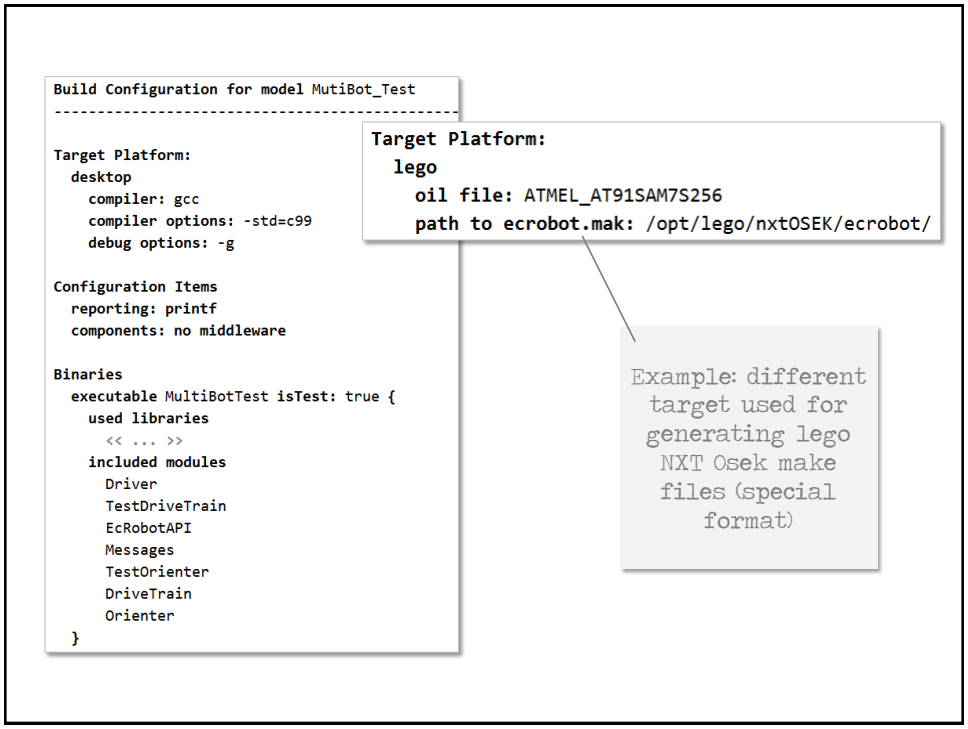
```
module HelloWorld from cdesignpaper.helloWorld imports Calculator {

  int32_t main(int32_t argc, int8_t*[ ] argv) {
    return add(2, 2) + multiply(10, 2);
  } main (function)
}
```



Retargettable Build Integration

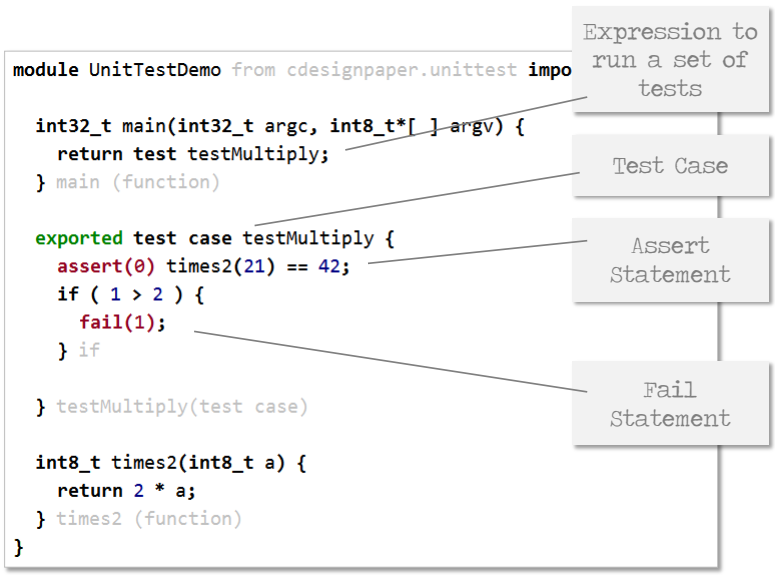
```
Build Configuration for model MutiBot_Test
-------------------------------------------------

Target Platform:
  desktop
    compiler: gcc
    compiler options: -std=c99
    debug options: -g

Configuration Items
  reporting: printf
  components: no middleware

Binaries
  executable MultiBotTest isTest: true {
    used libraries
      << ... >>
    included modules
      Driver
      TestDriveTrain
      EcRobotAPI
      Messages
      TestOrienter
      DriveTrain
      Orienter
  }
```

```
Target Platform:
  lego
    oil file: ATMEL_AT91SAM7S256
    path to ecrobot.mak: /opt/lego/nxtOSEK/ecrobot/
```



