2015-2016

POLYTECH PARIS-SUD

Cycle Ingénieur – 2ème année

Département Informatique

Verification and Validation

Part IV : Test Intro

Burkhart Wolff
Département Informatique
Université Paris-Sud / Orsay

2015-2016

POLYTECH PARIS-SUD

Cycle Ingénieur – 2ème année

Département Informatique

Verification and Validation

Part IV : Test Intro

Burkhart Wolff
Département Informatique
Université Paris-Sud / Orsay

2015-2016

POLYTECH PARIS-SUD

Cycle Ingénieur – 2ème année

Département Informatique

Verification and Validation

Part IV : Test Intro

Burkhart Wolff
Département Informatique
Université Paris-Sud / Orsay

2015-2016

POLYTECH PARIS-SUD

Cycle Ingénieur – 2ème année

Département Informatique

Verification and Validation

Part IV : Test Intro

Burkhart Wolff
Département Informatique
Université Paris-Sud / Orsay

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

16/02/18 B. Wolff - Ingé. 2 - Test 2

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

16/02/18 B. Wolff - Ingé. 2 - Test 2

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

16/02/18 B. Wolff - Ingé. 2 - Test 2

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Do we build the right system ?

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Do we build the right system ?

16/02/18 B. Wolff - Ingé. 2 - Test 3

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Do we build the right system ?

16/02/18 B. Wolff - Ingé. 2 - Test 3

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Do we build the right system ?

16/02/18 B. Wolff - Ingé. 2 - Test 3

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Do we build the right system ?

- Verification: Does the system meet the specification ?

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Do we build the right system ?

- Verification: Does the system meet the specification ?

16/02/18 B. Wolff - Ingé. 2 - Test 4

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Do we build the right system ?

- Verification: Does the system meet the specification ?

16/02/18 B. Wolff - Ingé. 2 - Test 4

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Do we build the right system ?

- Verification: Does the system meet the specification ?

16/02/18 B. Wolff - Ingé. 2 - Test 4

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Do we build the right system ?

- Verification: Does the system meet the specification ?

Do we build the system right ?
Is it « correct » ?

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Do we build the right system ?

- Verification: Does the system meet the specification ?

Do we build the system right ?
Is it « correct » ?

16/02/18 B. Wolff - Ingé. 2 - Test 5

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Do we build the right system ?

- Verification: Does the system meet the specification ?

Do we build the system right ?
Is it « correct » ?

16/02/18 B. Wolff - Ingé. 2 - Test 5

Difference between Validation and Verification

- Validation :
  - Does the system meet the clients requirements ?
  - Will the performance be sufficient ?
  - Will the usability be sufficient ?

Do we build the right system ?

- Verification: Does the system meet the specification ?

Do we build the system right ?
Is it « correct » ?

16/02/18 B. Wolff - Ingé. 2 - Test 5

How to do Validation ?

- Tests and Experiments ...

How to do Validation ?

- Tests and Experiments ...

16/02/18 B. Wolff - Ingé. 2 - Test 6

How to do Validation ?

- Tests and Experiments ...

16/02/18 B. Wolff - Ingé. 2 - Test 6

How to do Validation ?

- Tests and Experiments ...

16/02/18 B. Wolff - Ingé. 2 - Test 6

How to do Verification ?

- Test and Proof on the basis of formal specifications (e.g., à la OCL, MOAL, ACSL, ... !) against programs or systems ...

How to do Verification ?

- Test and Proof on the basis of formal specifications (e.g., à la OCL, MOAL, ACSL, ... !) against programs or systems ...

16/02/18 B. Wolff - Ingé. 2 - Test 7

How to do Verification ?

- Test and Proof on the basis of formal specifications (e.g., à la OCL, MOAL, ACSL, ... !) against programs or systems ...

16/02/18 B. Wolff - Ingé. 2 - Test 7

How to do Verification ?

- Test and Proof on the basis of formal specifications (e.g., à la OCL, MOAL, ACSL, ... !) against programs or systems ...

16/02/18 B. Wolff - Ingé. 2 - Test 7

Test in the SE Process

- General questions for verification in a process:
  - How to select test-data ? To which purpose ?
  - How to focus verification activities?
    Where to verify formally, and
    where to test, and when did we test enough?

    Note: The quality of a test does not increase necessarily by the number of test-cases !
  - Automation ? Tools ?

Test in the SE Process

- General questions for verification in a process:
  - How to select test-data ? To which purpose ?
  - How to focus verification activities?
    Where to verify formally, and
    where to test, and when did we test enough?

    Note: The quality of a test does not increase necessarily by the number of test-cases !
  - Automation ? Tools ?

16/02/18 B. Wolff - Ingé. 2 - Test 8

Test in the SE Process

- General questions for verification in a process:
  - How to select test-data ? To which purpose ?
  - How to focus verification activities?
    Where to verify formally, and
    where to test, and when did we test enough?

    Note: The quality of a test does not increase necessarily by the number of test-cases !
  - Automation ? Tools ?

16/02/18 B. Wolff - Ingé. 2 - Test 8

Test in the SE Process

- General questions for verification in a process:
  - How to select test-data ? To which purpose ?
  - How to focus verification activities?
    Where to verify formally, and
    where to test, and when did we test enough?

    Note: The quality of a test does not increase necessarily by the number of test-cases !
  - Automation ? Tools ?

16/02/18 B. Wolff - Ingé. 2 - Test 8

Verification Costs

- costs ? *35 - 50 % of the global effort ?*
- all "real" (large) software has remaining bugs …
- The cost of bug ?
  - the cost to reveal and fix it …
    or:
    the cost of a legal battle it may cause...
    or the potential damage to the image
    (difficult to evaluate, but veeeery real)
    or costs as a result to come later on the market
  - *on the other side – you can't test infinitely, and verification is again 10 times more costly than thoroughly testing !*

Verification Costs

- costs ? *35 - 50 % of the global effort ?*
- all "real" (large) software has remaining bugs …
- The cost of bug ?
  - the cost to reveal and fix it …
    or:
    the cost of a legal battle it may cause...
    or the potential damage to the image
    (difficult to evaluate, but veeeery real)
    or costs as a result to come later on the market
  - *on the other side – you can't test infinitely, and verification is again 10 times more costly than thoroughly testing !*

16/02/18 B. Wolff - Ingé. 2 - Test 9

Verification Costs

- costs ? *35 - 50 % of the global effort ?*
- all "real" (large) software has remaining bugs …
- The cost of bug ?
  - the cost to reveal and fix it …
    or:
    the cost of a legal battle it may cause...
    or the potential damage to the image
    (difficult to evaluate, but veeeery real)
    or costs as a result to come later on the market
  - *on the other side – you can't test infinitely, and verification is again 10 times more costly than thoroughly testing !*

16/02/18 B. Wolff - Ingé. 2 - Test 9

Verification Costs

- costs ? *35 - 50 % of the global effort ?*
- all "real" (large) software has remaining bugs …
- The cost of bug ?
  - the cost to reveal and fix it …
    or:
    the cost of a legal battle it may cause...
    or the potential damage to the image
    (difficult to evaluate, but veeeery real)
    or costs as a result to come later on the market
  - *on the other side – you can't test infinitely, and verification is again 10 times more costly than thoroughly testing !*

16/02/18 B. Wolff - Ingé. 2 - Test 9

Verification Costs

- Conclusion:
  - verification is vitally important,
    and also critical in the development
  - to do it cost-effectively, it requires
    - a lot of expertise on products and process
    - a lot of knowledge over methods,
      tools, and tool chains ...

Verification Costs

- Conclusion:
  - verification is vitally important,
    and also critical in the development
  - to do it cost-effectively, it requires
    - a lot of expertise on products and process
    - a lot of knowledge over methods,
      tools, and tool chains ...

16/02/18 B. Wolff - Ingé. 2 - Test 10

Verification Costs

- Conclusion:
  - verification is vitally important,
    and also critical in the development
  - to do it cost-effectively, it requires
    - a lot of expertise on products and process
    - a lot of knowledge over methods,
      tools, and tool chains ...

16/02/18 B. Wolff - Ingé. 2 - Test 10

Verification Costs

- Conclusion:
  - verification is vitally important,
    and also critical in the development
  - to do it cost-effectively, it requires
    - a lot of expertise on products and process
    - a lot of knowledge over methods,
      tools, and tool chains ...

16/02/18 B. Wolff - Ingé. 2 - Test 10

Overview on the part on « Test »

- WHAT IS TESTING ?
- A taxonomy on types of tests
  - Static Test / Dynamic (*Runtime*) Test
  - Structural Test / Functional Test
  - Statistic Tests
- Functional Test; Link to UML/OCL
  - Dynamic Unit Tests, Static Unit Tests,
  - Coverage Criteria
- Structural Tests
  - Control Flow and Data Flow Graphs
  - Tests and executed paths. Undecidability.
  - Coverage Criteria

Overview on the part on « Test »

- WHAT IS TESTING ?
- A taxonomy on types of tests
  - Static Test / Dynamic (*Runtime*) Test
  - Structural Test / Functional Test
  - Statistic Tests
- Functional Test; Link to UML/OCL
  - Dynamic Unit Tests, Static Unit Tests,
  - Coverage Criteria
- Structural Tests
  - Control Flow and Data Flow Graphs
  - Tests and executed paths. Undecidability.
  - Coverage Criteria

16/02/18 B. Wolff - Ingé. 2 - Test 11

Overview on the part on « Test »

- WHAT IS TESTING ?
- A taxonomy on types of tests
  - Static Test / Dynamic (*Runtime*) Test
  - Structural Test / Functional Test
  - Statistic Tests
- Functional Test; Link to UML/OCL
  - Dynamic Unit Tests, Static Unit Tests,
  - Coverage Criteria
- Structural Tests
  - Control Flow and Data Flow Graphs
  - Tests and executed paths. Undecidability.
  - Coverage Criteria

16/02/18 B. Wolff - Ingé. 2 - Test 11

Overview on the part on « Test »

- WHAT IS TESTING ?
- A taxonomy on types of tests
  - Static Test / Dynamic (*Runtime*) Test
  - Structural Test / Functional Test
  - Statistic Tests
- Functional Test; Link to UML/OCL
  - Dynamic Unit Tests, Static Unit Tests,
  - Coverage Criteria
- Structural Tests
  - Control Flow and Data Flow Graphs
  - Tests and executed paths. Undecidability.
  - Coverage Criteria

16/02/18 B. Wolff - Ingé. 2 - Test 11

What is testing ?

- It is an approximation to verification
- Main emphasis: finding bugs early,
  - either in the model
  - or in the program
  - or in both
- A systematic test is:
  - process programs and specifications and to compute a set of test-cases under controlled conditions.
  - *ideally*: testing is complete if a certain criteria, the adequacy criteria is reached.

What is testing ?

- It is an approximation to verification
- Main emphasis: finding bugs early,
  - either in the model
  - or in the program
  - or in both
- A systematic test is:
  - process programs and specifications and to compute a set of test-cases under controlled conditions.
  - *ideally*: testing is complete if a certain criteria, the adequacy criteria is reached.

16/02/18 B. Wolff - Ingé. 2 - Test 12

What is testing ?

- It is an approximation to verification
- Main emphasis: finding bugs early,
  - either in the model
  - or in the program
  - or in both
- A systematic test is:
  - process programs and specifications and to compute a set of test-cases under controlled conditions.
  - *ideally*: testing is complete if a certain criteria, the adequacy criteria is reached.

16/02/18 B. Wolff - Ingé. 2 - Test 12

What is testing ?

- It is an approximation to verification
- Main emphasis: finding bugs early,
  - either in the model
  - or in the program
  - or in both
- A systematic test is:
  - process programs and specifications and to compute a set of test-cases under controlled conditions.
  - *ideally*: testing is complete if a certain criteria, the adequacy criteria is reached.

16/02/18 B. Wolff - Ingé. 2 - Test 12

Limits of testing ?

- We said, test is an approximation to verification, usually easier (and less expensive)
- Note: Sometimes it is easier to verify than to test. In particular:
  - low-level OS implementations:
    memory allocation, garbage collection
    memory virtualization, ...
    crypt-algorithms, ...
  - non-deterministic programs with no control over the non-determinism.

Limits of testing ?

- We said, test is an approximation to verification, usually easier (and less expensive)
- Note: Sometimes it is easier to verify than to test. In particular:
  - low-level OS implementations:
    memory allocation, garbage collection
    memory virtualization, ...
    crypt-algorithms, ...
  - non-deterministic programs with no control over the non-determinism.

16/02/18 B. Wolff - Ingé. 2 - Test 13

Limits of testing ?

- We said, test is an approximation to verification, usually easier (and less expensive)
- Note: Sometimes it is easier to verify than to test. In particular:
  - low-level OS implementations:
    memory allocation, garbage collection
    memory virtualization, ...
    crypt-algorithms, ...
  - non-deterministic programs with no control over the non-determinism.

16/02/18 B. Wolff - Ingé. 2 - Test 13

Limits of testing ?

- We said, test is an approximation to verification, usually easier (and less expensive)
- Note: Sometimes it is easier to verify than to test. In particular:
  - low-level OS implementations:
    memory allocation, garbage collection
    memory virtualization, ...
    crypt-algorithms, ...
  - non-deterministic programs with no control over the non-determinism.

16/02/18 B. Wolff - Ingé. 2 - Test 13

Taxomomy: Static / Dynamic Tests

- **static**: running a program before deployment on data carefully constructed by the analyst (in a testing environ.)
  - analyse the result on the basis of all components
  - working on some classes of executions symbolically = representing infinitely many executions
- **dynamic**: running the programme (or component) after deployment, on "real data" as imposed by the application domain
  - experiment with the real behaviour
  - essentially used for post-hoc ananalysis and debugging

Taxomomy: Static / Dynamic Tests

- **static**: running a program before deployment on data carefully constructed by the analyst (in a testing environ.)
  - analyse the result on the basis of all components
  - working on some classes of executions symbolically = representing infinitely many executions
- **dynamic**: running the programme (or component) after deployment, on "real data" as imposed by the application domain
  - experiment with the real behaviour
  - essentially used for post-hoc ananalysis and debugging

16/02/18 B. Wolff - Ingé. 2 - Test 14

Taxomomy: Static / Dynamic Tests

- **static**: running a program before deployment on data carefully constructed by the analyst (in a testing environ.)
  - analyse the result on the basis of all components
  - working on some classes of executions symbolically = representing infinitely many executions
- **dynamic**: running the programme (or component) after deployment, on "real data" as imposed by the application domain
  - experiment with the real behaviour
  - essentially used for post-hoc ananalysis and debugging

16/02/18 B. Wolff - Ingé. 2 - Test 14

Taxomomy: Static / Dynamic Tests

- **static**: running a program before deployment on data carefully constructed by the analyst (in a testing environ.)
  - analyse the result on the basis of all components
  - working on some classes of executions symbolically = representing infinitely many executions
- **dynamic**: running the programme (or component) after deployment, on "real data" as imposed by the application domain
  - experiment with the real behaviour
  - essentially used for post-hoc ananalysis and debugging

16/02/18 B. Wolff - Ingé. 2 - Test 14

Taxonomy: Unit / Sequence / Reactive Tests

- **unit**: testing of a local component (function, module), typically only one step of the underlying state. (In functional programs, thats essentially all what you have to do!)
- **sequence**: testing of a local component (function, module), but typicallY sequences of executions, which typically depend on internal state
- **reactive sequence**: testing components by sequences of steps, but these sequences represent communication where later parts in the seqience depend on what has been earlier cummunicated

Taxonomy: Unit / Sequence / Reactive Tests

- **unit**: testing of a local component (function, module), typically only one step of the underlying state. (In functional programs, thats essentially all what you have to do!)
- **sequence**: testing of a local component (function, module), but typicallY sequences of executions, which typically depend on internal state
- **reactive sequence**: testing components by sequences of steps, but these sequences represent communication where later parts in the seqience depend on what has been earlier cummunicated

16/02/18 B. Wolff - Ingé. 2 - Test 15

Taxonomy: Unit / Sequence / Reactive Tests

- **unit**: testing of a local component (function, module), typically only one step of the underlying state. (In functional programs, thats essentially all what you have to do!)
- **sequence**: testing of a local component (function, module), but typicallY sequences of executions, which typically depend on internal state
- **reactive sequence**: testing components by sequences of steps, but these sequences represent communication where later parts in the seqience depend on what has been earlier cummunicated

16/02/18 B. Wolff - Ingé. 2 - Test 15

Taxonomy: Unit / Sequence / Reactive Tests

- **unit**: testing of a local component (function, module), typically only one step of the underlying state. (In functional programs, thats essentially all what you have to do!)
- **sequence**: testing of a local component (function, module), but typicallY sequences of executions, which typically depend on internal state
- **reactive sequence**: testing components by sequences of steps, but these sequences represent communication where later parts in the seqience depend on what has been earlier cummunicated

16/02/18 B. Wolff - Ingé. 2 - Test 15

Taxonomy: Functional / Structural Test

- **functional**: (also: black-box tests). Tests were generated on a specification of the component, the test focusses on input output behaviour.
- **structural**: (also: white-box tests). Tests were generated on the basis of the structure or the program, i.e. using control-flow, data-flow paths or by using symbolic executions.
- **both**: (also: grey-box testing).

Taxonomy: Functional / Structural Test

- **functional**: (also: black-box tests). Tests were generated on a specification of the component, the test focusses on input output behaviour.
- **structural**: (also: white-box tests). Tests were generated on the basis of the structure or the program, i.e. using control-flow, data-flow paths or by using symbolic executions.
- **both**: (also: grey-box testing).

16/02/18 B. Wolff - Ingé. 2 - Test 16

Taxonomy: Functional / Structural Test

- **functional**: (also: black-box tests). Tests were generated on a specification of the component, the test focusses on input output behaviour.
- **structural**: (also: white-box tests). Tests were generated on the basis of the structure or the program, i.e. using control-flow, data-flow paths or by using symbolic executions.
- **both**: (also: grey-box testing).

16/02/18 B. Wolff - Ingé. 2 - Test 16

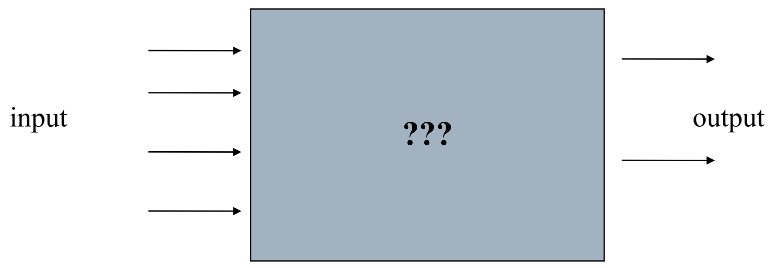
Taxonomy: Functional / Structural Test

- **functional**: (also: black-box tests). Tests were generated on a specification of the component, the test focusses on input output behaviour.
- **structural**: (also: white-box tests). Tests were generated on the basis of the structure or the program, i.e. using control-flow, data-flow paths or by using symbolic executions.
- **both**: (also: grey-box testing).

16/02/18 B. Wolff - Ingé. 2 - Test 16

Functional Dynamic Unit Test

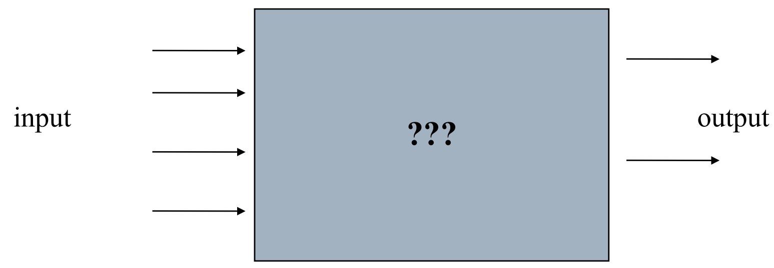
- We got the spec, but not the program, which is considered a black box:



we focus on what the program *should* do !!!

Functional Dynamic Unit Test

- We got the spec, but not the program, which is considered a black box:

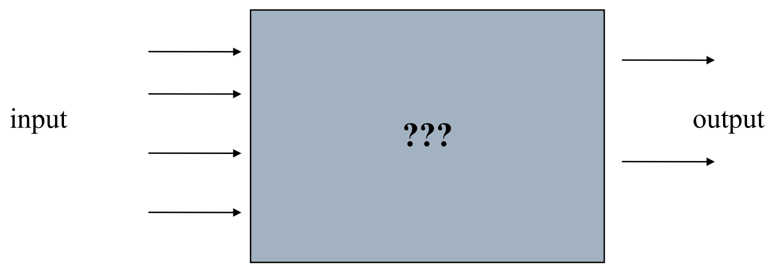


we focus on what the program *should* do !!!

16/02/18 B. Wolff - Ingé. 2 - Test 17

Functional Dynamic Unit Test

- We got the spec, but not the program, which is considered a black box:

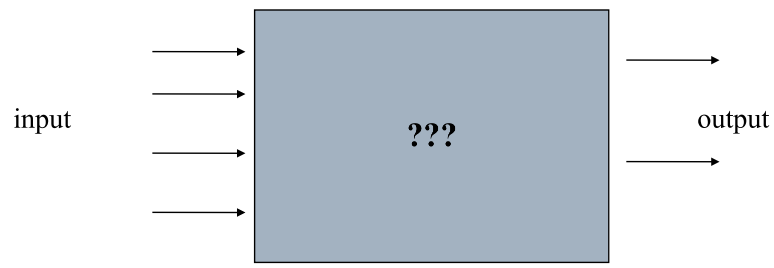


we focus on what the program *should* do !!!

16/02/18 B. Wolff - Ingé. 2 - Test 17

Functional Dynamic Unit Test

- We got the spec, but not the program, which is considered a black box:



we focus on what the program *should* do !!!

16/02/18 B. Wolff - Ingé. 2 - Test 17

Functional Dynamic Unit Test : an example

The (informal) specification:

Read a "Triangle Object" (with three sides of integral type), and test if it is isoscele, equilateral, or (default) arbitrary.

Each length should be strictly positive.

Give a specification, and develop a test set ...

Functional Dynamic Unit Test : an example

The (informal) specification:

Read a "Triangle Object" (with three sides of integral type), and test if it is isoscele, equilateral, or (default) arbitrary.

Each length should be strictly positive.

Give a specification, and develop a test set ...

16/02/18 B. Wolff - Ingé. 2 - Test 18

Functional Dynamic Unit Test : an example

The (informal) specification:

Read a "Triangle Object" (with three sides of integral type), and test if it is isoscele, equilateral, or (default) arbitrary.

Each length should be strictly positive.

Give a specification, and develop a test set ...

16/02/18 B. Wolff - Ingé. 2 - Test 18

Functional Dynamic Unit Test : an example

The (informal) specification:

Read a "Triangle Object" (with three sides of integral type), and test if it is isoscele, equilateral, or (default) arbitrary.

Each length should be strictly positive.

Give a specification, and develop a test set ...

16/02/18 B. Wolff - Ingé. 2 - Test 18

Functional Unit Test : An Example

The specification in UML/MOAL:

```
Triangles
a, b, c: Integer
- mk(Integer,Integer,Integer):Triangle
- is_Triangle(): {equ (*equilateral*),
                  iso (*isosceles*),
                  arb (*arbitrary*)}
```


Functional Unit Test : An Example

The specification in UML/MOAL:

Triangles
a, b, c: Integer
- mk(Integer,Integer,Integer):Triangle
- is_Triangle(): {equ (*equilateral*),
iso (*isosceles*),
arb (*arbitrary*)}

16/02/18 B. Wolff - Ingé. 2 - Test 19

Functional Unit Test : An Example

The specification in UML/MOAL:

Triangles
a, b, c: Integer
- mk(Integer,Integer,Integer):Triangle
- is_Triangle(): {equ (*equilateral*),
iso (*isosceles*),
arb (*arbitrary*)}

16/02/18 B. Wolff - Ingé. 2 - Test 19

Functional Unit Test : An Example

The specification in UML/MOAL:

Triangles
a, b, c: Integer
- mk(Integer,Integer,Integer):Triangle
- is_Triangle(): {equ (*equilateral*),
iso (*isosceles*),
arb (*arbitrary*)}

16/02/18 B. Wolff - Ingé. 2 - Test 19

Functional Unit Test : An Example

We add the constraints of the analysis:

```
inv   0<a ∧ 0<b ∧ 0<c
inv   c≤a+b ∧ a≤b+c ∧ b≤c+a
```

```
Triangles
a, b, c: Integer
- mk(Integer,Integer,Integer):Triangle
- is_Triangle(): {equ (*equilateral*),
                  iso (*isosceles*),
                  arb (*arbitrary*)}
```

```
operation t.is_Triangle():
  post  t.a=t.b ∧ t.b=t.c ⟶ result=equ
  post (t.a≠t.b ∨ t.b≠t.c) ∧
       (t.a=t.b ∨ t.b=t.c ∨ t.a=t.c))⟶ result=iso
  post (t.a≠t.b ∨ t.b≠t.c ∨ t.a≠t.c))⟶ result=arb
```


Functional Unit Test : An Example

We add the constraints of the analysis:

inv 0<a ∧ 0<b ∧ 0<c
inv c≤a+b ∧ a≤b+c ∧ b≤c+a

Triangles
a, b, c: Integer
- mk(Integer,Integer,Integer):Triangle
- is_Triangle(): {equ (*equilateral*), iso (*isosceles*), arb (*arbitrary*)}

operation t.is_Triangle():
post t.a=t.b ∧ t.b=t.c ⟶ result=equ
post (t.a≠t.b ∨ t.b≠t.c) ∧ (t.a=t.b ∨ t.b=t.c ∨ t.a=t.c))⟶ result=iso
post (t.a≠t.b ∨ t.b≠t.c ∨ t.a≠t.c))⟶ result=arb

16/02/18 B. Wolff - Ingé. 2 - Test 20

Functional Unit Test : An Example

We add the constraints of the analysis:

inv 0<a ∧ 0<b ∧ 0<c
inv c≤a+b ∧ a≤b+c ∧ b≤c+a

Triangles
a, b, c: Integer
- mk(Integer,Integer,Integer):Triangle
- is_Triangle(): {equ (*equilateral*), iso (*isosceles*), arb (*arbitrary*)}

operation t.is_Triangle():
post t.a=t.b ∧ t.b=t.c ⟶ result=equ
post (t.a≠t.b ∨ t.b≠t.c) ∧ (t.a=t.b ∨ t.b=t.c ∨ t.a=t.c))⟶ result=iso
post (t.a≠t.b ∨ t.b≠t.c ∨ t.a≠t.c))⟶ result=arb

16/02/18 B. Wolff - Ingé. 2 - Test 20

Functional Unit Test : An Example

We add the constraints of the analysis:

inv 0<a ∧ 0<b ∧ 0<c
inv c≤a+b ∧ a≤b+c ∧ b≤c+a

Triangles
a, b, c: Integer
- mk(Integer,Integer,Integer):Triangle
- is_Triangle(): {equ (*equilateral*), iso (*isosceles*), arb (*arbitrary*)}

operation t.is_Triangle():
post t.a=t.b ∧ t.b=t.c ⟶ result=equ
post (t.a≠t.b ∨ t.b≠t.c) ∧ (t.a=t.b ∨ t.b=t.c ∨ t.a=t.c))⟶ result=iso
post (t.a≠t.b ∨ t.b≠t.c ∨ t.a≠t.c))⟶ result=arb

16/02/18 B. Wolff - Ingé. 2 - Test 20

Intuitive Test-Data Generation

- Consider the test specification (the "Test Case"):

  mk(x,y,z).isTriangle() ≡ X

  i.e. for which input (x,y,z) should an implementation of our contract yield which X ?

  Note that we define mk(0,0,0) to invalid, as well as all other invalid triangles …

Intuitive Test-Data Generation

- Consider the test specification (the "Test Case"):

  mk(x,y,z).isTriangle() ≡ X

  i.e. for which input (x,y,z) should an implementation of our contract yield which X ?

  Note that we define mk(0,0,0) to invalid, as well as all other invalid triangles …

16/02/18 B. Wolff - Ingé. 2 - Test 21

Intuitive Test-Data Generation

- Consider the test specification (the "Test Case"):

  mk(x,y,z).isTriangle() ≡ X

  i.e. for which input (x,y,z) should an implementation of our contract yield which X ?

  Note that we define mk(0,0,0) to invalid, as well as all other invalid triangles …

16/02/18 B. Wolff - Ingé. 2 - Test 21

Intuitive Test-Data Generation

- Consider the test specification (the "Test Case"):

  mk(x,y,z).isTriangle() ≡ X

  i.e. for which input (x,y,z) should an implementation of our contract yield which X ?

  Note that we define mk(0,0,0) to invalid, as well as all other invalid triangles …

16/02/18 B. Wolff - Ingé. 2 - Test 21

Intuitive Test-Data Generation

- an arbitrary valid triangle: (3, 4, 5)
- an equilateral triangle: (5, 5, 5)
- an isoscele triangle and its permutations :
  (6, 6, 7), (7, 6, 6), (6, 7, 6)
- impossible triangles and their permutations :
  (1, 2, 4), (4, 1, 2), (2, 4, 1)   -- x + y > z
  (1, 2, 3), (2, 4, 2), (5, 3, 2)   -- x + y = z (necessary?)
- a zero length : (0, 5, 4), (4, 0, 5),
- . . .
- Would we have to consider negative values?

Intuitive Test-Data Generation

- an arbitrary valid triangle: (3, 4, 5)
- an equilateral triangle: (5, 5, 5)
- an isoscele triangle and its permutations :
  (6, 6, 7), (7, 6, 6), (6, 7, 6)
- impossible triangles and their permutations :
  (1, 2, 4), (4, 1, 2), (2, 4, 1)   -- x + y > z
  (1, 2, 3), (2, 4, 2), (5, 3, 2)   -- x + y = z (necessary?)
- a zero length : (0, 5, 4), (4, 0, 5),
- . . .
- Would we have to consider negative values?

16/02/18 B. Wolff - Ingé. 2 - Test 22

Intuitive Test-Data Generation

- an arbitrary valid triangle: (3, 4, 5)
- an equilateral triangle: (5, 5, 5)
- an isoscele triangle and its permutations :
  (6, 6, 7), (7, 6, 6), (6, 7, 6)
- impossible triangles and their permutations :
  (1, 2, 4), (4, 1, 2), (2, 4, 1)   -- x + y > z
  (1, 2, 3), (2, 4, 2), (5, 3, 2)   -- x + y = z (necessary?)
- a zero length : (0, 5, 4), (4, 0, 5),
- . . .
- Would we have to consider negative values?

16/02/18 B. Wolff - Ingé. 2 - Test 22

Intuitive Test-Data Generation

- an arbitrary valid triangle: (3, 4, 5)
- an equilateral triangle: (5, 5, 5)
- an isoscele triangle and its permutations :
  (6, 6, 7), (7, 6, 6), (6, 7, 6)
- impossible triangles and their permutations :
  (1, 2, 4), (4, 1, 2), (2, 4, 1)   -- x + y > z
  (1, 2, 3), (2, 4, 2), (5, 3, 2)   -- x + y = z (necessary?)
- a zero length : (0, 5, 4), (4, 0, 5),
- . . .
- Would we have to consider negative values?

16/02/18 B. Wolff - Ingé. 2 - Test 22

Intuitive Test-Data Generation

- Ouf, is there a systematic and automatic way to compute all these tests ?
- Can we avoid hand-written test-scripts ? Avoid the task to maintain them ?
- And the question remains:

When did we test „enough“ ?

Intuitive Test-Data Generation

- Ouf, is there a systematic and automatic way to compute all these tests ?
- Can we avoid hand-written test-scripts ? Avoid the task to maintain them ?
- And the question remains:

When did we test „enough“ ?

16/02/18 B. Wolff - Ingé. 2 - Test 23

Intuitive Test-Data Generation

- Ouf, is there a systematic and automatic way to compute all these tests ?
- Can we avoid hand-written test-scripts ? Avoid the task to maintain them ?
- And the question remains:

When did we test „enough“ ?

16/02/18 B. Wolff - Ingé. 2 - Test 23

Intuitive Test-Data Generation

- Ouf, is there a systematic and automatic way to compute all these tests ?
- Can we avoid hand-written test-scripts ? Avoid the task to maintain them ?
- And the question remains:

When did we test „enough“ ?

16/02/18 B. Wolff - Ingé. 2 - Test 23

Functional Dynamic Unit Test : an example

How to perform Runtime-Test?

Moreover, compile:

context C::m(a_1:C_1,...,a_n:C_n)
pre : P(self,a_1,...,a_n)
post : Q(self,a_1,...,a_n,result)

to some checking code (with assert as in Junit, VCC, Boogie, ...)

check_C(); check_C_1(); ... ; check_C_n();
assert(P(self,a_1,...,a_n));
result=run_m(self,a_1,...,a_n);
assert(Q(self,a_1,...,a_n,result));

Functional Dynamic Unit Test : an example

How to perform Runtime-Test?

Moreover, compile:

context C::m(a_1:C_1,...,a_n:C_n)
pre : P(self,a_1,...,a_n)
post : Q(self,a_1,...,a_n,result)

to some checking code (with assert as in Junit, VCC, Boogie, ...)

check_C(); check_C_1(); ... ; check_C_n();
assert(P(self,a_1,...,a_n));
result=run_m(self,a_1,...,a_n);
assert(Q(self,a_1,...,a_n,result));

16/02/18 B. Wolff - Ingé. 2 - Test 24

Functional Dynamic Unit Test : an example

How to perform Runtime-Test?

Moreover, compile:

context C::m(a_1:C_1,...,a_n:C_n)
pre : P(self,a_1,...,a_n)
post : Q(self,a_1,...,a_n,result)

to some checking code (with assert as in Junit, VCC, Boogie, ...)

check_C(); check_C_1(); ... ; check_C_n();
assert(P(self,a_1,...,a_n));
result=run_m(self,a_1,...,a_n);
assert(Q(self,a_1,...,a_n,result));

16/02/18 B. Wolff - Ingé. 2 - Test 24

Functional Dynamic Unit Test : an example

How to perform Runtime-Test?

Moreover, compile:

context C::m(a_1:C_1,...,a_n:C_n)
pre : P(self,a_1,...,a_n)
post : Q(self,a_1,...,a_n,result)

to some checking code (with assert as in Junit, VCC, Boogie, ...)

check_C(); check_C_1(); ... ; check_C_n();
assert(P(self,a_1,...,a_n));
result=run_m(self,a_1,...,a_n);
assert(Q(self,a_1,...,a_n,result));

16/02/18 B. Wolff - Ingé. 2 - Test 24

Intuitive Test-Data Generation

- Consider the test specification (the "Test Case"):

  mk(x,y,z).isTriangle() ≡ X

  i.e. for which input (x,y,z) should an implementation of our contract yield which X ?

  Note that we define mk(0,0,0) to invalid, as well as all other invalid triangles …

Intuitive Test-Data Generation

- Consider the test specification (the "Test Case"):

  mk(x,y,z).isTriangle() ≡ X

  i.e. for which input (x,y,z) should an implementation of our contract yield which X ?

  Note that we define mk(0,0,0) to invalid, as well as all other invalid triangles …

16/02/18 B. Wolff - Ingé. 2 - Test 25

Intuitive Test-Data Generation

- Consider the test specification (the "Test Case"):

  mk(x,y,z).isTriangle() ≡ X

  i.e. for which input (x,y,z) should an implementation of our contract yield which X ?

  Note that we define mk(0,0,0) to invalid, as well as all other invalid triangles …

16/02/18 B. Wolff - Ingé. 2 - Test 25

Intuitive Test-Data Generation

- Consider the test specification (the "Test Case"):

  mk(x,y,z).isTriangle() ≡ X

  i.e. for which input (x,y,z) should an implementation of our contract yield which X ?

  Note that we define mk(0,0,0) to invalid, as well as all other invalid triangles …

16/02/18 B. Wolff - Ingé. 2 - Test 25

Functional Dynamic Unit Test : Problems

- Thus, any violation of an invariant, a pre-condition or a post-condition is detected.
- If a violation occurs within an execution of a method, the error is precisely reported.
- On the other hand – runtime checking is post-hoc. Only when a problem occured, we know where. And we need the complete program.
- Inefficiencies can be partly overcome by optimized compilations.

Functional Dynamic Unit Test : Problems

- Thus, any violation of an invariant, a pre-condition or a post-condition is detected.
- If a violation occurs within an execution of a method, the error is precisely reported.
- On the other hand – runtime checking is post-hoc. Only when a problem occured, we know where. And we need the complete program.
- Inefficiencies can be partly overcome by optimized compilations.

16/02/18 B. Wolff - Ingé. 2 - Test 26

Functional Dynamic Unit Test : Problems

- Thus, any violation of an invariant, a pre-condition or a post-condition is detected.
- If a violation occurs within an execution of a method, the error is precisely reported.
- On the other hand – runtime checking is post-hoc. Only when a problem occured, we know where. And we need the complete program.
- Inefficiencies can be partly overcome by optimized compilations.

16/02/18 B. Wolff - Ingé. 2 - Test 26

Functional Dynamic Unit Test : Problems

- Thus, any violation of an invariant, a pre-condition or a post-condition is detected.
- If a violation occurs within an execution of a method, the error is precisely reported.
- On the other hand – runtime checking is post-hoc. Only when a problem occured, we know where. And we need the complete program.
- Inefficiencies can be partly overcome by optimized compilations.