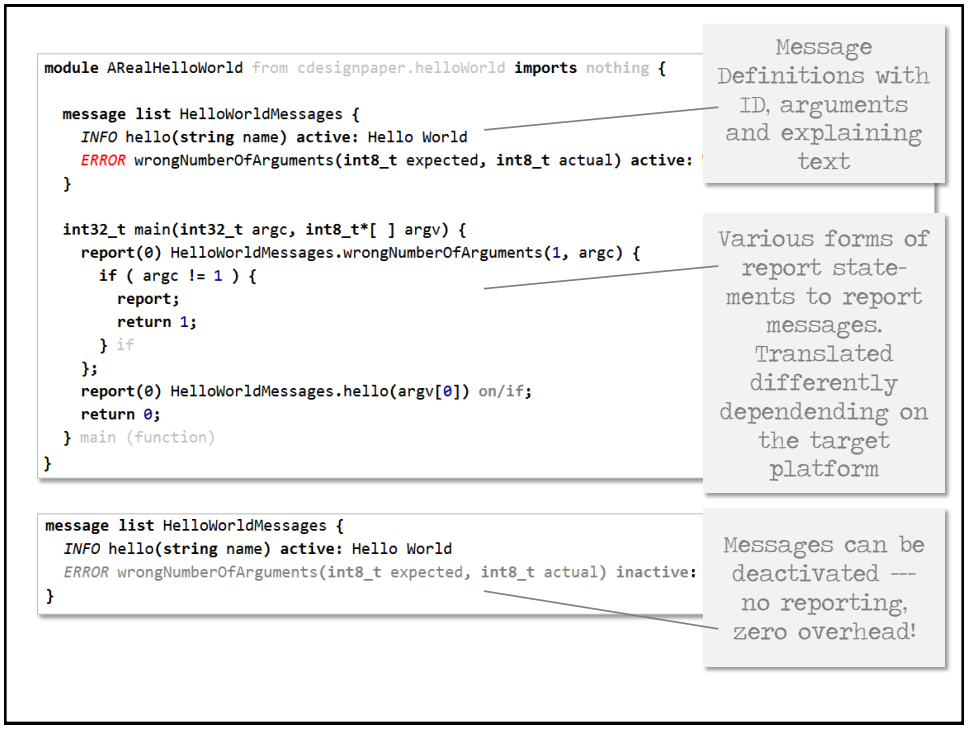
Native Support for Unit Testing and Logging

```
module UnitTestDemo from cdesignpaper.unittest imports nothing {

  int32_t main(int32_t argc, int8_t*[ ] argv) {
    return test testMultiply;
  } main (function)

  exported test case testMultiply {
    assert(0) times2(21) == 42;
    if ( 1 > 2 ) {
      fail(1);
    } if

  } testMultiply(test case)

  int8_t times2(int8_t a) {
    return 2 * a;
  } times2 (function)
}
```



```
module ARealHelloWorld from cdesignpaper.helloWorld imports nothing {

  message list HelloWorldMessages {
    INFO hello(string name) active: Hello World
    ERROR wrongNumberOfArguments(int8_t expected, int8_t actual) active: Wrong number of Arguments
  }

  int32_t main(int32_t argc, int8_t*[ ] argv) {
    report(0) HelloWorldMessages.wrongNumberOfArguments(1, argc) {
      if ( argc != 1 ) {
        report;
        return 1;
      } if
    };
    report(0) HelloWorldMessages.hello(argv[0]) on/if;
    return 0;
  } main (function)
}
```

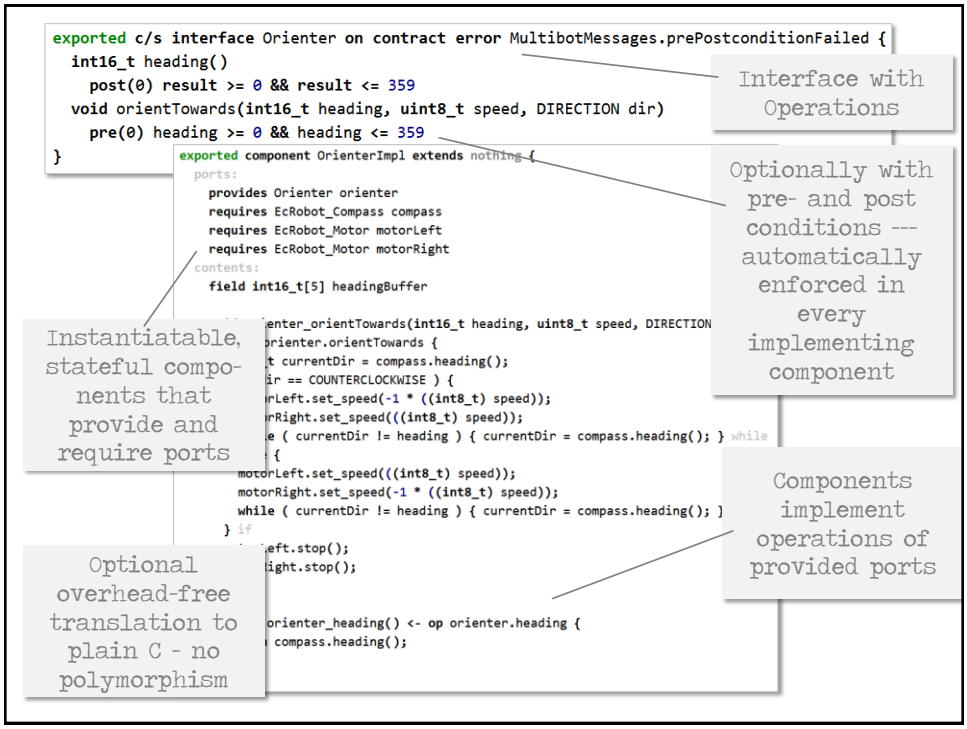
```
message list HelloWorldMessages {
  INFO hello(string name) active: Hello World
  ERROR wrongNumberOfArguments(int8_t expected, int8_t actual) inactive: Wrong number of Arguments
}
```