16/02/18 B. Wolff - Ingé. 2 - Test 26

Functional Unit Test : An Example

We add the constraints of the analysis:

```
inv   0<a  ∧  0<b  ∧  0<c
inv   c≤a+b  ∧  a≤b+c  ∧  b≤c+a
```

```
Triangles
a, b, c: Integer
- mk(Integer,Integer,Integer):Triangle
- is_Triangle(): {equ (*equilateral*),
                  iso (*isosceles*),
                  arb (*arbitrary*)}
```

```
operation t.is_Triangle():
  post  t.a=t.b  ∧  t.b=t.c  ⟶  result=equ
  post (t.a≠t.b  ∨  t.b≠t.c)  ∧
       (t.a=t.b  ∨  t.b=t.c  ∨  t.a=t.c))⟶ result=iso
  post (t.a≠t.b  ∨  t.b≠t.c  ∨  t.a≠t.c))⟶ result=arb
  post modifiesOnly({})
```


Functional Unit Test : An Example

We add the constraints of the analysis:

```
inv   0<a  ∧  0<b  ∧  0<c
inv   c≤a+b  ∧  a≤b+c  ∧  b≤c+a
```

```
Triangles
a, b, c: Integer
- mk(Integer,Integer,Integer):Triangle
- is_Triangle(): {equ (*equilateral*),
                  iso (*isosceles*),
                  arb (*arbitrary*)}
```

```
operation t.is_Triangle():
  post  t.a=t.b  ∧  t.b=t.c  ⟶  result=equ
  post (t.a≠t.b  ∨  t.b≠t.c)  ∧
       (t.a=t.b  ∨  t.b=t.c  ∨  t.a=t.c))⟶ result=iso
  post (t.a≠t.b  ∨  t.b≠t.c  ∨  t.a≠t.c))⟶ result=arb
  post modifiesOnly({})
```

16/02/18 B. Wolff - Ingé. 2 - Test 27

Functional Unit Test : An Example

We add the constraints of the analysis:

```
inv   0<a  ∧  0<b  ∧  0<c
inv   c≤a+b  ∧  a≤b+c  ∧  b≤c+a
```

```
Triangles
a, b, c: Integer
- mk(Integer,Integer,Integer):Triangle
- is_Triangle(): {equ (*equilateral*),
                  iso (*isosceles*),
                  arb (*arbitrary*)}
```

```
operation t.is_Triangle():
  post  t.a=t.b  ∧  t.b=t.c  ⟶  result=equ
  post (t.a≠t.b  ∨  t.b≠t.c)  ∧
       (t.a=t.b  ∨  t.b=t.c  ∨  t.a=t.c))⟶ result=iso
  post (t.a≠t.b  ∨  t.b≠t.c  ∨  t.a≠t.c))⟶ result=arb
  post modifiesOnly({})
```

16/02/18 B. Wolff - Ingé. 2 - Test 27

Functional Unit Test : An Example

We add the constraints of the analysis:

```
inv   0<a  ∧  0<b  ∧  0<c
inv   c≤a+b  ∧  a≤b+c  ∧  b≤c+a
```

```
Triangles
a, b, c: Integer
- mk(Integer,Integer,Integer):Triangle
- is_Triangle(): {equ (*equilateral*),
                  iso (*isosceles*),
                  arb (*arbitrary*)}
```

```
operation t.is_Triangle():
  post  t.a=t.b  ∧  t.b=t.c  ⟶  result=equ
  post (t.a≠t.b  ∨  t.b≠t.c)  ∧
       (t.a=t.b  ∨  t.b=t.c  ∨  t.a=t.c))⟶ result=iso
  post (t.a≠t.b  ∨  t.b≠t.c  ∨  t.a≠t.c))⟶ result=arb
  post modifiesOnly({})
```

16/02/18 B. Wolff - Ingé. 2 - Test 27

Functional Dynamic Unit Test : Problems

- Thus, any violation of an invariant, a pre-condition or a post-condition is detected.
- If a violation occurs within an execution of a method, the error is precisely reported.
- On the other hand – runtime checking is post-hoc. Only when a problem occured, we know where. And we need the complete program.
- Inefficiencies can be partly overcome by optimized compilations.

Functional Dynamic Unit Test : Problems

- Thus, any violation of an invariant, a pre-condition or a post-condition is detected.
- If a violation occurs within an execution of a method, the error is precisely reported.
- On the other hand – runtime checking is post-hoc. Only when a problem occured, we know where. And we need the complete program.
- Inefficiencies can be partly overcome by optimized compilations.

16/02/18 B. Wolff - Ingé. 2 - Test 28

Functional Dynamic Unit Test : Problems

- Thus, any violation of an invariant, a pre-condition or a post-condition is detected.
- If a violation occurs within an execution of a method, the error is precisely reported.
- On the other hand – runtime checking is post-hoc. Only when a problem occured, we know where. And we need the complete program.
- Inefficiencies can be partly overcome by optimized compilations.

16/02/18 B. Wolff - Ingé. 2 - Test 28

Functional Dynamic Unit Test : Problems

- Thus, any violation of an invariant, a pre-condition or a post-condition is detected.
- If a violation occurs within an execution of a method, the error is precisely reported.
- On the other hand – runtime checking is post-hoc. Only when a problem occured, we know where. And we need the complete program.
- Inefficiencies can be partly overcome by optimized compilations.

16/02/18 B. Wolff - Ingé. 2 - Test 28

Functional Dynamic Unit Test : an example

The specification in UML/OCL (Classes in USE Notation):

```
class Triangles inherits_from Shapes
  attributes
    a : Integer
    b : Integer
    c : Integer

  operations
    mk(Integer,Integer,Integer):Triangle
    is_Triangle(): triangle
  end
```


Functional Dynamic Unit Test : an example

The specification in UML/OCL (Classes in USE Notation):

```
class Triangles inherits_from Shapes
  attributes
    a : Integer
    b : Integer
    c : Integer

  operations
    mk(Integer,Integer,Integer):Triangle
    is_Triangle(): triangle
  end
```

16/02/18 B. Wolff - Ingé. 2 - Test 29

Functional Dynamic Unit Test : an example

The specification in UML/OCL (Classes in USE Notation):

```
class Triangles inherits_from Shapes
  attributes
    a : Integer
    b : Integer
    c : Integer

  operations
    mk(Integer,Integer,Integer):Triangle
    is_Triangle(): triangle
  end
```

16/02/18 B. Wolff - Ingé. 2 - Test 29

Functional Dynamic Unit Test : an example

The specification in UML/OCL (Classes in USE Notation):

```
class Triangles inherits_from Shapes
  attributes
    a : Integer
    b : Integer
    c : Integer

  operations
    mk(Integer,Integer,Integer):Triangle
    is_Triangle(): triangle
  end
```

16/02/18 B. Wolff - Ingé. 2 - Test 29

Functional Dynamic Unit Test : an example

How to perform Runtime-Test?

Well, compile for class invariants:

context X:
inv l_1 : C_1, ...,
inv l_n : C_n

to some checking code (with assert *as in Java/Junit, assert.h in C, ...)*

check_X() = assert(C_1); ... ; assert(C_n)

Functional Dynamic Unit Test : an example

How to perform Runtime-Test?

Well, compile for class invariants:

context X:
inv l_1 : C_1, ...,
inv l_n : C_n

to some checking code (with assert *as in Java/Junit, assert.h in C, ...)*

check_X() = assert(C_1); ... ; assert(C_n)

16/02/18 B. Wolff - Ingé. 2 - Test 30

Functional Dynamic Unit Test : an example

How to perform Runtime-Test?

Well, compile for class invariants:

context X:
inv l_1 : C_1, ...,
inv l_n : C_n

to some checking code (with assert *as in Java/Junit, assert.h in C, ...)*

check_X() = assert(C_1); ... ; assert(C_n)

16/02/18 B. Wolff - Ingé. 2 - Test 30

Functional Dynamic Unit Test : an example

How to perform Runtime-Test?

Well, compile for class invariants:

context X:
inv l_1 : C_1, ...,
inv l_n : C_n

to some checking code (with assert *as in Java/Junit, assert.h in C, ...)*

check_X() = assert(C_1); ... ; assert(C_n)

16/02/18 B. Wolff - Ingé. 2 - Test 30

Functional Dynamic Unit Test : an example

How to perform Runtime-Test?

Moreover, compile for contracts:

```
context C::m(a_1:C_1,...,a_n:C_n)
pre     : P(self,a_1,...,a_n)
post    : Q(self,a_1,...,a_n,result)
```

to some checking code (with assert *as in Java/Junit, assert.h in C, ...)*

```
check_C(); check_C_1(); ... ; check_C_n();
assert(P(self,a_1,...,a_n));
result=run_m(self,a_1,...,a_n);
assert(Q(self,a_1,...,a_n,result));
```


Functional Dynamic Unit Test : an example

How to perform Runtime-Test?

Moreover, compile for contracts:

context C::m(a_1:C_1,...,a_n:C_n)
pre   : P(self,a_1,...,a_n)
post   : Q(self,a_1,...,a_n,result)

to some checking code (with assert as in Java/Junit, assert.h in C, ...)

check_C(); check_C_1(); ... ; check_C_n();
assert(P(self,a_1,...,a_n));
result=run_m(self,a_1,...,a_n);
assert(Q(self,a_1,...,a_n,result));

16/02/18 B. Wolff - Ingé. 2 - Test 31

Functional Dynamic Unit Test : an example

How to perform Runtime-Test?

Moreover, compile for contracts:

context C::m(a_1:C_1,...,a_n:C_n)
pre   : P(self,a_1,...,a_n)
post   : Q(self,a_1,...,a_n,result)

to some checking code (with assert as in Java/Junit, assert.h in C, ...)

check_C(); check_C_1(); ... ; check_C_n();
assert(P(self,a_1,...,a_n));
result=run_m(self,a_1,...,a_n);
assert(Q(self,a_1,...,a_n,result));

16/02/18 B. Wolff - Ingé. 2 - Test 31

Functional Dynamic Unit Test : an example

How to perform Runtime-Test?

Moreover, compile for contracts:

context C::m(a_1:C_1,...,a_n:C_n)
pre   : P(self,a_1,...,a_n)
post   : Q(self,a_1,...,a_n,result)

to some checking code (with assert as in Java/Junit, assert.h in C, ...)

check_C(); check_C_1(); ... ; check_C_n();
assert(P(self,a_1,...,a_n));
result=run_m(self,a_1,...,a_n);
assert(Q(self,a_1,...,a_n,result));

16/02/18 B. Wolff - Ingé. 2 - Test 31

Functional Dynamic Unit Test : Problems

- Thus, any violation of an invariant, a pre-condition or a post-condition is detected.
- If a violation occurs within an execution of a method, the error is precisely reported.
- On the other hand – runtime checking is post-hoc. Only when a problem occured, we know where. And we need the complete program.
- Inefficiencies can be partly overcome by optimized compilations.

Functional Dynamic Unit Test : Problems

- Thus, any violation of an invariant, a pre-condition or a post-condition is detected.
- If a violation occurs within an execution of a method, the error is precisely reported.
- On the other hand – runtime checking is post-hoc. Only when a problem occured, we know where. And we need the complete program.
- Inefficiencies can be partly overcome by optimized compilations.

16/02/18 B. Wolff - Ingé. 2 - Test 32

Functional Dynamic Unit Test : Problems

- Thus, any violation of an invariant, a pre-condition or a post-condition is detected.
- If a violation occurs within an execution of a method, the error is precisely reported.
- On the other hand – runtime checking is post-hoc. Only when a problem occured, we know where. And we need the complete program.
- Inefficiencies can be partly overcome by optimized compilations.

16/02/18 B. Wolff - Ingé. 2 - Test 32

Functional Dynamic Unit Test : Problems

- Thus, any violation of an invariant, a pre-condition or a post-condition is detected.
- If a violation occurs within an execution of a method, the error is precisely reported.
- On the other hand – runtime checking is post-hoc. Only when a problem occured, we know where. And we need the complete program.
- Inefficiencies can be partly overcome by optimized compilations.

16/02/18 B. Wolff - Ingé. 2 - Test 32

Can we do better ?

- We need a method that:
  - generates the tests from the model („model-based testing"):
    if the model changes, the tests follow. This would allevate
    the maintenance problem of large test sets.
  - ... works for partial programs ...
  - ... works in the implementation phase
    (and gives immediate feedback to programmers)
    and not at the deployment phase (so: runs very late) ...
  - ... gives clear criteria on the question:
    „did we test enough" ?

Can we do better ?

We need a method that:
generates the tests from the model („model-based testing"):
if the model changes, the tests follow. This would allevate
the maintenance problem of large test sets.
... works for partial programs ...
... works in the implementation phase
(and gives immediate feedback to programmers)
and not at the deployment phase (so: runs very late) ...
... gives clear criteria on the question:
„did we test enough" ?

16/02/18 B. Wolff - Ingé. 2 - Test 33

Can we do better ?

We need a method that:
generates the tests from the model („model-based testing"):
if the model changes, the tests follow. This would allevate
the maintenance problem of large test sets.
... works for partial programs ...
... works in the implementation phase
(and gives immediate feedback to programmers)
and not at the deployment phase (so: runs very late) ...
... gives clear criteria on the question:
„did we test enough" ?

16/02/18 B. Wolff - Ingé. 2 - Test 33

Can we do better ?

We need a method that:
generates the tests from the model („model-based testing"):
if the model changes, the tests follow. This would allevate
the maintenance problem of large test sets.
... works for partial programs ...
... works in the implementation phase
(and gives immediate feedback to programmers)
and not at the deployment phase (so: runs very late) ...
... gives clear criteria on the question:
„did we test enough" ?

16/02/18 B. Wolff - Ingé. 2 - Test 33

Revision: Boolean Logic + Some Basic Rules

- $\neg(a \wedge b) = \neg a \vee \neg b$ (* deMorgan1 *)
- $\neg(a \vee b) = \neg a \wedge \neg b$ (* deMorgan2 *)
- $a \wedge (b \vee c) = (a \wedge b) \vee (a \wedge c)$
- $\neg(\neg a) = a$, $a \vee \neg a = T$, , $a \wedge \neg a = F$,
- $a \wedge b = b \wedge a$; $a \vee b = b \vee a$
- $a \wedge (b \wedge c) = (a \wedge b) \wedge c$
- $a \vee (b \vee c) = (a \vee b) \vee c$
- $a \longrightarrow b = (\neg a) \vee b$
- $(a=b \wedge P(a)) = P(b)$ (* one point rule *)

- let x = E in C(x) = C(E) (* let elimination *)
- if c then C else D = $(c \wedge C) \vee (\neg c \wedge D)$
  $= (c \longrightarrow C) \wedge (\neg c \longrightarrow D)$

Revision: Boolean Logic + Some Basic Rules

- $\neg(a \wedge b) = \neg a \vee \neg b$ (* deMorgan1 *)
- $\neg(a \vee b) = \neg a \wedge \neg b$ (* deMorgan2 *)
- $a \wedge (b \vee c) = (a \wedge b) \vee (a \wedge c)$
- $\neg(\neg a) = a$, $a \vee \neg a = T$, , $a \wedge \neg a = F$,
- $a \wedge b = b \wedge a$; $a \vee b = b \vee a$
- $a \wedge (b \wedge c) = (a \wedge b) \wedge c$
- $a \vee (b \vee c) = (a \vee b) \vee c$
- $a \longrightarrow b = (\neg a) \vee b$
- $(a=b \wedge P(a)) = P(b)$ (* one point rule *)

- let x = E in C(x) = C(E) (* let elimination *)
- if c then C else D = $(c \wedge C) \vee (\neg c \wedge D)$
  $= (c \longrightarrow C) \wedge (\neg c \longrightarrow D)$

16/02/18 B. Wolff - Ingé. 2 - Test 34

Revision: Boolean Logic + Some Basic Rules

- $\neg(a \wedge b) = \neg a \vee \neg b$ (* deMorgan1 *)
- $\neg(a \vee b) = \neg a \wedge \neg b$ (* deMorgan2 *)
- $a \wedge (b \vee c) = (a \wedge b) \vee (a \wedge c)$
- $\neg(\neg a) = a$, $a \vee \neg a = T$, , $a \wedge \neg a = F$,
- $a \wedge b = b \wedge a$; $a \vee b = b \vee a$
- $a \wedge (b \wedge c) = (a \wedge b) \wedge c$
- $a \vee (b \vee c) = (a \vee b) \vee c$
- $a \longrightarrow b = (\neg a) \vee b$
- $(a=b \wedge P(a)) = P(b)$ (* one point rule *)

- let x = E in C(x) = C(E) (* let elimination *)
- if c then C else D = $(c \wedge C) \vee (\neg c \wedge D)$
  $= (c \longrightarrow C) \wedge (\neg c \longrightarrow D)$

16/02/18 B. Wolff - Ingé. 2 - Test 34

Revision: Boolean Logic + Some Basic Rules

- $\neg(a \wedge b) = \neg a \vee \neg b$ (* deMorgan1 *)
- $\neg(a \vee b) = \neg a \wedge \neg b$ (* deMorgan2 *)
- $a \wedge (b \vee c) = (a \wedge b) \vee (a \wedge c)$
- $\neg(\neg a) = a$, $a \vee \neg a = T$, , $a \wedge \neg a = F$,
- $a \wedge b = b \wedge a$; $a \vee b = b \vee a$
- $a \wedge (b \wedge c) = (a \wedge b) \wedge c$
- $a \vee (b \vee c) = (a \vee b) \vee c$
- $a \longrightarrow b = (\neg a) \vee b$
- $(a=b \wedge P(a)) = P(b)$ (* one point rule *)

- let x = E in C(x) = C(E) (* let elimination *)
- if c then C else D = $(c \wedge C) \vee (\neg c \wedge D)$
  $= (c \longrightarrow C) \wedge (\neg c \longrightarrow D)$

16/02/18 B. Wolff - Ingé. 2 - Test 34

Test-Data Generation

- Ouf, is there a systematic and automatic way to compute all these cases ?

  Well, lets see and calculate ...

Test-Data Generation

- Ouf, is there a systematic and automatic way to compute all these cases ?

  Well, lets see and calculate ...

16/02/18 B. Wolff - Ingé. 2 - Test 35

Test-Data Generation

- Ouf, is there a systematic and automatic way to compute all these cases ?

  Well, lets see and calculate ...

16/02/18 B. Wolff - Ingé. 2 - Test 35

Test-Data Generation

- Ouf, is there a systematic and automatic way to compute all these cases ?

  Well, lets see and calculate ...

16/02/18 B. Wolff - Ingé. 2 - Test 35

Test-Data Generation

- Recall the test specification:

  mk(x,y,z).isTriangle() = r

Test-Data Generation

- Recall the test specification:

  mk(x,y,z).isTriangle() = r

16/02/18 B. Wolff - Ingé. 2 - Test 36

Test-Data Generation

- Recall the test specification:

  mk(x,y,z).isTriangle() = r

16/02/18 B. Wolff - Ingé. 2 - Test 36

Test-Data Generation

- Recall the test specification:

  mk(x,y,z).isTriangle() = r

16/02/18 B. Wolff - Ingé. 2 - Test 36

Test-Data Generation

- Recall the test specification:

  mk(x,y,z).isTriangle() = r

  ≡ $inv_{Triangle}(\sigma) \wedge pre_{isTriangle}(mk(x,y,z))(\sigma) \wedge$

  $inv_{Triangle}(\sigma') \wedge post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma')$

  (* see semantics in MOAL II, page 22. *)

  Some Facts:

  - From modifiesOnly({}) follows $\sigma = \sigma'$ hence

    $inv_{Triangle}(\sigma) = inv_{Triangle}(\sigma')$

  - From mk(x,y,z) ≠ null (see $pre_{isTriangle}$) and from $inv_{Triangle}(\sigma)$ and mk(x,y,z) ∈ Triangle (σ) follows that:

    `0<x∧0<y∧0<z ∧ x≤y+z ∧ y≤x+z ∧ z≤x+y` (≡ `inv`)

Test-Data Generation

- Recall the test specification:

  mk(x,y,z).isTriangle() = r

  ≡ $inv_{Triangle}(\sigma) \wedge pre_{isTriangle}(mk(x,y,z))(\sigma) \wedge$

  $inv_{Triangle}(\sigma') \wedge post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma')$

  (* see semantics in MOAL II, page 22. *)

  Some Facts:

  - From modifiesOnly({}) follows $\sigma = \sigma'$ hence

    $inv_{Triangle}(\sigma) = inv_{Triangle}(\sigma')$

  - From mk(x,y,z) ≠ null (see $pre_{isTriangle}$) and from $inv_{Triangle}(\sigma)$ and mk(x,y,z) ∈ Triangle (σ) follows that:

    `0<x∧0<y∧0<z ∧ x≤y+z ∧ y≤x+z ∧ z≤x+y` (≡ `inv`)

16/02/18 B. Wolff - Ingé. 2 - Test 37

Test-Data Generation

- Recall the test specification:

  mk(x,y,z).isTriangle() = r

  ≡ $inv_{Triangle}(\sigma) \wedge pre_{isTriangle}(mk(x,y,z))(\sigma) \wedge$

  $inv_{Triangle}(\sigma') \wedge post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma')$

  (* see semantics in MOAL II, page 22. *)

  Some Facts:

  - From modifiesOnly({}) follows $\sigma = \sigma'$ hence

    $inv_{Triangle}(\sigma) = inv_{Triangle}(\sigma')$

  - From mk(x,y,z) ≠ null (see $pre_{isTriangle}$) and from $inv_{Triangle}(\sigma)$ and mk(x,y,z) ∈ Triangle (σ) follows that:

    `0<x∧0<y∧0<z ∧ x≤y+z ∧ y≤x+z ∧ z≤x+y` (≡ `inv`)

16/02/18 B. Wolff - Ingé. 2 - Test 37

Test-Data Generation

- Recall the test specification:

  mk(x,y,z).isTriangle() = r

  ≡ $inv_{Triangle}(\sigma) \wedge pre_{isTriangle}(mk(x,y,z))(\sigma) \wedge$

  $inv_{Triangle}(\sigma') \wedge post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma')$

  (* see semantics in MOAL II, page 22. *)

  Some Facts:

  - From modifiesOnly({}) follows $\sigma = \sigma'$ hence

    $inv_{Triangle}(\sigma) = inv_{Triangle}(\sigma')$

  - From mk(x,y,z) ≠ null (see $pre_{isTriangle}$) and from $inv_{Triangle}(\sigma)$ and mk(x,y,z) ∈ Triangle (σ) follows that:

    `0<x∧0<y∧0<z ∧ x≤y+z ∧ y≤x+z ∧ z≤x+y` (≡ `inv`)

16/02/18 B. Wolff - Ingé. 2 - Test 37

Test-Data Generation

- Recall the test specification:

  mk(x,y,z).isTriangle() = r

  ≡ $inv_{Triangle}(\sigma) \wedge pre_{isTriangle}(mk(x,y,z))(\sigma) \wedge$

  $inv_{Triangle}(\sigma') \wedge post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma')$

  (* see semantics in MOAL II, page 22. *)

  Some Facts:

  - arb≠equ≠iso
  - $post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma)$ can be simplified to:

    (x=y ∧ y=z ⟶ r=equ) ∧
    ((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z) ⟶ r=iso) ∧
    ((x≠y ∧ y≠z ∧ x≠z) ⟶ r=arb)

Test-Data Generation

- Recall the test specification:

  mk(x,y,z).isTriangle() = r

  ≡ $inv_{Triangle}(\sigma) \wedge pre_{isTriangle}(mk(x,y,z))(\sigma) \wedge$

  $inv_{Triangle}(\sigma') \wedge post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma')$

  (* see semantics in MOAL II, page 22. *)

  Some Facts:

  - arb≠equ≠iso
  - $post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma)$ can be simplified to:

    (x=y ∧ y=z ⟶ r=equ) ∧
    ((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z) ⟶ r=iso) ∧
    ((x≠y ∧ y≠z ∧ x≠z) ⟶ r=arb)

16/02/18 B. Wolff - Ingé. 2 - Test 38

Test-Data Generation

- Recall the test specification:

  mk(x,y,z).isTriangle() = r

  ≡ $inv_{Triangle}(\sigma) \wedge pre_{isTriangle}(mk(x,y,z))(\sigma) \wedge$

  $inv_{Triangle}(\sigma') \wedge post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma')$

  (* see semantics in MOAL II, page 22. *)

  Some Facts:

  - arb≠equ≠iso
  - $post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma)$ can be simplified to:

    (x=y ∧ y=z ⟶ r=equ) ∧
    ((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z) ⟶ r=iso) ∧
    ((x≠y ∧ y≠z ∧ x≠z) ⟶ r=arb)

16/02/18 B. Wolff - Ingé. 2 - Test 38

Test-Data Generation

- Recall the test specification:

  mk(x,y,z).isTriangle() = r

  ≡ $inv_{Triangle}(\sigma) \wedge pre_{isTriangle}(mk(x,y,z))(\sigma) \wedge$

  $inv_{Triangle}(\sigma') \wedge post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma')$

  (* see semantics in MOAL II, page 22. *)

  Some Facts:

  - arb≠equ≠iso
  - $post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma)$ can be simplified to:

    (x=y ∧ y=z ⟶ r=equ) ∧
    ((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z) ⟶ r=iso) ∧
    ((x≠y ∧ y≠z ∧ x≠z) ⟶ r=arb)

16/02/18 B. Wolff - Ingé. 2 - Test 38

Test-Data Generation

- Summing up:

  mk(x,y,z).isTriangle() = r

  $\equiv$ $inv_{Triangle}(\sigma) \wedge pre_{isTriangle}(mk(x,y,z))(\sigma) \wedge$

  $inv_{Triangle}(\sigma') \wedge post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma')$

  (* see semantics of MOAL II, page 22. *)

  $\Longrightarrow$ (* the discussed facts *)

```
inv ∧
(x=y ∧ y=z ⟶ r=equ) ∧
((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z)⟶ r=iso) ∧
(x≠y ∧ y≠z ∧ x≠z ⟶ r=arb)
```


Test-Data Generation

- Summing up:

  mk(x,y,z).isTriangle() = r

  $\equiv$ $inv_{Triangle}(\sigma) \wedge pre_{isTriangle}(mk(x,y,z))(\sigma) \wedge$

  $inv_{Triangle}(\sigma') \wedge post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma')$

  (* see semantics of MOAL II, page 22. *)

  $\Longrightarrow$ (* the discussed facts *)

inv ∧
(x=y ∧ y=z ⟶ r=equ) ∧
((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z)⟶ r=iso) ∧
(x≠y ∧ y≠z ∧ x≠z ⟶ r=arb)

16/02/18 B. Wolff - Ingé. 2 - Test 39

Test-Data Generation

- Summing up:

  mk(x,y,z).isTriangle() = r

  $\equiv$ $inv_{Triangle}(\sigma) \wedge pre_{isTriangle}(mk(x,y,z))(\sigma) \wedge$

  $inv_{Triangle}(\sigma') \wedge post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma')$

  (* see semantics of MOAL II, page 22. *)

  $\Longrightarrow$ (* the discussed facts *)

inv ∧
(x=y ∧ y=z ⟶ r=equ) ∧
((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z)⟶ r=iso) ∧
(x≠y ∧ y≠z ∧ x≠z ⟶ r=arb)

16/02/18 B. Wolff - Ingé. 2 - Test 39

Test-Data Generation

- Summing up:

  mk(x,y,z).isTriangle() = r

  $\equiv$ $inv_{Triangle}(\sigma) \wedge pre_{isTriangle}(mk(x,y,z))(\sigma) \wedge$

  $inv_{Triangle}(\sigma') \wedge post_{isTriangle}(mk(x,y,z),r)(\sigma,\sigma')$

  (* see semantics of MOAL II, page 22. *)

  $\Longrightarrow$ (* the discussed facts *)

inv ∧
(x=y ∧ y=z ⟶ r=equ) ∧
((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z)⟶ r=iso) ∧
(x≠y ∧ y≠z ∧ x≠z ⟶ r=arb)

16/02/18 B. Wolff - Ingé. 2 - Test 39

Test-Data Generation

- Recall the test specification:

  inv ∧ (x=y ∧ y=z ⟶ r=equ) ∧
  ((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z)⟶ r=iso) ∧
  (x≠y ∧ y≠z ∧ x≠z ⟶ r=arb)

  ≡ (* elimination ⟶ , deMorgan*)

  inv ∧
  (x≠y ∨ y≠z ∨ r=equ) ∧
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso) ∧
  (x=y ∨ y=z ∨ x=z ∨ r=arb)

Test-Data Generation

Recall the test specification:
inv ∧ (x=y ∧ y=z ⟶ r=equ) ∧
((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z)⟶ r=iso) ∧
(x≠y ∧ y≠z ∧ x≠z ⟶ r=arb)
≡ (* elimination ⟶ , deMorgan*)
inv ∧
(x≠y ∨ y≠z ∨ r=equ) ∧
((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso) ∧
(x=y ∨ y=z ∨ x=z ∨ r=arb)
16/02/18 B. Wolff - Ingé. 2 - Test 40

Test-Data Generation

Recall the test specification:
inv ∧ (x=y ∧ y=z ⟶ r=equ) ∧
((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z)⟶ r=iso) ∧
(x≠y ∧ y≠z ∧ x≠z ⟶ r=arb)
≡ (* elimination ⟶ , deMorgan*)
inv ∧
(x≠y ∨ y≠z ∨ r=equ) ∧
((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso) ∧
(x=y ∨ y=z ∨ x=z ∨ r=arb)
16/02/18 B. Wolff - Ingé. 2 - Test 40

Test-Data Generation

Recall the test specification:
inv ∧ (x=y ∧ y=z ⟶ r=equ) ∧
((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z)⟶ r=iso) ∧
(x≠y ∧ y≠z ∧ x≠z ⟶ r=arb)
≡ (* elimination ⟶ , deMorgan*)
inv ∧
(x≠y ∨ y≠z ∨ r=equ) ∧
((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso) ∧
(x=y ∨ y=z ∨ x=z ∨ r=arb)
16/02/18 B. Wolff - Ingé. 2 - Test 40

Test-Data Generation

- This first part of the calculation could be called

  PURIFICATION

  We eliminate UML, object-orientation, MOAL etcpp
  and reduce it to the pure logical core ...

Now, under which precise conditions do we have

- r = iso
- r = arb
- r = equ ???

Test-Data Generation

- This first part of the calculation could be called

  PURIFICATION

  We eliminate UML, object-orientation, MOAL etcpp
  and reduce it to the pure logical core ...

Now, under which precise conditions do we have

- r = iso
- r = arb
- r = equ ???

16/02/18 B. Wolff - Ingé. 2 - Test 41

Test-Data Generation

- This first part of the calculation could be called

  PURIFICATION

  We eliminate UML, object-orientation, MOAL etcpp
  and reduce it to the pure logical core ...

Now, under which precise conditions do we have

- r = iso
- r = arb
- r = equ ???

16/02/18 B. Wolff - Ingé. 2 - Test 41

Test-Data Generation

- This first part of the calculation could be called

  PURIFICATION

  We eliminate UML, object-orientation, MOAL etcpp
  and reduce it to the pure logical core ...

Now, under which precise conditions do we have

- r = iso
- r = arb
- r = equ ???

16/02/18 B. Wolff - Ingé. 2 - Test 41

Test-Data Generation

- This first part of the calculation could be called

  PURIFICATION

  We eliminate UML, object-orientation, MOAL etcpp and reduce it to the pure logical core ...

  Can we transform the spec into the form
  - $A_1 \wedge \ldots \wedge A_i \wedge r = iso$
  - $B_1 \wedge \ldots \wedge B_k \wedge r = arb$
  - $C_1 \wedge \ldots \wedge C_l \wedge r = equ$???

Test-Data Generation

- This first part of the calculation could be called

  PURIFICATION

  We eliminate UML, object-orientation, MOAL etcpp and reduce it to the pure logical core ...

  Can we transform the spec into the form
  - $A_1 \wedge \ldots \wedge A_i \wedge r = iso$
  - $B_1 \wedge \ldots \wedge B_k \wedge r = arb$
  - $C_1 \wedge \ldots \wedge C_l \wedge r = equ$???

16/02/18 B. Wolff - Ingé. 2 - Test 42

Test-Data Generation

- This first part of the calculation could be called

  PURIFICATION

  We eliminate UML, object-orientation, MOAL etcpp and reduce it to the pure logical core ...

  Can we transform the spec into the form
  - $A_1 \wedge \ldots \wedge A_i \wedge r = iso$
  - $B_1 \wedge \ldots \wedge B_k \wedge r = arb$
  - $C_1 \wedge \ldots \wedge C_l \wedge r = equ$???

16/02/18 B. Wolff - Ingé. 2 - Test 42

Test-Data Generation

- This first part of the calculation could be called

  PURIFICATION

  We eliminate UML, object-orientation, MOAL etcpp and reduce it to the pure logical core ...

  Can we transform the spec into the form
  - $A_1 \wedge \ldots \wedge A_i \wedge r = iso$
  - $B_1 \wedge \ldots \wedge B_k \wedge r = arb$
  - $C_1 \wedge \ldots \wedge C_l \wedge r = equ$???

16/02/18 B. Wolff - Ingé. 2 - Test 42

Test-Data Generation

- This first part of the calculation could be called

  PURIFICATION

  We eliminate UML, object-orientation, MOAL etcpp and reduce it to the pure logical core ...

  Can we transform the spec into a

  Disjunctive Normal Form (DNF) ?

Test-Data Generation

- This first part of the calculation could be called

  PURIFICATION

  We eliminate UML, object-orientation, MOAL etcpp and reduce it to the pure logical core ...

  Can we transform the spec into a

  Disjunctive Normal Form (DNF) ?

16/02/18 B. Wolff - Ingé. 2 - Test 43

Test-Data Generation

- This first part of the calculation could be called

  PURIFICATION

  We eliminate UML, object-orientation, MOAL etcpp and reduce it to the pure logical core ...

  Can we transform the spec into a

  Disjunctive Normal Form (DNF) ?

16/02/18 B. Wolff - Ingé. 2 - Test 43

Test-Data Generation

- This first part of the calculation could be called

  PURIFICATION

  We eliminate UML, object-orientation, MOAL etcpp and reduce it to the pure logical core ...

  Can we transform the spec into a

  Disjunctive Normal Form (DNF) ?

16/02/18 B. Wolff - Ingé. 2 - Test 43

Excursion

- Generalized Distribution Laws:

$(A_1 \vee A_2) \wedge (B_1 \vee B_2) = (A_1 \wedge (B_1 \vee B_2)) \vee (A_2 \wedge (B_1 \vee B_2))$
$= (A_1 \wedge B_1) \vee (A_2 \wedge B_1) \vee (A_1 \wedge B_2) \vee (A_2 \wedge B_2)$

$(A_1 \vee A_2 \vee A_3) \wedge (B_1 \vee B_2 \vee B_3) \wedge (C_1 \vee C_2 \vee C_3)$
$= \ldots$
$= (A_1 \wedge B_1 \wedge C_1) \vee (A_1 \wedge B_1 \wedge C_2) \vee (A_1 \wedge B_1 \wedge C_3) \vee$
$(A_2 \wedge B_1 \wedge C_1) \vee (A_2 \wedge B_1 \wedge C_2) \vee (A_2 \wedge B_1 \wedge C_3) \vee$
$\ldots$
$(A_1 \wedge B_3 \wedge C_3) \vee (A_2 \wedge B_3 \wedge C_3) \vee (A_3 \wedge B_3 \wedge C_3)$

Excursion

- Generalized Distribution Laws:

$(A_1 \vee A_2) \wedge (B_1 \vee B_2) = (A_1 \wedge (B_1 \vee B_2)) \vee (A_2 \wedge (B_1 \vee B_2))$
$= (A_1 \wedge B_1) \vee (A_2 \wedge B_1) \vee (A_1 \wedge B_2) \vee (A_2 \wedge B_2)$

$(A_1 \vee A_2 \vee A_3) \wedge (B_1 \vee B_2 \vee B_3) \wedge (C_1 \vee C_2 \vee C_3)$
$= \ldots$
$= (A_1 \wedge B_1 \wedge C_1) \vee (A_1 \wedge B_1 \wedge C_2) \vee (A_1 \wedge B_1 \wedge C_3) \vee$
$(A_2 \wedge B_1 \wedge C_1) \vee (A_2 \wedge B_1 \wedge C_2) \vee (A_2 \wedge B_1 \wedge C_3) \vee$
$\ldots$
$(A_1 \wedge B_3 \wedge C_3) \vee (A_2 \wedge B_3 \wedge C_3) \vee (A_3 \wedge B_3 \wedge C_3)$

16/02/18 B. Wolff - Ingé. 2 - Test 44

Excursion

- Generalized Distribution Laws:

$(A_1 \vee A_2) \wedge (B_1 \vee B_2) = (A_1 \wedge (B_1 \vee B_2)) \vee (A_2 \wedge (B_1 \vee B_2))$
$= (A_1 \wedge B_1) \vee (A_2 \wedge B_1) \vee (A_1 \wedge B_2) \vee (A_2 \wedge B_2)$