Components
Interfaces
Contracts
Instances
Mocks & Stubs

```
exported c/s interface Orienter on contract error MultibotMessages.prePostconditionFailed {
  int16_t heading()
    post(0) result >= 0 && result <= 359
  void orientTowards(int16_t heading, uint8_t speed, DIRECTION dir)
    pre(0) heading >= 0 && heading <= 359
}
```

```
exported component OrienterImpl extends nothing {
  ports:
    provides Orienter orienter
    requires EcRobot_Compass compass
    requires EcRobot_Motor motorLeft
    requires EcRobot_Motor motorRight
  contents:
    field int16_t[5] headingBuffer

    void orienter_orientTowards(int16_t heading, uint8_t speed, DIRECTION dir) <-
        op orienter.orientTowards {
      int16_t currentDir = compass.heading();
      if ( dir == COUNTERCLOCKWISE ) {
        motorLeft.set_speed(-1 * ((int8_t) speed));
        motorRight.set_speed(((int8_t) speed));
        while ( currentDir != heading ) { currentDir = compass.heading(); } while
      } else {
        motorLeft.set_speed(((int8_t) speed));
        motorRight.set_speed(-1 * ((int8_t) speed));
        while ( currentDir != heading ) { currentDir = compass.heading(); } while
      } if
      motorLeft.stop();
      motorRight.stop();
    }

    int16_t orienter_heading() <- op orienter.heading {
      return compass.heading();
    }
}
```




```
exported test case testDriveTrain {
  initialize instances;
  assert(0) dt.currentSpeed() == 0;
  dt.driveContinouslyForward(50);
  dt.stop();
  validate mock motorLeft;
  validate mock motorRight;
} testDriveTrain(test case)
```

```
instance configuration instances extends nothing {
  instances:
  instance MotorLeftMock motorLeft
  instance MotorRightMock motorRight
  instance DriveTrainImpl driveTrain
  instance EcUtil util
  connectors:
  connect driveTrain.motorLeft to motorLeft.motor
  connect driveTrain.motorRight to motorRight.motor
  connect driveTrain.util to util.util
  adapter:
  << ... >>
}
```

```
mock component MotorLeftMock {
  report messages: true
  ports:
    provides EcRobot_Motor motor
  expectations:
    total no. of calls is 2
    sequence {
      0: motor.set_speed {
          0: parameter speed: speed == 50
        }
      1: motor.stop
    }
}
```

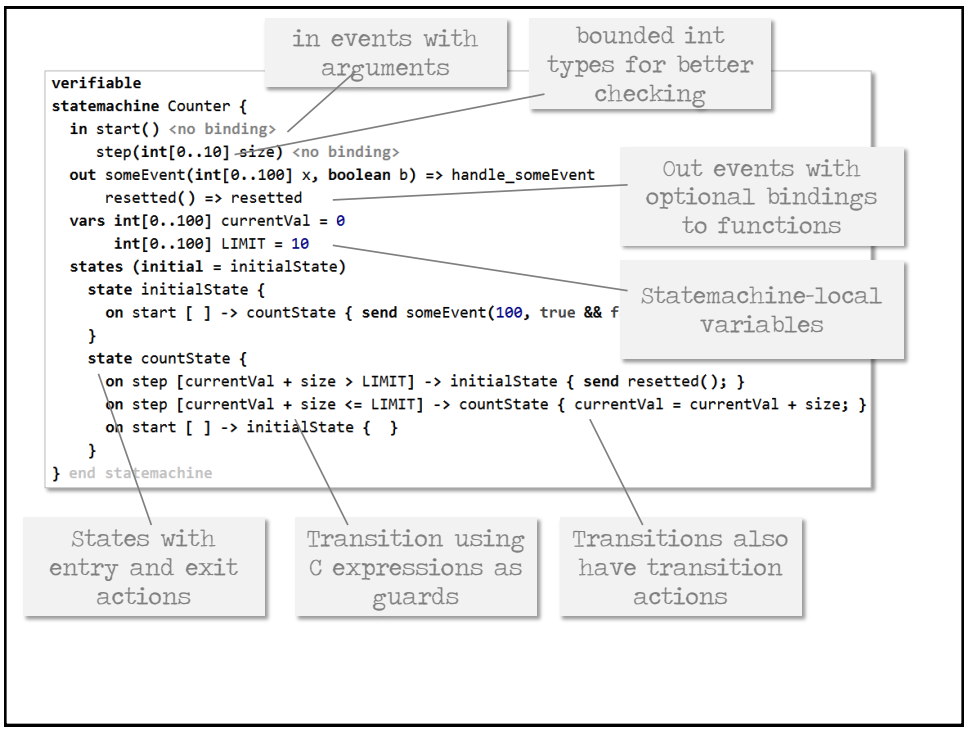
```
mock component MotorRightMock {
  report messages: true
  ports:
    provides EcRobot_Motor motor
  expectations:
    total no. of calls is 2
    sequence {
      0: motor.set_speed {
          0: parameter speed: speed == 50
        }
      1: motor.stop
    }
}
```