$(A_1 \vee A_2 \vee A_3) \wedge (B_1 \vee B_2 \vee B_3) \wedge (C_1 \vee C_2 \vee C_3)$
$= \ldots$
$= (A_1 \wedge B_1 \wedge C_1) \vee (A_1 \wedge B_1 \wedge C_2) \vee (A_1 \wedge B_1 \wedge C_3) \vee$
$(A_2 \wedge B_1 \wedge C_1) \vee (A_2 \wedge B_1 \wedge C_2) \vee (A_2 \wedge B_1 \wedge C_3) \vee$
$\ldots$
$(A_1 \wedge B_3 \wedge C_3) \vee (A_2 \wedge B_3 \wedge C_3) \vee (A_3 \wedge B_3 \wedge C_3)$

16/02/18 B. Wolff - Ingé. 2 - Test 44

Excursion

- Generalized Distribution Laws:

$(A_1 \vee A_2) \wedge (B_1 \vee B_2) = (A_1 \wedge (B_1 \vee B_2)) \vee (A_2 \wedge (B_1 \vee B_2))$
$= (A_1 \wedge B_1) \vee (A_2 \wedge B_1) \vee (A_1 \wedge B_2) \vee (A_2 \wedge B_2)$

$(A_1 \vee A_2 \vee A_3) \wedge (B_1 \vee B_2 \vee B_3) \wedge (C_1 \vee C_2 \vee C_3)$
$= \ldots$
$= (A_1 \wedge B_1 \wedge C_1) \vee (A_1 \wedge B_1 \wedge C_2) \vee (A_1 \wedge B_1 \wedge C_3) \vee$
$(A_2 \wedge B_1 \wedge C_1) \vee (A_2 \wedge B_1 \wedge C_2) \vee (A_2 \wedge B_1 \wedge C_3) \vee$
$\ldots$
$(A_1 \wedge B_3 \wedge C_3) \vee (A_2 \wedge B_3 \wedge C_3) \vee (A_3 \wedge B_3 \wedge C_3)$

16/02/18 B. Wolff - Ingé. 2 - Test 44

Test-Data Generation

- Recall the test specification:

```
     ...
≡ inv ∧
  (x≠y ∨ y≠z ∨ r=equ) ∧
  (x=y ∨ y=z ∨ x=z ∨ r=arb) ∧
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

≡ (* generalized distribution 2nd/3rd line *)
  inv ∧
  ((x≠y ∧ x=y)∨(x≠y ∧ y=z)∨(x≠y ∧ x=z)∨(x≠y ∧ r=arb)) ∨
  ((y≠z ∧ x=y)∨(y≠z ∧ y=z)∨(y≠z ∧ x=z)∨(y≠z ∧ r=arb)) ∨
  ((r=equ∧x=y)∨(r=equ∧y=z)∨(r=equ∧x=z)∨(r=equ∧r=arb)) ∨
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)
```


Test-Data Generation

- Recall the test specification:

```
     ...
≡ inv ∧
  (x≠y ∨ y≠z ∨ r=equ) ∧
  (x=y ∨ y=z ∨ x=z ∨ r=arb) ∧
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

≡ (* generalized distribution 2nd/3rd line *)
  inv ∧
  ((x≠y ∧ x=y)∨(x≠y ∧ y=z)∨(x≠y ∧ x=z)∨(x≠y ∧ r=arb)) ∨
  ((y≠z ∧ x=y)∨(y≠z ∧ y=z)∨(y≠z ∧ x=z)∨(y≠z ∧ r=arb)) ∨
  ((r=equ∧x=y)∨(r=equ∧y=z)∨(r=equ∧x=z)∨(r=equ∧r=arb)) ∨
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)
```

16/02/18 B. Wolff - Ingé. 2 - Test 45

Test-Data Generation

- Recall the test specification:

```
     ...
≡ inv ∧
  (x≠y ∨ y≠z ∨ r=equ) ∧
  (x=y ∨ y=z ∨ x=z ∨ r=arb) ∧
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

≡ (* generalized distribution 2nd/3rd line *)
  inv ∧
  ((x≠y ∧ x=y)∨(x≠y ∧ y=z)∨(x≠y ∧ x=z)∨(x≠y ∧ r=arb)) ∨
  ((y≠z ∧ x=y)∨(y≠z ∧ y=z)∨(y≠z ∧ x=z)∨(y≠z ∧ r=arb)) ∨
  ((r=equ∧x=y)∨(r=equ∧y=z)∨(r=equ∧x=z)∨(r=equ∧r=arb)) ∨
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)
```

16/02/18 B. Wolff - Ingé. 2 - Test 45

Test-Data Generation

- Recall the test specification:

```
     ...
≡ inv ∧
  (x≠y ∨ y≠z ∨ r=equ) ∧
  (x=y ∨ y=z ∨ x=z ∨ r=arb) ∧
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

≡ (* generalized distribution 2nd/3rd line *)
  inv ∧
  ((x≠y ∧ x=y)∨(x≠y ∧ y=z)∨(x≠y ∧ x=z)∨(x≠y ∧ r=arb)) ∨
  ((y≠z ∧ x=y)∨(y≠z ∧ y=z)∨(y≠z ∧ x=z)∨(y≠z ∧ r=arb)) ∨
  ((r=equ∧x=y)∨(r=equ∧y=z)∨(r=equ∧x=z)∨(r=equ∧r=arb)) ∨
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)
```

16/02/18 B. Wolff - Ingé. 2 - Test 45

Test-Data Generation

- Recall the test specification:

  ...

  ≡ inv ∧
  (x≠y ∨ y≠z ∨ r=equ) ∧
  (x=y ∨ y=z ∨ x=z ∨ r=arb) ∧
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

  ≡ (* elimination contradictions *)
  inv ∧
  (~~(x≠y ∧ x=y)~~∨(x≠y ∧ y=z)∨(x≠y ∧ x=z)∨(x≠y ∧ r=arb) ∨
  (y≠z ∧ x=y)∨~~(y≠z ∧ y=z)~~∨(y≠z ∧ x=z)∨(y≠z ∧ r=arb) ∨
  (r=equ∧x=y)∨(r=equ∧y=z)∨(r=equ∧x=z)∨~~(r=equ∧r=arb)~~) ∨
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

Test-Data Generation

- Recall the test specification:

  ...

  ≡ inv ∧
  (x≠y ∨ y≠z ∨ r=equ) ∧
  (x=y ∨ y=z ∨ x=z ∨ r=arb) ∧
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

  ≡ (* elimination contradictions *)
  inv ∧
  (~~(x≠y ∧ x=y)~~∨(x≠y ∧ y=z)∨(x≠y ∧ x=z)∨(x≠y ∧ r=arb) ∨
  (y≠z ∧ x=y)∨~~(y≠z ∧ y=z)~~∨(y≠z ∧ x=z)∨(y≠z ∧ r=arb) ∨
  (r=equ∧x=y)∨(r=equ∧y=z)∨(r=equ∧x=z)∨~~(r=equ∧r=arb)~~) ∨
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

16/02/18 B. Wolff - Ingé. 2 - Test 46

Test-Data Generation

- Recall the test specification:

  ...

  ≡ inv ∧
  (x≠y ∨ y≠z ∨ r=equ) ∧
  (x=y ∨ y=z ∨ x=z ∨ r=arb) ∧
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

  ≡ (* elimination contradictions *)
  inv ∧
  (~~(x≠y ∧ x=y)~~∨(x≠y ∧ y=z)∨(x≠y ∧ x=z)∨(x≠y ∧ r=arb) ∨
  (y≠z ∧ x=y)∨~~(y≠z ∧ y=z)~~∨(y≠z ∧ x=z)∨(y≠z ∧ r=arb) ∨
  (r=equ∧x=y)∨(r=equ∧y=z)∨(r=equ∧x=z)∨~~(r=equ∧r=arb)~~) ∨
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

16/02/18 B. Wolff - Ingé. 2 - Test 46

Test-Data Generation

- Recall the test specification:

  ...

  ≡ inv ∧
  (x≠y ∨ y≠z ∨ r=equ) ∧
  (x=y ∨ y=z ∨ x=z ∨ r=arb) ∧
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

  ≡ (* elimination contradictions *)
  inv ∧
  (~~(x≠y ∧ x=y)~~∨(x≠y ∧ y=z)∨(x≠y ∧ x=z)∨(x≠y ∧ r=arb) ∨
  (y≠z ∧ x=y)∨~~(y≠z ∧ y=z)~~∨(y≠z ∧ x=z)∨(y≠z ∧ r=arb) ∨
  (r=equ∧x=y)∨(r=equ∧y=z)∨(r=equ∧x=z)∨~~(r=equ∧r=arb)~~) ∨
  ((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

16/02/18 B. Wolff - Ingé. 2 - Test 46

Test-Data Generation

- Recall the test specification:

  ...

  ≡ (* elimination contradictions *)

```
inv ∧
((x≠y ∧ y=z)∨(x≠y ∧ x=z)∨(x≠y ∧ r=arb) ∨
 (y≠z ∧ x=y)∨(y≠z ∧ x=z)∨(y≠z ∧ r=arb) ∨
 (r=equ∧x=y)∨(r=equ∧y=z)∨(r=equ∧x=z)) ∧
((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)
```


Test-Data Generation

Recall the test specification:
...
≡ (* elimination contradictions *)
inv ∧
((x≠y ∧ y=z)∨(x≠y ∧ x=z)∨(x≠y ∧ r=arb) ∨
(y≠z ∧ x=y)∨(y≠z ∧ x=z)∨(y≠z ∧ r=arb) ∨
(r=equ∧x=y)∨(r=equ∧y=z)∨(r=equ∧x=z)) ∧
((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

16/02/18 B. Wolff - Ingé. 2 - Test 47

Test-Data Generation

Recall the test specification:
...
≡ (* elimination contradictions *)
inv ∧
((x≠y ∧ y=z)∨(x≠y ∧ x=z)∨(x≠y ∧ r=arb) ∨
(y≠z ∧ x=y)∨(y≠z ∧ x=z)∨(y≠z ∧ r=arb) ∨
(r=equ∧x=y)∨(r=equ∧y=z)∨(r=equ∧x=z)) ∧
((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

16/02/18 B. Wolff - Ingé. 2 - Test 47

Test-Data Generation

Recall the test specification:
...
≡ (* elimination contradictions *)
inv ∧
((x≠y ∧ y=z)∨(x≠y ∧ x=z)∨(x≠y ∧ r=arb) ∨
(y≠z ∧ x=y)∨(y≠z ∧ x=z)∨(y≠z ∧ r=arb) ∨
(r=equ∧x=y)∨(r=equ∧y=z)∨(r=equ∧x=z)) ∧
((x=y ∧ y=z) ∨ (x≠y ∧ y≠z ∧ x≠z) ∨ r=iso)

16/02/18 B. Wolff - Ingé. 2 - Test 47

Test-Data Generation

- ≡ (* generalized distribution 2nd/3rd ((9 * 3 = 27 cases !)*)

```
inv ∧
((x≠y∧y=z∧x=y∧y=z)∨(x≠y∧x=z∧
                    x=y∧y=z)∨(x≠y∧r=arb∧x=y∧y=z)  ∨
 (y≠z∧x=y∧x=y∧y=z)∨(y≠z∧x=z∧
                    x=y∧y=z)∨(y≠z∧r=arb∧x=y∧y=z)  ∨
 (r=equ∧x=y∧x=y∧y=z)∨(r=equ∧
                    y=z∧x=y∧y=z)∨(r=equ∧x=z∧x=y∧y=z)) ∨
((x≠y∧y=z∧x≠y∧y≠z∧x≠z)∨(x≠y∧x=z∧x≠y∧y≠z∧x≠z)∨(x≠y∧r=arb∧
x≠y∧y≠z∧x≠z)∨(y≠z∧x=y∧x≠y∧y≠z∧x≠z)∨(y≠z∧x=z∧x≠y∧y≠z∧
x≠z)∨(y≠z∧r=arb∧x≠y∧y≠z∧x≠z)∨(r=equ∧x=y∧x≠y∧y≠z∧x≠z)∨(r
=equ∧y=z∧x≠y∧y≠z∧x≠z)∨(r=equ∧x=z∧x≠y∧y≠z∧ x≠z)) ∨
((x≠y ∧ y=z∧r=iso)∨(x≠y ∧ x=z∧r=iso)∨(x≠y∧r=arb∧r=iso)
 ∨(y≠z∧x=y∧r=iso)∨(y≠z∧x=z∧r=iso)∨(y≠z∧r=arb∧r=iso)  ∨
 (r=equ∧x=y∧r=iso)∨(r=equ∧y=z∧r=iso)∨(r=equ∧x=z∧r=iso))
```


Test-Data Generation

- ≡ (* generalized distribution 2nd/3rd ((9 * 3 = 27 cases !)*)

```
inv ∧
((x≠y∧y=z∧x=y∧y=z)∨(x≠y∧x=z∧
                    x=y∧y=z)∨(x≠y∧r=arb∧x=y∧y=z)  ∨
 (y≠z∧x=y∧x=y∧y=z)∨(y≠z∧x=z∧
                    x=y∧y=z)∨(y≠z∧r=arb∧x=y∧y=z)  ∨
 (r=equ∧x=y∧x=y∧y=z)∨(r=equ∧
                    y=z∧x=y∧y=z)∨(r=equ∧x=z∧x=y∧y=z)) ∨
((x≠y∧y=z∧x≠y∧y≠z∧x≠z)∨(x≠y∧x=z∧x≠y∧y≠z∧x≠z)∨(x≠y∧r=arb∧
x≠y∧y≠z∧x≠z)∨(y≠z∧x=y∧x≠y∧y≠z∧x≠z)∨(y≠z∧x=z∧x≠y∧y≠z∧
x≠z)∨(y≠z∧r=arb∧x≠y∧y≠z∧x≠z)∨(r=equ∧x=y∧x≠y∧y≠z∧x≠z)∨(r
=equ∧y=z∧x≠y∧y≠z∧x≠z)∨(r=equ∧x=z∧x≠y∧y≠z∧ x≠z)) ∨
((x≠y ∧ y=z∧r=iso)∨(x≠y ∧ x=z∧r=iso)∨(x≠y∧r=arb∧r=iso)
 ∨(y≠z∧x=y∧r=iso)∨(y≠z∧x=z∧r=iso)∨(y≠z∧r=arb∧r=iso)  ∨
 (r=equ∧x=y∧r=iso)∨(r=equ∧y=z∧r=iso)∨(r=equ∧x=z∧r=iso))
```

16/02/18 B. Wolff - Ingé. 2 - Test 48

Test-Data Generation

- ≡ (* generalized distribution 2nd/3rd ((9 * 3 = 27 cases !)*)

```
inv ∧
((x≠y∧y=z∧x=y∧y=z)∨(x≠y∧x=z∧
                    x=y∧y=z)∨(x≠y∧r=arb∧x=y∧y=z)  ∨
 (y≠z∧x=y∧x=y∧y=z)∨(y≠z∧x=z∧
                    x=y∧y=z)∨(y≠z∧r=arb∧x=y∧y=z)  ∨
 (r=equ∧x=y∧x=y∧y=z)∨(r=equ∧
                    y=z∧x=y∧y=z)∨(r=equ∧x=z∧x=y∧y=z)) ∨
((x≠y∧y=z∧x≠y∧y≠z∧x≠z)∨(x≠y∧x=z∧x≠y∧y≠z∧x≠z)∨(x≠y∧r=arb∧
x≠y∧y≠z∧x≠z)∨(y≠z∧x=y∧x≠y∧y≠z∧x≠z)∨(y≠z∧x=z∧x≠y∧y≠z∧
x≠z)∨(y≠z∧r=arb∧x≠y∧y≠z∧x≠z)∨(r=equ∧x=y∧x≠y∧y≠z∧x≠z)∨(r
=equ∧y=z∧x≠y∧y≠z∧x≠z)∨(r=equ∧x=z∧x≠y∧y≠z∧ x≠z)) ∨
((x≠y ∧ y=z∧r=iso)∨(x≠y ∧ x=z∧r=iso)∨(x≠y∧r=arb∧r=iso)
 ∨(y≠z∧x=y∧r=iso)∨(y≠z∧x=z∧r=iso)∨(y≠z∧r=arb∧r=iso)  ∨
 (r=equ∧x=y∧r=iso)∨(r=equ∧y=z∧r=iso)∨(r=equ∧x=z∧r=iso))
```

16/02/18 B. Wolff - Ingé. 2 - Test 48

Test-Data Generation

- ≡ (* generalized distribution 2nd/3rd ((9 * 3 = 27 cases !)*)

```
inv ∧
((x≠y∧y=z∧x=y∧y=z)∨(x≠y∧x=z∧
                    x=y∧y=z)∨(x≠y∧r=arb∧x=y∧y=z)  ∨
 (y≠z∧x=y∧x=y∧y=z)∨(y≠z∧x=z∧
                    x=y∧y=z)∨(y≠z∧r=arb∧x=y∧y=z)  ∨
 (r=equ∧x=y∧x=y∧y=z)∨(r=equ∧
                    y=z∧x=y∧y=z)∨(r=equ∧x=z∧x=y∧y=z)) ∨
((x≠y∧y=z∧x≠y∧y≠z∧x≠z)∨(x≠y∧x=z∧x≠y∧y≠z∧x≠z)∨(x≠y∧r=arb∧
x≠y∧y≠z∧x≠z)∨(y≠z∧x=y∧x≠y∧y≠z∧x≠z)∨(y≠z∧x=z∧x≠y∧y≠z∧
x≠z)∨(y≠z∧r=arb∧x≠y∧y≠z∧x≠z)∨(r=equ∧x=y∧x≠y∧y≠z∧x≠z)∨(r
=equ∧y=z∧x≠y∧y≠z∧x≠z)∨(r=equ∧x=z∧x≠y∧y≠z∧ x≠z)) ∨
((x≠y ∧ y=z∧r=iso)∨(x≠y ∧ x=z∧r=iso)∨(x≠y∧r=arb∧r=iso)
 ∨(y≠z∧x=y∧r=iso)∨(y≠z∧x=z∧r=iso)∨(y≠z∧r=arb∧r=iso)  ∨
 (r=equ∧x=y∧r=iso)∨(r=equ∧y=z∧r=iso)∨(r=equ∧x=z∧r=iso))
```

16/02/18 B. Wolff - Ingé. 2 - Test 48

Test-Data Generation

- ≡ (* elimination of the contradictions and redundancies *)

inv ∧
(~~(x≠y∧y=z∧x=y∧y=z)~~∨~~(x≠y∧x=z∧x=y∧y=z)~~∨~~(x≠y∧r=arb∧x=y∧y=z)~~ ∨
~~(y≠z∧x=y∧x=y∧y=z)~~∨~~(y≠z∧x=z∧x=y∧y=z)~~∨~~(y≠z∧r=arb∧x=y∧y=z)~~ ∨
(r=equ∧x=y∧x=y∧y=z)∨(r=equ∧y=z∧x=y∧y=z)∨(r=equ∧x=z∧x=y∧y=z)) ∨
(~~(x≠y∧y=z∧x≠y∧y≠z∧x≠z)~~∨~~(x≠y∧x=z∧x≠y∧y≠z∧x≠z)~~∨(x≠y∧r=arb∧x≠y∧y≠z∧x≠z)∨~~(y≠z∧x=y∧x≠y∧y≠z∧x≠z)~~∨~~(y≠z∧x=z∧x≠y∧y≠z∧x≠z)~~∨(y≠z∧r=arb∧x≠y∧y≠z∧x≠z)∨~~(r=equ∧x=y∧x≠y∧y≠z∧x≠z)~~∨~~(r=equ∧y=z∧x≠y∧y≠z∧x≠z)~~∨~~(r=equ∧x=z∧x≠y∧y≠z∧x≠z)~~) ∨
((x≠y ∧ y=z∧r=iso)∨(x≠y ∧ x=z∧r=iso)∨~~(x≠y∧r=arb∧r=iso)~~
∨(y≠z∧x=y∧r=iso)∨(y≠z∧x=z∧r=iso)∨~~(y≠z∧r=arb∧r=iso)~~ ∨
~~(r=equ∧x=y∧r=iso)~~∨~~(r=equ∧y=z∧r=iso)~~∨~~(r=equ∧x=z∧r=iso)~~)

Test-Data Generation

- ≡ (* elimination of the contradictions and redundancies *)

inv ∧ ... (same content as above)

Test-Data Generation

- ≡ (* elimination of the contradictions and redundancies *)

inv ∧ ... (same content as above)

Test-Data Generation

- ≡ (* elimination of the contradictions and redundancies *)

inv ∧ ... (same content as above)

Test-Data Generation

- ≡ (* cleanup, distribution *)

```
(inv ∧ x=y ∧ x=y ∧ y=z ∧ r=equ) ∨        (1)
(inv ∧ x≠y ∧ y≠z ∧ x≠z ∧ r=arb ) ∨       (2)
(inv ∧ x≠y ∧ y=z ∧ r=iso) ∨              (3)
(inv ∧ x≠y ∧ x=z ∧ r=iso) ∨              (4)
(inv ∧ y≠z ∧ x=y ∧ r=iso) ∨              (5)
(inv ∧ y≠z ∧ x=z ∧ r=iso)                (6)
```

- Test-Case-Construction by DNF Method
  yields six abstract test cases
  relatibng input x y z to output r
- Note: In general, output r is not necessarily uniquely defined as in our example …
  The spec can be non-deterministic admitting several results.