State Machines

+

Model Checking

```
verifiable
statemachine Counter {
  in start() <no binding>
     step(int[0..10] size) <no binding>
  out someEvent(int[0..100] x, boolean b) => handle_someEvent
      resetted() => resetted
  vars int[0..100] currentVal = 0
       int[0..100] LIMIT = 10
  states (initial = initialState)
    state initialState {
      on start [ ] -> countState { send someEvent(100, true && false || true); }
    }
    state countState {
      on step [currentVal + size > LIMIT] -> initialState { send resetted(); }
      on step [currentVal + size <= LIMIT] -> countState { currentVal = currentVal + size; }
      on start [ ] -> initialState {  }
    }
} end statemachine
```



```
verifiable
statemachine Counter {
  in start() <no binding>
     step(int[0..10] size) <no binding>
  out someEvent(int[0..100] x, boolean b) => handle_someE
      resetted() => resetted
  vars int[0..100] currentVal = 0
       int[0..100] LIMIT = 10
  states (initial = initialState)
    state initialState {
      on start [ ] -> countState { send someEvent(100, tr
    }
    state countState {
      on step [currentVal + size > LIMIT] -> initialState
      on step [currentVal + size <= LIMIT] -> countState
      on start [ ] -> initialState {  }
    }
} end statemachine
```

NuSMV Tool

Property	Status	Trace Size
State 'initialState' can be reached	SUCCESS	
State 'countState' can be reached	SUCCESS	
Variable 'currentVal' is always between its defi...	SUCCESS	
Variable 'LIMIT' is always between its defined ...	SUCCESS	
State 'initialState' has deterministic transitions	SUCCESS	
State 'countState' has deterministic transitions	SUCCESS	
Transition 0 of state 'initialState' is not dead	SUCCESS	
Transition 0 of state 'countState' is not dead	SUCCESS	
Transition 1 of state 'countState' is not dead	SUCCESS	
Transition 2 of state 'countState' is not dead	SUCCESS	
Condition 'currentVal == 8' can be true	FAIL	4

Node	Value
State initialState	
LIMIT	10
currentVal	0
State initialState	
in_event: start	star)
LIMIT	10
currentVal	0
State countState	
in_event: step	step(8)
out_event:someEvent	someEvent(100, true)
LIMIT	10
currentVal	0
State countState	
LIMIT	10
currentVal	8


```
verifiable
statemachine Counter {
  in start() <no bindi
     step(int[0..10] s
  out someEvent(int[0.
      resetted() => re
  vars int[0..100] curr
       int[0..100] LIM
  states (initial = in
    state initialState {
      on start [ ] -> c
    }
    state countState {
      on step [currentV
      on step [currentV
      on start [ ] -> i
    }
} end statemachine
```


A number of default properties for reachability, non-determinism, variable ranges

Model Checker Results as Tabke

Additional properties can be described using an abstraction of LTL/CTL

Counter example if a property failes --- clicking on example highlights code in model