Test-Data Generation

- ≡ (* cleanup, distribution *)

```
(inv ∧ x=y ∧ x=y ∧ y=z ∧ r=equ) ∨        (1)
(inv ∧ x≠y ∧ y≠z ∧ x≠z ∧ r=arb ) ∨       (2)
(inv ∧ x≠y ∧ y=z ∧ r=iso) ∨              (3)
(inv ∧ x≠y ∧ x=z ∧ r=iso) ∨              (4)
(inv ∧ y≠z ∧ x=y ∧ r=iso) ∨              (5)
(inv ∧ y≠z ∧ x=z ∧ r=iso)                (6)
```

- Test-Case-Construction by DNF Method
  yields six abstract test cases
  relatibng input x y z to output r
- Note: In general, output r is not necessarily uniquely defined as in our example …
  The spec can be non-deterministic admitting several results.

16/02/18 B. Wolff - Ingé. 2 - Test 50

Test-Data Generation

- ≡ (* cleanup, distribution *)

```
(inv ∧ x=y ∧ x=y ∧ y=z ∧ r=equ) ∨        (1)
(inv ∧ x≠y ∧ y≠z ∧ x≠z ∧ r=arb ) ∨       (2)
(inv ∧ x≠y ∧ y=z ∧ r=iso) ∨              (3)
(inv ∧ x≠y ∧ x=z ∧ r=iso) ∨              (4)
(inv ∧ y≠z ∧ x=y ∧ r=iso) ∨              (5)
(inv ∧ y≠z ∧ x=z ∧ r=iso)                (6)
```

- Test-Case-Construction by DNF Method
  yields six abstract test cases
  relatibng input x y z to output r
- Note: In general, output r is not necessarily uniquely defined as in our example …
  The spec can be non-deterministic admitting several results.

16/02/18 B. Wolff - Ingé. 2 - Test 50

Test-Data Generation

- ≡ (* cleanup, distribution *)

```
(inv ∧ x=y ∧ x=y ∧ y=z ∧ r=equ) ∨        (1)
(inv ∧ x≠y ∧ y≠z ∧ x≠z ∧ r=arb ) ∨       (2)
(inv ∧ x≠y ∧ y=z ∧ r=iso) ∨              (3)
(inv ∧ x≠y ∧ x=z ∧ r=iso) ∨              (4)
(inv ∧ y≠z ∧ x=y ∧ r=iso) ∨              (5)
(inv ∧ y≠z ∧ x=z ∧ r=iso)                (6)
```

- Test-Case-Construction by DNF Method
  yields six abstract test cases
  relatibng input x y z to output r
- Note: In general, output r is not necessarily uniquely defined as in our example …
  The spec can be non-deterministic admitting several results.

16/02/18 B. Wolff - Ingé. 2 - Test 50

Test-Data Generation

- Test-Data-Selection:
  For each abstract test-case, we construct one concrete test, by choosing values that make the abstract test case true (« that satisfies the abstract test case »)

case	x	y	z	result
(1)	3	3	3	equ
(2)	3	4	6	arb
(3)	4	5	5	iso
(4)	5	4	5	iso
(5)	5	5	4	iso
(6)	4	3	4	iso

Test-Data Generation

Test-Data-Selection:
For each abstract test-case, we construct one concrete test, by choosing values that make the abstract test case true (« that satisfies the abstract test case »)

case x y z result
(1) 3 3 3 equ
(2) 3 4 6 arb
(3) 4 5 5 iso
(4) 5 4 5 iso
(5) 5 5 4 iso
(6) 4 3 4 iso

16/02/18 B. Wolff - Ingé. 2 - Test 51

Test-Data Generation

Test-Data-Selection:
For each abstract test-case, we construct one concrete test, by choosing values that make the abstract test case true (« that satisfies the abstract test case »)

case x y z result
(1) 3 3 3 equ
(2) 3 4 6 arb
(3) 4 5 5 iso
(4) 5 4 5 iso
(5) 5 5 4 iso
(6) 4 3 4 iso

16/02/18 B. Wolff - Ingé. 2 - Test 51

Test-Data Generation

Test-Data-Selection:
For each abstract test-case, we construct one concrete test, by choosing values that make the abstract test case true (« that satisfies the abstract test case »)

case x y z result
(1) 3 3 3 equ
(2) 3 4 6 arb
(3) 4 5 5 iso
(4) 5 4 5 iso
(5) 5 5 4 iso
(6) 4 3 4 iso

16/02/18 B. Wolff - Ingé. 2 - Test 51

Test-Data Generation

- A First Summary on the Test-Generation Method:
  - PHASE I: Stripping the Domain-Language (UML-MOAL) away, "purification"
  - PHASE II: Abstract Test Case Construction by "DNF computation"
  - PHASE III: Constraint Resolution (by solvers like CVC4 or Z3) "Test Data Selection"
  - COVERAGE CRITERION:
    DNF - coverage of the Spec; for each abstract test-case one concrete test-input is constructed.
    (**ISO/IEC/IEEE** 29119 calls this: Equivalence class testing)
- Remark: During Codiung phase, when the Spec does not change, the test-data-selection can be repeated easily creating always different test sets …

Test-Data Generation

- A First Summary on the Test-Generation Method:
  - PHASE I: Stripping the Domain-Language (UML-MOAL) away, "purification"
  - PHASE II: Abstract Test Case Construction by "DNF computation"
  - PHASE III: Constraint Resolution (by solvers like CVC4 or Z3) "Test Data Selection"
  - COVERAGE CRITERION:
    DNF - coverage of the Spec; for each abstract test-case one concrete test-input is constructed.
    (**ISO/IEC/IEEE** 29119 calls this: Equivalence class testing)
- Remark: During Codiung phase, when the Spec does not change, the test-data-selection can be repeated easily creating always different test sets …

16/02/18 B. Wolff - Ingé. 2 - Test 52

Test-Data Generation

- A First Summary on the Test-Generation Method:
  - PHASE I: Stripping the Domain-Language (UML-MOAL) away, "purification"
  - PHASE II: Abstract Test Case Construction by "DNF computation"
  - PHASE III: Constraint Resolution (by solvers like CVC4 or Z3) "Test Data Selection"
  - COVERAGE CRITERION:
    DNF - coverage of the Spec; for each abstract test-case one concrete test-input is constructed.
    (**ISO/IEC/IEEE** 29119 calls this: Equivalence class testing)
- Remark: During Codiung phase, when the Spec does not change, the test-data-selection can be repeated easily creating always different test sets …

16/02/18 B. Wolff - Ingé. 2 - Test 52

Test-Data Generation

- A First Summary on the Test-Generation Method:
  - PHASE I: Stripping the Domain-Language (UML-MOAL) away, "purification"
  - PHASE II: Abstract Test Case Construction by "DNF computation"
  - PHASE III: Constraint Resolution (by solvers like CVC4 or Z3) "Test Data Selection"
  - COVERAGE CRITERION:
    DNF - coverage of the Spec; for each abstract test-case one concrete test-input is constructed.
    (**ISO/IEC/IEEE** 29119 calls this: Equivalence class testing)
- Remark: During Codiung phase, when the Spec does not change, the test-data-selection can be repeated easily creating always different test sets …

16/02/18 B. Wolff - Ingé. 2 - Test 52

Test-Data Generation

- Variants:
  - Alternative to PHASE II (DNF construction): Predicate Abstraction and Tableaux-Exploration.

    Reconsider the (purified) specification:

    ```
    inv ∧
    (x=y ∧ y=z ⟶ r=equ) ∧
    ((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z)⟶ r=iso) ∧
    (x≠y ∧ y≠z ∧ x≠z ⟶ r=arb)
    ```

    It is possible to abstract this spec to a fairly small number of „base predicates" … They should be logically independent and not contain the output variable…

Test-Data Generation

- Variants:
  - Alternative to PHASE II (DNF construction): Predicate Abstraction and Tableaux-Exploration.

    Reconsider the (purified) specification:

    ```
    inv ∧
    (x=y ∧ y=z ⟶ r=equ) ∧
    ((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z)⟶ r=iso) ∧
    (x≠y ∧ y≠z ∧ x≠z ⟶ r=arb)
    ```

    It is possible to abstract this spec to a fairly small number of „base predicates" … They should be logically independent and not contain the output variable…

16/02/18 B. Wolff - Ingé. 2 - Test 53

Test-Data Generation

- Variants:
  - Alternative to PHASE II (DNF construction): Predicate Abstraction and Tableaux-Exploration.

    Reconsider the (purified) specification:

    ```
    inv ∧
    (x=y ∧ y=z ⟶ r=equ) ∧
    ((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z)⟶ r=iso) ∧
    (x≠y ∧ y≠z ∧ x≠z ⟶ r=arb)
    ```

    It is possible to abstract this spec to a fairly small number of „base predicates" … They should be logically independent and not contain the output variable…

16/02/18 B. Wolff - Ingé. 2 - Test 53

Test-Data Generation

- Variants:
  - Alternative to PHASE II (DNF construction): Predicate Abstraction and Tableaux-Exploration.

    Reconsider the (purified) specification:

    ```
    inv ∧
    (x=y ∧ y=z ⟶ r=equ) ∧
    ((x≠y ∨ y≠z) ∧ (x=y ∨ y=z ∨ x=z)⟶ r=iso) ∧
    (x≠y ∧ y≠z ∧ x≠z ⟶ r=arb)
    ```

    It is possible to abstract this spec to a fairly small number of „base predicates" … They should be logically independent and not contain the output variable…

16/02/18 B. Wolff - Ingé. 2 - Test 53

Test-Data Generation

- Variants:
  - Alternative to PHASE II (DNF construction): Predicate Abstraction and Tableaux-Exploration.

    Reconsider the (purified) specification:

    $\texttt{inv} \wedge$
    $(A \wedge B \longrightarrow r{=}equ) \wedge$
    $((\neg A \vee \neg B) \wedge (A \vee B \vee C) \longrightarrow r{=}iso) \wedge$
    $(\neg A \wedge \neg B \wedge \neg C \longrightarrow r{=}arb)$

    where $A \mapsto x{=}y$, $B \mapsto y{=}z$, $C \mapsto x{=}z$

    (actually: A and B imply C)

Test-Data Generation

- Variants:
  - Alternative to PHASE II (DNF construction): Predicate Abstraction and Tableaux-Exploration.

    Reconsider the (purified) specification:

    $\texttt{inv} \wedge$
    $(A \wedge B \longrightarrow r{=}equ) \wedge$
    $((\neg A \vee \neg B) \wedge (A \vee B \vee C) \longrightarrow r{=}iso) \wedge$
    $(\neg A \wedge \neg B \wedge \neg C \longrightarrow r{=}arb)$

    where $A \mapsto x{=}y$, $B \mapsto y{=}z$, $C \mapsto x{=}z$

    (actually: A and B imply C)

16/02/18 B. Wolff - Ingé. 2 - Test 54

Test-Data Generation

- Variants:
  - Alternative to PHASE II (DNF construction): Predicate Abstraction and Tableaux-Exploration.

    Reconsider the (purified) specification:

    $\texttt{inv} \wedge$
    $(A \wedge B \longrightarrow r{=}equ) \wedge$
    $((\neg A \vee \neg B) \wedge (A \vee B \vee C) \longrightarrow r{=}iso) \wedge$
    $(\neg A \wedge \neg B \wedge \neg C \longrightarrow r{=}arb)$

    where $A \mapsto x{=}y$, $B \mapsto y{=}z$, $C \mapsto x{=}z$

    (actually: A and B imply C)

16/02/18 B. Wolff - Ingé. 2 - Test 54

Test-Data Generation

- Variants:
  - Alternative to PHASE II (DNF construction): Predicate Abstraction and Tableaux-Exploration.

    Reconsider the (purified) specification:

    $\texttt{inv} \wedge$
    $(A \wedge B \longrightarrow r{=}equ) \wedge$
    $((\neg A \vee \neg B) \wedge (A \vee B \vee C) \longrightarrow r{=}iso) \wedge$
    $(\neg A \wedge \neg B \wedge \neg C \longrightarrow r{=}arb)$

    where $A \mapsto x{=}y$, $B \mapsto y{=}z$, $C \mapsto x{=}z$

    (actually: A and B imply C)

16/02/18 B. Wolff - Ingé. 2 - Test 54

Test-Data Generation

- Variants:
  - ... Now we can construct a tableau and get by simplification:

case	A	B	C	spec reduces to
(1)	T	T	T	• r=equ
(2)	T	T	F	• r=equ (!!!)
(3)	T	F	T	• r=iso
(4)	T	F	F	• r=iso
(5)	F	T	T	• r=iso
(6)	F	T	F	• r=iso
(7)	F	F	T	• r=iso
(8)	F	F	F	• r=arb

Test-Data Generation

- Variants:
  - ... Now we can construct a tableau and get by simplification:

case	A	B	C	spec reduces to
(1)	T	T	T	• r=equ
(2)	T	T	F	• r=equ (!!!)
(3)	T	F	T	• r=iso
(4)	T	F	F	• r=iso
(5)	F	T	T	• r=iso
(6)	F	T	F	• r=iso
(7)	F	F	T	• r=iso
(8)	F	F	F	• r=arb

16/02/18 B. Wolff - Ingé. 2 - Test 55

Test-Data Generation

- Variants:
  - ... Now we can construct a tableau and get by simplification:

case	A	B	C	spec reduces to
(1)	T	T	T	• r=equ
(2)	T	T	F	• r=equ (!!!)
(3)	T	F	T	• r=iso
(4)	T	F	F	• r=iso
(5)	F	T	T	• r=iso
(6)	F	T	F	• r=iso
(7)	F	F	T	• r=iso
(8)	F	F	F	• r=arb

16/02/18 B. Wolff - Ingé. 2 - Test 55

Test-Data Generation

- Variants:
  - ... Now we can construct a tableau and get by simplification:

case	A	B	C	spec reduces to
(1)	T	T	T	• r=equ
(2)	T	T	F	• r=equ (!!!)
(3)	T	F	T	• r=iso
(4)	T	F	F	• r=iso
(5)	F	T	T	• r=iso
(6)	F	T	F	• r=iso
(7)	F	F	T	• r=iso
(8)	F	F	F	• r=arb

16/02/18 B. Wolff - Ingé. 2 - Test 55

Test-Data Generation

- Variants:
  - PHASE III: Borderline analysis.
    Principle: we replace in our DNF inequalities by „the closest values that make the spec true"

    $x \neq y \mapsto x = y + 1 \lor x = y - 1$

    $x \leq y \mapsto x = y \lor x < y$

    $x < y \mapsto x = y - 1$ etc.

  - ... and recompute the DNF. In general, this gives a much finer mesh ...

Test-Data Generation

- Variants:
  - PHASE III: Borderline analysis.
    Principle: we replace in our DNF inequalities by „the closest values that make the spec true"

    $x \neq y \mapsto x = y + 1 \lor x = y - 1$

    $x \leq y \mapsto x = y \lor x < y$

    $x < y \mapsto x = y - 1$ etc.

  - ... and recompute the DNF. In general, this gives a much finer mesh ...

16/02/18 B. Wolff - Ingé. 2 - Test 56

Test-Data Generation

- Variants:
  - PHASE III: Borderline analysis.
    Principle: we replace in our DNF inequalities by „the closest values that make the spec true"

    $x \neq y \mapsto x = y + 1 \lor x = y - 1$

    $x \leq y \mapsto x = y \lor x < y$

    $x < y \mapsto x = y - 1$ etc.

  - ... and recompute the DNF. In general, this gives a much finer mesh ...

16/02/18 B. Wolff - Ingé. 2 - Test 56

Test-Data Generation

- Variants:
  - PHASE III: Borderline analysis.
    Principle: we replace in our DNF inequalities by „the closest values that make the spec true"

    $x \neq y \mapsto x = y + 1 \lor x = y - 1$

    $x \leq y \mapsto x = y \lor x < y$

    $x < y \mapsto x = y - 1$ etc.

  - ... and recompute the DNF. In general, this gives a much finer mesh ...

16/02/18 B. Wolff - Ingé. 2 - Test 56

Test-Data Generation

- Variants:
  - PHASE I: Test for exceptional behaviour.

    We negate the precondition and to DNF generation on the precondition only.