NuSMV Tool

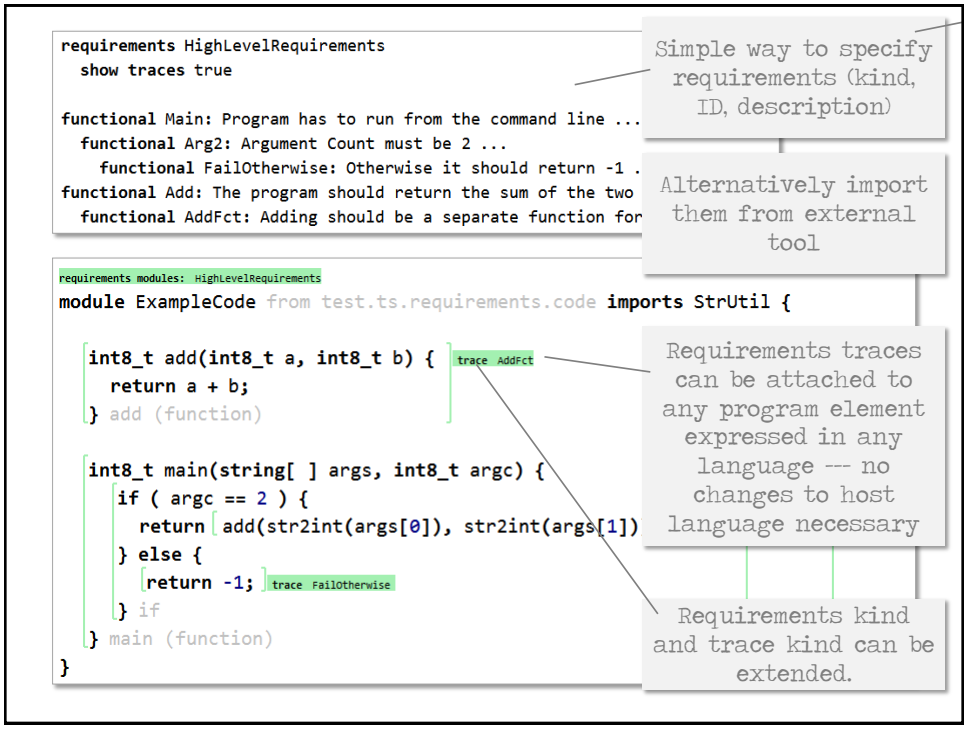
Property	Status	Trace Size
State 'initialState' can be reached	SUCCESS	
State 'countState' can be reached	SUCCESS	
Variable 'currentVal' is always between its defi...	SUCCESS	
Variable 'LIMIT' is always between its defined ...	SUCCESS	
State 'initialState' has deterministic transitions	SUCCESS	
State 'countState' has deterministic transitions	SUCCESS	
Transition 0 of state 'initialState' is not dead	SUCCESS	
Transition 0 of state 'countState' is not dead	SUCCESS	
Transition 1 of state 'countState' is not dead	SUCCESS	
Transition 2 of state 'countState' is not dead	SUCCESS	
Condition 'currentVal == 8' can be true	FAIL	4

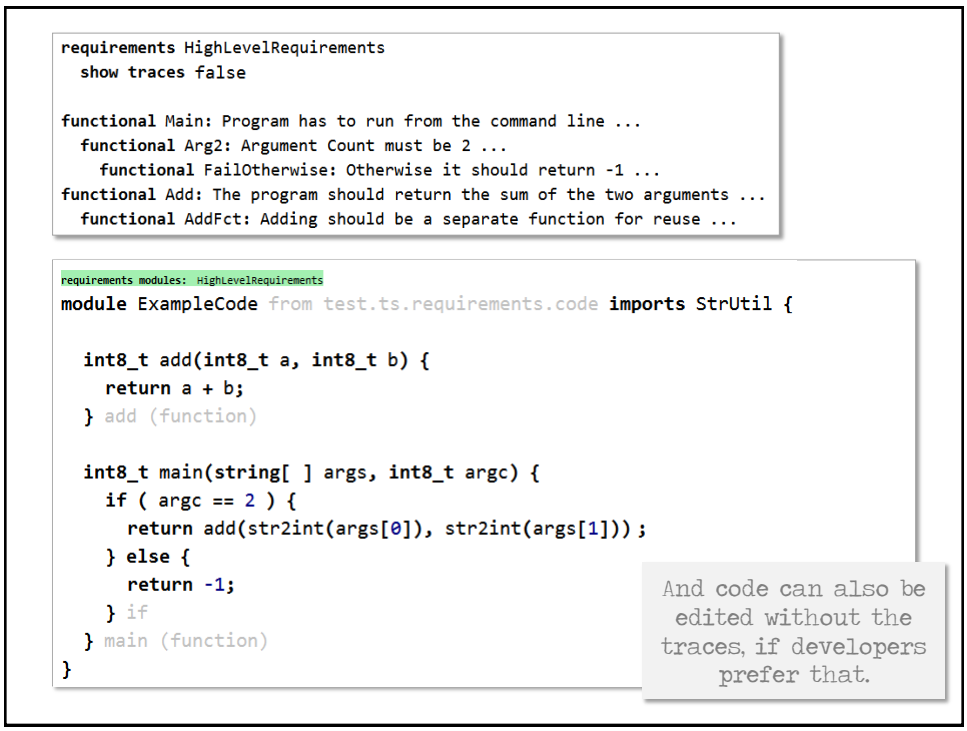
Node	Value
State initialState	
LIMIT	10
currentVal	0
State initialState	
in_event: start	star)
LIMIT	10
currentVal	0
State countState	
in_event: step	step(8)
out_event:someEvent	someEvent(100, true)
LIMIT	10
currentVal	0
State countState	
LIMIT	10
currentVal	8

Requirements Tracability

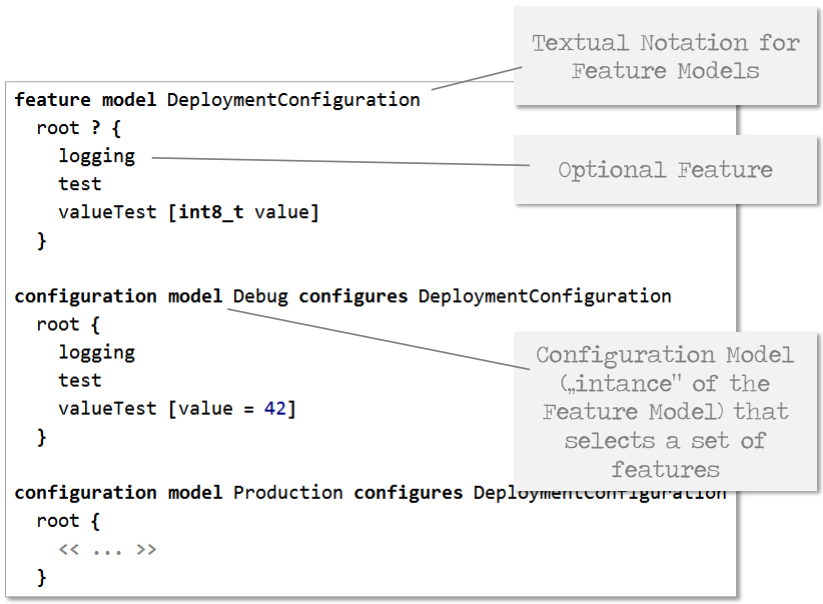
```
requirements HighLevelRequirements
  show traces true

functional Main: Program has to run from the command line ...
  functional Arg2: Argument Count must be 2 ...
    functional FailOtherwise: Otherwise it should return -1 ...
functional Add: The program should return the sum of the two arguments ...
  functional AddFct: Adding should be a separate function for reuse ...
```

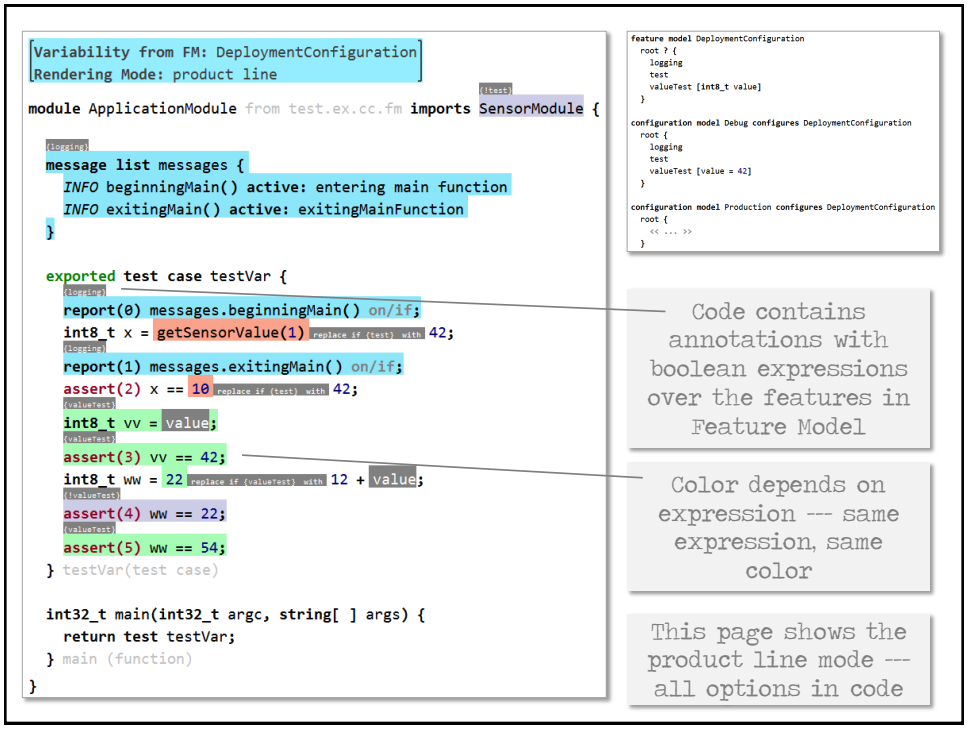
```
requirements modules: HighLevelRequirements
module ExampleCode from test.ts.requirements.code imports StrUtil {

  int8_t add(int8_t a, int8_t b) {  trace AddFct
    return a + b;
  } add (function)

  int8_t main(string[ ] args, int8_t argc) {                                  trace Main
    if ( argc == 2 ) {                                                        trace Arg2
      return add(str2int(args[0]), str2int(args[1])) trace Add;
    } else {
      return -1; trace FailOtherwise
    } if
  } main (function)
}
```