    Test objectives could be:

    - should raise an exception if public
    - should not diverge

Test-Data Generation

- Variants:
  - PHASE I: Test for exceptional behaviour.

    We negate the precondition and to DNF generation on the precondition only.

    Test objectives could be:

    - should raise an exception if public
    - should not diverge

16/02/18 B. Wolff - Ingé. 2 - Test 57

Test-Data Generation

- Variants:
  - PHASE I: Test for exceptional behaviour.

    We negate the precondition and to DNF generation on the precondition only.

    Test objectives could be:

    - should raise an exception if public
    - should not diverge

16/02/18 B. Wolff - Ingé. 2 - Test 57

Test-Data Generation

- Variants:
  - PHASE I: Test for exceptional behaviour.

    We negate the precondition and to DNF generation on the precondition only.

    Test objectives could be:

    - should raise an exception if public
    - should not diverge

16/02/18 B. Wolff - Ingé. 2 - Test 57

Test-Data Generation

- How to handle Recursion ?

Test-Data Generation

- How to handle Recursion ?

16/02/18 B. Wolff - Ingé. 2 - Test 58

Test-Data Generation

- How to handle Recursion ?

16/02/18 B. Wolff - Ingé. 2 - Test 58

Test-Data Generation

- How to handle Recursion ?

16/02/18 B. Wolff - Ingé. 2 - Test 58

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:

  - at the level of data

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:

  - at the level of data

16/02/18 B. Wolff - Ingé. 2 - Test 59

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:

  - at the level of data

16/02/18 B. Wolff - Ingé. 2 - Test 59

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:

  - at the level of data

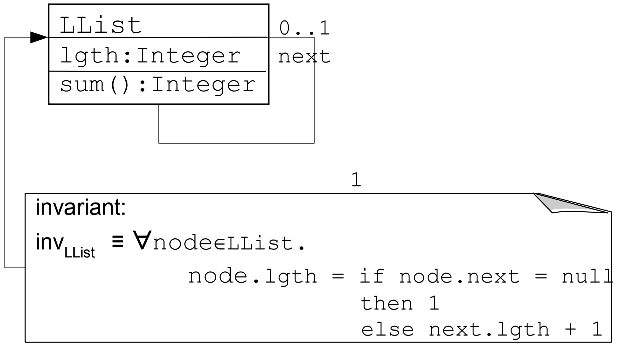
16/02/18 B. Wolff - Ingé. 2 - Test 59

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:

  - at the level of data

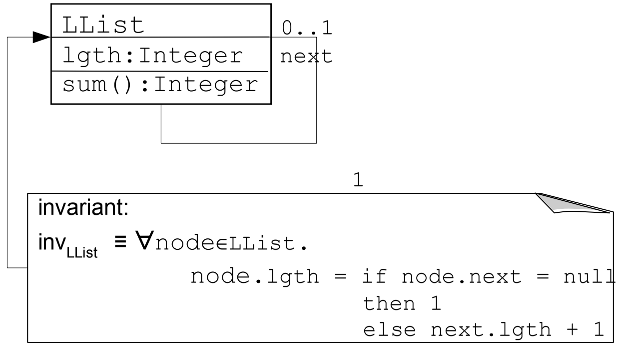


Test-Data Generation

How to handle Recursion ?

In UML/MOAL, recursion occurs (at least) at two points:

at the level of data



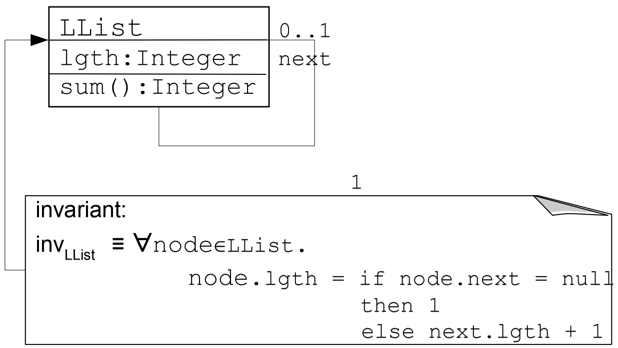
16/02/18 B. Wolff - Ingé. 2 - Test 60

Test-Data Generation

How to handle Recursion ?

In UML/MOAL, recursion occurs (at least) at two points:

at the level of data



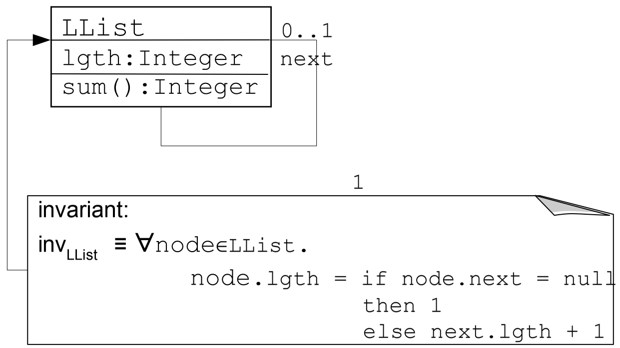
16/02/18 B. Wolff - Ingé. 2 - Test 60

Test-Data Generation

How to handle Recursion ?

In UML/MOAL, recursion occurs (at least) at two points:

at the level of data



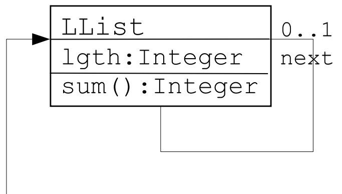
16/02/18 B. Wolff - Ingé. 2 - Test 60

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:

  - at the level of data



invariant:

```
inv_LList ≡ ∀node∊LList.
        node.lgth = if node.next = null
                    then 1
                    else next.lgth + 1
```

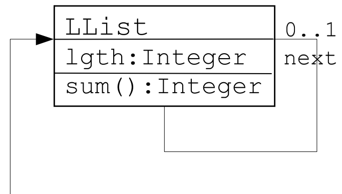
Note that this excludes cyclic lists !!!

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:

  - at the level of data



invariant:

```
inv_LList ≡ ∀node∊LList.
        node.lgth = if node.next = null
                    then 1
                    else next.lgth + 1
```

Note that this excludes cyclic lists !!!

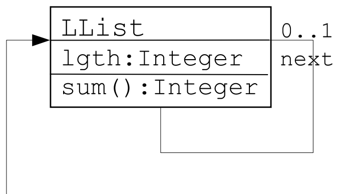
16/02/18 B. Wolff - Ingé. 2 - Test 61

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:

  - at the level of data



invariant:

```
inv_LList ≡ ∀node∊LList.
        node.lgth = if node.next = null
                    then 1
                    else next.lgth + 1
```

Note that this excludes cyclic lists !!!

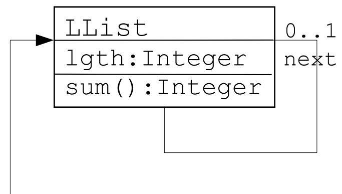
16/02/18 B. Wolff - Ingé. 2 - Test 61

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:

  - at the level of data



invariant:

```
inv_LList ≡ ∀node∊LList.
        node.lgth = if node.next = null
                    then 1
                    else next.lgth + 1
```

Note that this excludes cyclic lists !!!

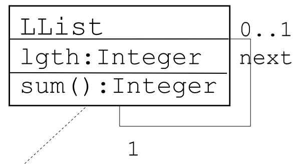
16/02/18 B. Wolff - Ingé. 2 - Test 61

Test-Data Generation

- How to handle Recursion ?

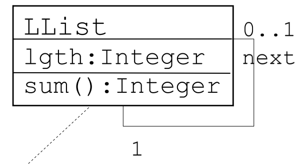
  In UML/MOAL, recursion occurs (at least) at two points:

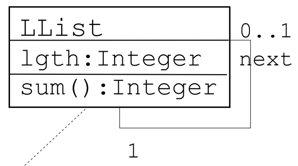
  - at the level of operations (post-conds may contain calls ...)

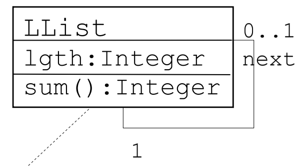


query contract (modifiesOnly({})):

```
definition pre_sum(l)  ≡ True
definition post_sum(l,res)≡ res=if l.next=null then l.lgth
                                else l.lgth + l.next.sum()
definition sum(l)≡ arb{r|pre_sum(l) ∧ post_sum(l,r)}
```


Test-Data Generation
How to handle Recursion ?
In UML/MOAL, recursion occurs (at least) at two points:
at the level of operations (post-conds may contain calls ...)

query contract (modifiesOnly({})):
definition pre_sum(l) ≡ True
definition post_sum(l,res)≡ res=if l.next=null then l.lgth else l.lgth + l.next.sum()
definition sum(l)≡ arb{r|pre_sum(l) ∧ post_sum(l,r)}
16/02/18 B. Wolff - Ingé. 2 - Test 62

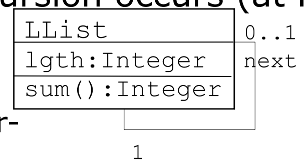
Test-Data Generation
How to handle Recursion ?
In UML/MOAL, recursion occurs (at least) at two points:
at the level of operations (post-conds may contain calls ...)

query contract (modifiesOnly({})):
definition pre_sum(l) ≡ True
definition post_sum(l,res)≡ res=if l.next=null then l.lgth else l.lgth + l.next.sum()
definition sum(l)≡ arb{r|pre_sum(l) ∧ post_sum(l,r)}
16/02/18 B. Wolff - Ingé. 2 - Test 62

Test-Data Generation
How to handle Recursion ?
In UML/MOAL, recursion occurs (at least) at two points:
at the level of operations (post-conds may contain calls ...)

query contract (modifiesOnly({})):
definition pre_sum(l) ≡ True
definition post_sum(l,res)≡ res=if l.next=null then l.lgth else l.lgth + l.next.sum()
definition sum(l)≡ arb{r|pre_sum(l) ∧ post_sum(l,r)}
16/02/18 B. Wolff - Ingé. 2 - Test 62

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:



f oper-
conds
calls …)

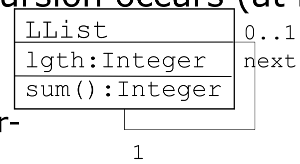
```
um(l)  ≡ True
sum(l,res)≡ res=if l.next=null then l.lgth
                else l.lgth + l.next.sum()
(l)≡ arb{r|pre_sum(l) ∧ post_sum(l,r)}
```

Note that arb(S) gives an arbitrary member of S: arb(S)∈S.
Since from x=arb({y}) follows x=y;
thus sum(l) is (uniquely) defined.
The (σ,σ') convention applies.

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:



f oper-
conds
calls …)

um(l) ≡ True
sum(l,res)≡ res=if l.next=null then l.lgth else l.lgth + l.next.sum()
(l)≡ arb{r|pre_sum(l) ∧ post_sum(l,r)}

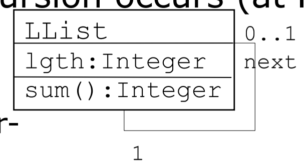
Note that arb(S) gives an arbitrary member of S: arb(S)∈S.
Since from x=arb({y}) follows x=y;
thus sum(l) is (uniquely) defined.
The (σ,σ') convention applies.

16/02/18 B. Wolff - Ingé. 2 - Test 63

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:



f oper-
conds
calls …)

um(l) ≡ True
sum(l,res)≡ res=if l.next=null then l.lgth else l.lgth + l.next.sum()
(l)≡ arb{r|pre_sum(l) ∧ post_sum(l,r)}

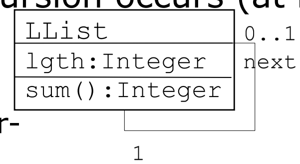
Note that arb(S) gives an arbitrary member of S: arb(S)∈S.
Since from x=arb({y}) follows x=y;
thus sum(l) is (uniquely) defined.
The (σ,σ') convention applies.

16/02/18 B. Wolff - Ingé. 2 - Test 63

Test-Data Generation

- How to handle Recursion ?

  In UML/MOAL, recursion occurs (at least) at two points:



f oper-
conds
calls …)

um(l) ≡ True
sum(l,res)≡ res=if l.next=null then l.lgth else l.lgth + l.next.sum()
(l)≡ arb{r|pre_sum(l) ∧ post_sum(l,r)}

Note that arb(S) gives an arbitrary member of S: arb(S)∈S.
Since from x=arb({y}) follows x=y;
thus sum(l) is (uniquely) defined.
The (σ,σ') convention applies.

16/02/18 B. Wolff - Ingé. 2 - Test 63

Test-Data Generation

- Prerequisite: We present the invariant as recursive predicate.

definition inv_{LList_Core} n σ ≡ (n.lgth(σ) = if n.next(σ)=null then 1
else n.next.lgth(σ) + 1)

we have:

inv_{LList} (σ) = ∀n∈LList(σ). inv_{LList_Core} n σ

and

inv_{LList_Core} (n) (σ) = (if n.next(σ)=null then n.lgth(σ) = 1
else n.lgth(σ) =n.next.lgth(σ) + 1
∧ n.next(σ)∈LList(σ)
∧ inv_{LList_Core} (n.next) (σ))

(under the assumption that n∈LList(σ))

Furthermore we have:

sum(l)(σ',σ) = if l.next(σ)=null then l.lgth(σ)
else l.lgth(σ) + sum(l.next)(σ',σ)

We have σ'=σ (why?). We will again apply (σ',σ) – convention.

Test-Data Generation

- Prerequisite: We present the invariant as recursive predicate.

definition inv_{LList_Core} n σ ≡ (n.lgth(σ) = if n.next(σ)=null then 1
else n.next.lgth(σ) + 1)

we have:

inv_{LList} (σ) = ∀n∈LList(σ). inv_{LList_Core} n σ

and

inv_{LList_Core} (n) (σ) = (if n.next(σ)=null then n.lgth(σ) = 1
else n.lgth(σ) =n.next.lgth(σ) + 1
∧ n.next(σ)∈LList(σ)
∧ inv_{LList_Core} (n.next) (σ))

(under the assumption that n∈LList(σ))

Furthermore we have:

sum(l)(σ',σ) = if l.next(σ)=null then l.lgth(σ)
else l.lgth(σ) + sum(l.next)(σ',σ)

We have σ'=σ (why?). We will again apply (σ',σ) – convention.

16/02/18 B. Wolff - Ingé. 2 - Test 64

Test-Data Generation

- Prerequisite: We present the invariant as recursive predicate.

definition inv_{LList_Core} n σ ≡ (n.lgth(σ) = if n.next(σ)=null then 1
else n.next.lgth(σ) + 1)

we have:

inv_{LList} (σ) = ∀n∈LList(σ). inv_{LList_Core} n σ

and

inv_{LList_Core} (n) (σ) = (if n.next(σ)=null then n.lgth(σ) = 1
else n.lgth(σ) =n.next.lgth(σ) + 1
∧ n.next(σ)∈LList(σ)
∧ inv_{LList_Core} (n.next) (σ))

(under the assumption that n∈LList(σ))

Furthermore we have:

sum(l)(σ',σ) = if l.next(σ)=null then l.lgth(σ)
else l.lgth(σ) + sum(l.next)(σ',σ)

We have σ'=σ (why?). We will again apply (σ',σ) – convention.

16/02/18 B. Wolff - Ingé. 2 - Test 64

Test-Data Generation

- Prerequisite: We present the invariant as recursive predicate.

definition inv_{LList_Core} n σ ≡ (n.lgth(σ) = if n.next(σ)=null then 1
else n.next.lgth(σ) + 1)

we have:

inv_{LList} (σ) = ∀n∈LList(σ). inv_{LList_Core} n σ

and

inv_{LList_Core} (n) (σ) = (if n.next(σ)=null then n.lgth(σ) = 1
else n.lgth(σ) =n.next.lgth(σ) + 1
∧ n.next(σ)∈LList(σ)
∧ inv_{LList_Core} (n.next) (σ))

(under the assumption that n∈LList(σ))

Furthermore we have:

sum(l)(σ',σ) = if l.next(σ)=null then l.lgth(σ)
else l.lgth(σ) + sum(l.next)(σ',σ)

We have σ'=σ (why?). We will again apply (σ',σ) – convention.