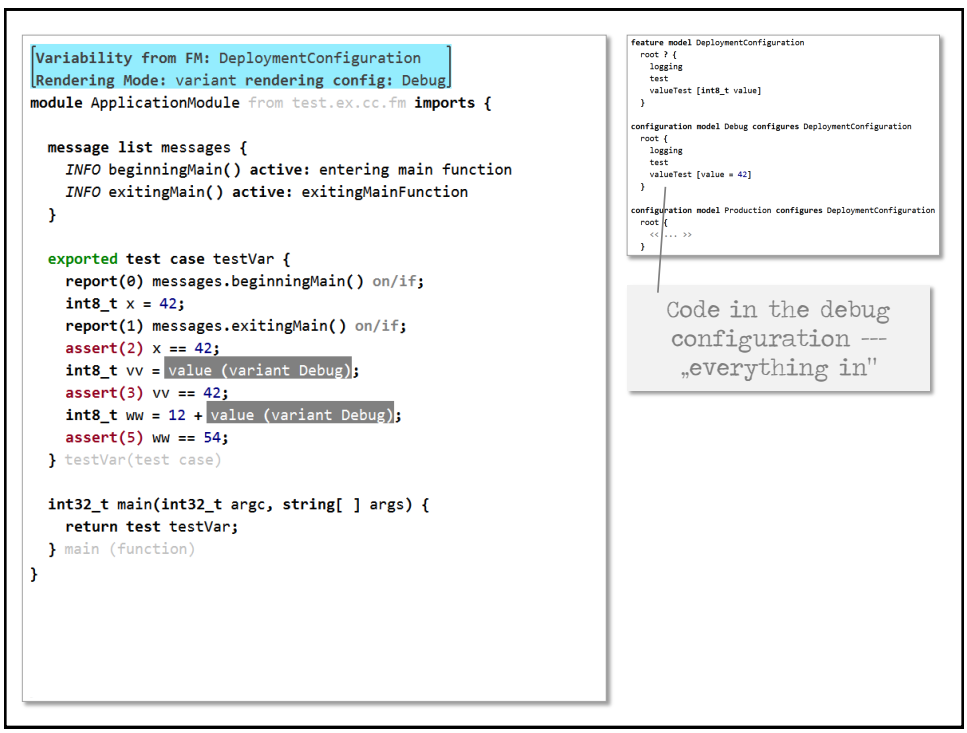

requirements HighLevelRequirements
show traces true
functional Main: Program has to run from the command line ...
functional Arg2: Argument Count must be 2 ...
functional FailOtherwise: Otherwise it should return -1 .
functional Add: The program should return the sum of the two
functional AddFct: Adding should be a separate function for
requirements modules: HighLevelRequirements
module ExampleCode from test.ts.requirements.code imports StrUtil {
int8_t add(int8_t a, int8_t b) {
return a + b;
} add (function)
trace AddFct
int8_t main(string[ ] args, int8_t argc) {
if (argc == 2) {
return add(str2int(args[0]), str2int(args[1]))
} else {
return -1;
trace FailOtherwise
} if
} main (function)
}
Simple way to specify requirements (kind, ID, description)
Alternatively import them from external tool
Requirements traces can be attached to any program element expressed in any language --- no changes to host language necessary
Requirements kind and trace kind can be extended.


requirements HighLevelRequirements
show traces false
functional Main: Program has to run from the command line ...
functional Arg2: Argument Count must be 2 ...
functional FailOtherwise: Otherwise it should return -1 ...
functional Add: The program should return the sum of the two arguments ...
functional AddFct: Adding should be a separate function for reuse ...
requirements modules: HighLevelRequirements
module ExampleCode from test.ts.requirements.code imports StrUtil {
int8_t add(int8_t a, int8_t b) {
return a + b;
} add (function)
int8_t main(string[ ] args, int8_t argc) {
if (argc == 2) {
return add(str2int(args[0]), str2int(args[1]));
} else {
return -1;
} if
} main (function)
}
And code can also be edited without the traces, if developers prefer that.

Product Line Variability




Variability from FM: DeploymentConfiguration
Rendering Mode: product line
module ApplicationModule from test.ex.cc.fm imports SensorModule {
message list messages {
INFO beginningMain() active: entering main function
INFO exitingMain() active: exitingMainFunction
}
exported test case testVar {
report(0) messages.beginningMain() on/if;
int8_t x = getSensorValue(1) replace if {test} with 42;
report(1) messages.exitingMain() on/if;
assert(2) x == 10 replace if {test} with 42;
int8_t vv = value;
assert(3) vv == 42;
int8_t ww = 22 replace if {valueTest} with 12 + value;
assert(4) ww == 22;
assert(5) ww == 54;
} testVar(test case)
int32_t main(int32_t argc, string[ ] args) {
return test testVar;
} main (function)
}
feature model DeploymentConfiguration
root ? {
logging
test
valueTest [int8_t value]
}
configuration model Debug configures DeploymentConfiguration
root {
logging
test
valueTest [value = 42]
}
configuration model Production configures DeploymentConfiguration
root {
<< ... >>
}
Code contains annotations with boolean expressions over the features in Feature Model
Color depends on expression --- same expression, same color
This page shows the product line mode --- all options in code


Variability from FM: DeploymentConfiguration
Rendering Mode: variant rendering config: Debug
module ApplicationModule from test.ex.cc.fm imports {
message list messages {
INFO beginningMain() active: entering main function
INFO exitingMain() active: exitingMainFunction
}
exported test case testVar {
report(0) messages.beginningMain() on/if;
int8_t x = 42;
report(1) messages.exitingMain() on/if;
assert(2) x == 42;
int8_t vv = value (variant Debug);
assert(3) vv == 42;
int8_t ww = 12 + value (variant Debug);
assert(5) ww == 54;
} testVar(test case)
int32_t main(int32_t argc, string[ ] args) {
return test testVar;
} main (function)
}
feature model DeploymentConfiguration
root ? {
logging
test
valueTest [int8_t value]
}
configuration model Debug configures DeploymentConfiguration
root {
logging
test
valueTest [value = 42]
}
configuration model Production configures DeploymentConfiguration
root {
<< ... >>
}
Code in the debug configuration --- „everything in"

```
Variability from FM: DeploymentConfiguration
Rendering Mode: variant rendering config: Production
module ApplicationModule from test.ex.cc.fm imports SensorModule {


  exported test case testVar {
    int8_t x = getSensorValue(1);
    assert(2) x == 10;
    int8_t ww = 22;
    assert(4) ww == 22;
  } testVar(test case)

  int32_t main(int32_t argc, string[ ] args) {
    return test testVar;
  } main (function)
}
```

```
feature model DeploymentConfiguration
  root ? {
    logging
    test
    valueTest [int8_t value]
  }

configuration model Debug configures DeploymentConfiguration
  root {
    logging
    test
    valueTest [value = 42]
  }

configuration model Production configures DeploymentConfiguration
  root {
    << ... >>
  }
```

Code in the production configuration --- „everything out"

Status and Availability

http://mbeddr.com

- Introduction, Blog, Papers, Code

Developed in the

- Project runs till June 2013
- itemis, fortiss, SICK, Lear

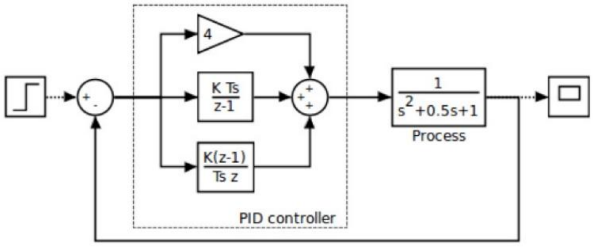
gefördert durch das BMBF
Förderkennzeichen 01IS11014

Core is Open Source (EPL)

- Eclipse Public License
- Essentually no restrictions regarding commercial use

All other Extensions will be Open Sourced this year

- We have to finish/stabilize them before we make them available

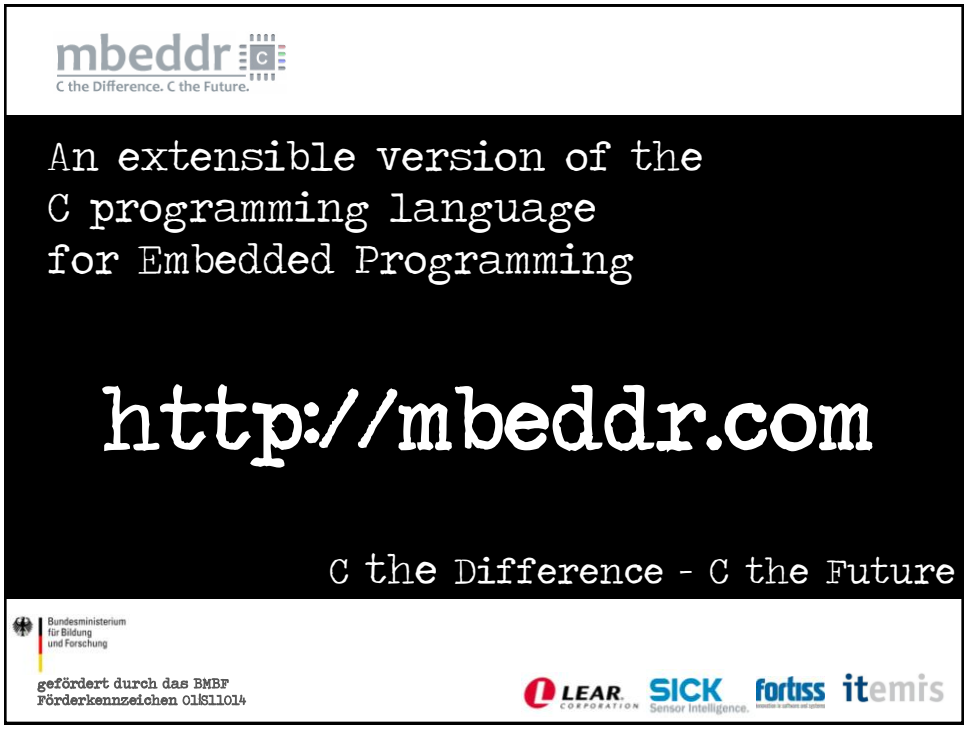


support for graphical early 2013

- state machines and block diagrams
- integrated with text

integration in early 2013

- native integration with Eclipse UI
- EMF export already possible today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