16/02/18 B. Wolff - Ingé. 2 - Test 64

Test-Data Generation

- Consider the test specification:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ≡ inv_{LList}(X) ∧ pre_{sum}(X) ∧ $post_{sum}$(X,Y)

  where:

  pre_{sum}(X) ≡ true

  $post_{sum}$(X,Y) ≡ (if X.next = null then Y = X.lgth
  else Y = X.lgth + sum(X.next))
  ≡ (X.next=null ∧ Y = X.lgth)
  ∨ (X.next≠null ∧ Y = X.lgth+sum(X.next))

Test-Data Generation

- Consider the test specification:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ≡ inv_{LList}(X) ∧ pre_{sum}(X) ∧ $post_{sum}$(X,Y)

  where:

  pre_{sum}(X) ≡ true

  $post_{sum}$(X,Y) ≡ (if X.next = null then Y = X.lgth
  else Y = X.lgth + sum(X.next))
  ≡ (X.next=null ∧ Y = X.lgth)
  ∨ (X.next≠null ∧ Y = X.lgth+sum(X.next))

16/02/18 B. Wolff - Ingé. 2 - Test 65

Test-Data Generation

- Consider the test specification:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ≡ inv_{LList}(X) ∧ pre_{sum}(X) ∧ $post_{sum}$(X,Y)

  where:

  pre_{sum}(X) ≡ true

  $post_{sum}$(X,Y) ≡ (if X.next = null then Y = X.lgth
  else Y = X.lgth + sum(X.next))
  ≡ (X.next=null ∧ Y = X.lgth)
  ∨ (X.next≠null ∧ Y = X.lgth+sum(X.next))

16/02/18 B. Wolff - Ingé. 2 - Test 65

Test-Data Generation

- Consider the test specification:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ≡ inv_{LList}(X) ∧ pre_{sum}(X) ∧ $post_{sum}$(X,Y)

  where:

  pre_{sum}(X) ≡ true

  $post_{sum}$(X,Y) ≡ (if X.next = null then Y = X.lgth
  else Y = X.lgth + sum(X.next))
  ≡ (X.next=null ∧ Y = X.lgth)
  ∨ (X.next≠null ∧ Y = X.lgth+sum(X.next))

16/02/18 B. Wolff - Ingé. 2 - Test 65

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ inv_{LList_Core}(X) ∧ $post_{sum}$(X,Y))
  ≡ (if X.next=null then X.lgth = 1
  else X.lgth =X.next.lgth+1 ∧ X.next∈LList ∧ inv_{LList_Core}(X.next)) ∧
  (if X.next = null then Y = X.lgth
  else Y = X.lgth + sum(X.next))
  ≡ (DNF)
  (X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
  ∨ (X.next≠null ∧ X.lgth =X.next.lgth+1
  ∧ X.next∈LList ∧ inv_{LList_Core}(X.next)
  ∧ Y = X.lgth+sum(X.next))

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ inv_{LList_Core}(X) ∧ $post_{sum}$(X,Y))
  ≡ (if X.next=null then X.lgth = 1
  else X.lgth =X.next.lgth+1 ∧ X.next∈LList ∧ inv_{LList_Core}(X.next)) ∧
  (if X.next = null then Y = X.lgth
  else Y = X.lgth + sum(X.next))
  ≡ (DNF)
  (X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
  ∨ (X.next≠null ∧ X.lgth =X.next.lgth+1
  ∧ X.next∈LList ∧ inv_{LList_Core}(X.next)
  ∧ Y = X.lgth+sum(X.next))

16/02/18 B. Wolff - Ingé. 2 - Test 66

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ inv_{LList_Core}(X) ∧ $post_{sum}$(X,Y))
  ≡ (if X.next=null then X.lgth = 1
  else X.lgth =X.next.lgth+1 ∧ X.next∈LList ∧ inv_{LList_Core}(X.next)) ∧
  (if X.next = null then Y = X.lgth
  else Y = X.lgth + sum(X.next))
  ≡ (DNF)
  (X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
  ∨ (X.next≠null ∧ X.lgth =X.next.lgth+1
  ∧ X.next∈LList ∧ inv_{LList_Core}(X.next)
  ∧ Y = X.lgth+sum(X.next))

16/02/18 B. Wolff - Ingé. 2 - Test 66

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ inv_{LList_Core}(X) ∧ $post_{sum}$(X,Y))
  ≡ (if X.next=null then X.lgth = 1
  else X.lgth =X.next.lgth+1 ∧ X.next∈LList ∧ inv_{LList_Core}(X.next)) ∧
  (if X.next = null then Y = X.lgth
  else Y = X.lgth + sum(X.next))
  ≡ (DNF)
  (X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
  ∨ (X.next≠null ∧ X.lgth =X.next.lgth+1
  ∧ X.next∈LList ∧ inv_{LList_Core}(X.next)
  ∧ Y = X.lgth+sum(X.next))

16/02/18 B. Wolff - Ingé. 2 - Test 66

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

```
⟹  inv_LList_Core(X) ∧ post_sum(X,Y))
≡  (if X.next=null then X.lgth = 1
    else X.lgth =X.next.lgth+1 ∧ X.next∈LList ∧ inv_LList_Cor
   (if X.next = null then Y = X.lgth
                     else Y =X.lgth + sum(X.next))
≡  (if c then C else D elim, DNF)
    (X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
  ∨ (X.next≠null ∧ X.lgth =X.next.lgth+1
     ∧ X.next∈LList ∧ inv_LList_Core(X.next)
     ∧ Y = X.lgth+sum(X.next))
```

New Test-Case!!

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

```
⟹  inv_LList_Core(X) ∧ post_sum(X,Y))
≡  (if X.next=null then X.lgth = 1
    else X.lgth =X.next.lgth+1 ∧ X.next∈LList ∧ inv_LList_Cor
   (if X.next = null then Y = X.lgth
                     else Y =X.lgth + sum(X.next))
≡  (if c then C else D elim, DNF)
    (X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
  ∨ (X.next≠null ∧ X.lgth =X.next.lgth+1
     ∧ X.next∈LList ∧ inv_LList_Core(X.next)
     ∧ Y = X.lgth+sum(X.next))
```

New Test-Case!!

16/02/18 B. Wolff - Ingé. 2 - Test 67

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

```
⟹  inv_LList_Core(X) ∧ post_sum(X,Y))
≡  (if X.next=null then X.lgth = 1
    else X.lgth =X.next.lgth+1 ∧ X.next∈LList ∧ inv_LList_Cor
   (if X.next = null then Y = X.lgth
                     else Y =X.lgth + sum(X.next))
≡  (if c then C else D elim, DNF)
    (X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
  ∨ (X.next≠null ∧ X.lgth =X.next.lgth+1
     ∧ X.next∈LList ∧ inv_LList_Core(X.next)
     ∧ Y = X.lgth+sum(X.next))
```

New Test-Case!!

16/02/18 B. Wolff - Ingé. 2 - Test 67

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

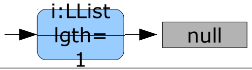
```
⟹  inv_LList_Core(X) ∧ post_sum(X,Y))
≡  (if X.next=null then X.lgth = 1
    else X.lgth =X.next.lgth+1 ∧ X.next∈LList ∧ inv_LList_Cor
   (if X.next = null then Y = X.lgth
                     else Y =X.lgth + sum(X.next))
≡  (if c then C else D elim, DNF)
    (X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
  ∨ (X.next≠null ∧ X.lgth =X.next.lgth+1
     ∧ X.next∈LList ∧ inv_LList_Core(X.next)
     ∧ Y = X.lgth+sum(X.next))
```

New Test-Case!!

16/02/18 B. Wolff - Ingé. 2 - Test 67

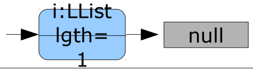
Test-Data Generation

- Intermediate Summary: test-cases known so far ?

X	Y
	1
...	...
...	...

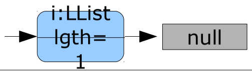
Test-Data Generation

Intermediate Summary: test-cases known so far ?

X	Y
	1
...	...
...	...

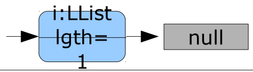
Test-Data Generation

Intermediate Summary: test-cases known so far ?

X	Y
	1
...	...
...	...

Test-Data Generation

Intermediate Summary: test-cases known so far ?

X	Y
	1
...	...
...	...

Test-Data Generation

- Prerequisite: We present the invariant as recursive predicate.

inv_{LList_Core} `(n) = (if n.next=null then n.lgth = 1`
`else n.lgth =n.next.lgth + 1`
`∧ n.next∈LList ∧` inv_{LList_Core} `(n.next))`

- ```
  sum(l) = if l.next=null then l.lgth
           else l.lgth + sum(l.next)
  ```

```
sum(l) = if X.next.next=null then X.next.lgth
         else X.next.lgth + sum(X.next.next)
```


Test-Data Generation

- Prerequisite: We present the invariant as recursive predicate.

inv_{LList_Core} `(n) = (if n.next=null then n.lgth = 1`
`else n.lgth =n.next.lgth + 1`
`∧ n.next∈LList ∧` inv_{LList_Core} `(n.next))`

- sum(l) = if l.next=null then l.lgth
  else l.lgth + sum(l.next)

sum(l) = if X.next.next=null then X.next.lgth
else X.next.lgth + sum(X.next.next)

16/02/18 B. Wolff - Ingé. 2 - Test 69

Test-Data Generation

- Prerequisite: We present the invariant as recursive predicate.

inv_{LList_Core} `(n) = (if n.next=null then n.lgth = 1`
`else n.lgth =n.next.lgth + 1`
`∧ n.next∈LList ∧` inv_{LList_Core} `(n.next))`

- sum(l) = if l.next=null then l.lgth
  else l.lgth + sum(l.next)

sum(l) = if X.next.next=null then X.next.lgth
else X.next.lgth + sum(X.next.next)

16/02/18 B. Wolff - Ingé. 2 - Test 69

Test-Data Generation

- Prerequisite: We present the invariant as recursive predicate.

inv_{LList_Core} `(n) = (if n.next=null then n.lgth = 1`
`else n.lgth =n.next.lgth + 1`
`∧ n.next∈LList ∧` inv_{LList_Core} `(n.next))`

- sum(l) = if l.next=null then l.lgth
  else l.lgth + sum(l.next)

sum(l) = if X.next.next=null then X.next.lgth
else X.next.lgth + sum(X.next.next)

16/02/18 B. Wolff - Ingé. 2 - Test 69
```

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ … ≡ …

  ≡ (unfolding sum and inv_{LList_Core})

```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ (if X.next.next=null then X.next.lgth = 1
          else X.next.lgth =X.next.next.lgth + 1
               ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next))
   ∧ (Y = X.lgth+(if X.next.next=null then X.next.lgth
                    else X.next.lgth + sum(X.next.next))))
```


Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ … ≡ …

  ≡ (unfolding sum and inv_{LList_Core})

```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ (if X.next.next=null then X.next.lgth = 1
          else X.next.lgth =X.next.next.lgth + 1
               ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next))
   ∧ (Y = X.lgth+(if X.next.next=null then X.next.lgth
                    else X.next.lgth + sum(X.next.next))))
```

16/02/18 B. Wolff - Ingé. 2 - Test 70

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ … ≡ …

  ≡ (unfolding sum and inv_{LList_Core})

```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ (if X.next.next=null then X.next.lgth = 1
          else X.next.lgth =X.next.next.lgth + 1
               ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next))
   ∧ (Y = X.lgth+(if X.next.next=null then X.next.lgth
                    else X.next.lgth + sum(X.next.next))))
```

16/02/18 B. Wolff - Ingé. 2 - Test 70

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ … ≡ …

  ≡ (unfolding sum and inv_{LList_Core})

```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ (if X.next.next=null then X.next.lgth = 1
          else X.next.lgth =X.next.next.lgth + 1
               ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next))
   ∧ (Y = X.lgth+(if X.next.next=null then X.next.lgth
                    else X.next.lgth + sum(X.next.next))))
```

16/02/18 B. Wolff - Ingé. 2 - Test 70

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ … ≡ ...

  ≡ (DNF partial)

```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ ((X.next.next=null ∧ X.next.lgth = 1 ∧
      Y = X.lgth+X.next.lgth)
     ∨(X.next.next≠null ∧ X.next.lgth=X.next.next.lgth+1
       ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next)
       ∧ Y = X.lgth+ X.next.lgth + sum(X.next.next))
     )
```


Test-Data Generation

DNF computation yields already the test cases:

X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

⟹ … ≡ ...

≡ (DNF partial)

(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
∧ ((X.next.next=null ∧ X.next.lgth = 1 ∧
Y = X.lgth+X.next.lgth)
∨(X.next.next≠null ∧ X.next.lgth=X.next.next.lgth+1
∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next)
∧ Y = X.lgth+ X.next.lgth + sum(X.next.next))
)

16/02/18 B. Wolff - Ingé. 2 - Test 71

Test-Data Generation

DNF computation yields already the test cases:

X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

⟹ … ≡ ...

≡ (DNF partial)

(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
∧ ((X.next.next=null ∧ X.next.lgth = 1 ∧
Y = X.lgth+X.next.lgth)
∨(X.next.next≠null ∧ X.next.lgth=X.next.next.lgth+1
∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next)
∧ Y = X.lgth+ X.next.lgth + sum(X.next.next))
)

16/02/18 B. Wolff - Ingé. 2 - Test 71

Test-Data Generation

DNF computation yields already the test cases:

X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

⟹ … ≡ ...

≡ (DNF partial)

(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
∧ ((X.next.next=null ∧ X.next.lgth = 1 ∧
Y = X.lgth+X.next.lgth)
∨(X.next.next≠null ∧ X.next.lgth=X.next.next.lgth+1
∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next)
∧ Y = X.lgth+ X.next.lgth + sum(X.next.next))
)

16/02/18 B. Wolff - Ingé. 2 - Test 71

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ … ≡ …

  ≡ (DNF partial)

```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next=null ∧ X.next.lgth=1 ∧
     Y = X.lgth+X.next.lgth))
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next≠null ∧ X.next.lgth=X.next.next.lgth+1
          ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next)
          ∧ Y = X.lgth+ X.next.lgth + sum(X.next.next)))
```


Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ … ≡ …

  ≡ (DNF partial)

```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next=null ∧ X.next.lgth=1 ∧
     Y = X.lgth+X.next.lgth))
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next≠null ∧ X.next.lgth=X.next.next.lgth+1
          ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next)
          ∧ Y = X.lgth+ X.next.lgth + sum(X.next.next)))
```

16/02/18 B. Wolff - Ingé. 2 - Test 72

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ … ≡ …

  ≡ (DNF partial)

```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next=null ∧ X.next.lgth=1 ∧
     Y = X.lgth+X.next.lgth))
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next≠null ∧ X.next.lgth=X.next.next.lgth+1
          ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next)
          ∧ Y = X.lgth+ X.next.lgth + sum(X.next.next)))
```

16/02/18 B. Wolff - Ingé. 2 - Test 72

Test-Data Generation

- DNF computation yields already the test cases:

  X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

  ⟹ … ≡ …

  ≡ (DNF partial)

```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next=null ∧ X.next.lgth=1 ∧
     Y = X.lgth+X.next.lgth))
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next≠null ∧ X.next.lgth=X.next.next.lgth+1
          ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next)
          ∧ Y = X.lgth+ X.next.lgth + sum(X.next.next)))
```

16/02/18 B. Wolff - Ingé. 2 - Test 72

Test-Data Generation

- DNF computation yields already the test cases:

X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

⟹ … ≡ …

≡ (DNF partial)

```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next=null ∧ X.next.lgth=1 ∧
     Y = X.lgth+X.next.lgth))
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next≠null ∧ X.next.lgth=X.next.next.lgth+1
         ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next)
         ∧ Y = X.lgth+ X.next.lgth + sum(X.next.next)))
```

New Test-Case!!

Test-Data Generation

- DNF computation yields already the test cases:

X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

⟹ … ≡ …

≡ (DNF partial)

```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next=null ∧ X.next.lgth=1 ∧
     Y = X.lgth+X.next.lgth))
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next≠null ∧ X.next.lgth=X.next.next.lgth+1
         ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next)
         ∧ Y = X.lgth+ X.next.lgth + sum(X.next.next)))
```

New Test-Case!!

16/02/18 B. Wolff - Ingé. 2 - Test 73

Test-Data Generation

- DNF computation yields already the test cases:

X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

⟹ … ≡ …

≡ (DNF partial)

```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next=null ∧ X.next.lgth=1 ∧
     Y = X.lgth+X.next.lgth))
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next≠null ∧ X.next.lgth=X.next.next.lgth+1
         ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next)
         ∧ Y = X.lgth+ X.next.lgth + sum(X.next.next)))
```

New Test-Case!!

16/02/18 B. Wolff - Ingé. 2 - Test 73

Test-Data Generation

- DNF computation yields already the test cases:

X.sum() ≡ Y (for some X∈LList, i.e. X≠null)

⟹ … ≡ …

≡ (DNF partial)

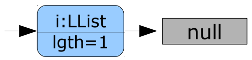
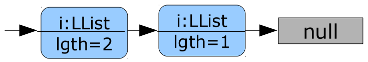
```
(X.next=null ∧ X.lgth=1 ∧ Y = X.lgth)
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next=null ∧ X.next.lgth=1 ∧
     Y = X.lgth+X.next.lgth))
∨ (X.next≠null ∧ X.lgth=X.next.lgth+1 ∧ X.next∈LList
   ∧ X.next.next≠null ∧ X.next.lgth=X.next.next.lgth+1
         ∧ X.next.next∈LList ∧ inv_LList_Core(X.next.next)
         ∧ Y = X.lgth+ X.next.lgth + sum(X.next.next)))
```

New Test-Case!!

16/02/18 B. Wolff - Ingé. 2 - Test 73

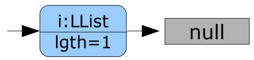
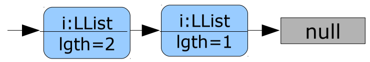
Test-Data Generation

Intermediate Summary: test-cases known so far ?

X	Y
	1
	3
...	...

Test-Data Generation

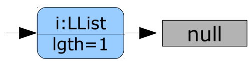
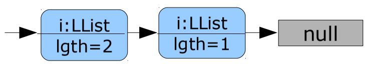
Intermediate Summary: test-cases known so far ?

X	Y
	1
	3
...	...

16/02/18 B. Wolff - Ingé. 2 - Test 74

Test-Data Generation

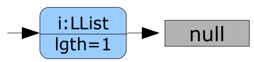
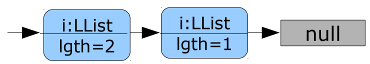
Intermediate Summary: test-cases known so far ?

X	Y
	1
	3
...	...

16/02/18 B. Wolff - Ingé. 2 - Test 74

Test-Data Generation

Intermediate Summary: test-cases known so far ?

X	Y
	1
	3
...	...

16/02/18 B. Wolff - Ingé. 2 - Test 74

Summary: Symbolic Test-Case Generation

- ... and we could continue forever
  - compile to semantics
    (-> convert in mathematical, logical notation)
  - use recursive predicates, recursive contracts
  - enter loop:
    - unfold predicates one step
    - compute DNF
    - simplify DNF
    - extract test-cases

      until we are satisfied, i.e. have „enough" test cases ...
  - Select test-data: constraint resolution of test cases.

Summary: Symbolic Test-Case Generation
... and we could continue forever
compile to semantics
(-> convert in mathematical, logical notation)
use recursive predicates, recursive contracts
enter loop:
unfold predicates one step
compute DNF
simplify DNF
extract test-cases
until we are satisfied, i.e. have „enough" test cases ...
Select test-data: constraint resolution of test cases.
16/02/18 B. Wolff - Ingé. 2 - Test 75

Summary: Symbolic Test-Case Generation
... and we could continue forever
compile to semantics
(-> convert in mathematical, logical notation)
use recursive predicates, recursive contracts
enter loop:
unfold predicates one step
compute DNF
simplify DNF
extract test-cases
until we are satisfied, i.e. have „enough" test cases ...
Select test-data: constraint resolution of test cases.
16/02/18 B. Wolff - Ingé. 2 - Test 75

Summary: Symbolic Test-Case Generation
... and we could continue forever
compile to semantics
(-> convert in mathematical, logical notation)
use recursive predicates, recursive contracts
enter loop:
unfold predicates one step
compute DNF
simplify DNF
extract test-cases
until we are satisfied, i.e. have „enough" test cases ...
Select test-data: constraint resolution of test cases.
16/02/18 B. Wolff - Ingé. 2 - Test 75

Test-Data Generation

- Observation: "all other cases" ... were represented by the clauses still containing recursive predicates.
- Logically: we used a regularity hypothesis, i.e ...

$$(\forall X.\ |X|<k \Rightarrow X.sum() \equiv Y) \Rightarrow (\forall X.\ X.sum() \equiv Y)$$

where we choose as "complexity mesure" |X| just X.lgth and k (the number of unfoldings) was 2 ...

Test-Data Generation

- Observation: "all other cases" ... were represented by the clauses still containing recursive predicates.
- Logically: we used a regularity hypothesis, i.e ...

$$(\forall X.\ |X|<k \Rightarrow X.sum() \equiv Y) \Rightarrow (\forall X.\ X.sum() \equiv Y)$$

where we choose as "complexity mesure" |X| just X.lgth and k (the number of unfoldings) was 2 ...

16/02/18 B. Wolff - Ingé. 2 - Test 76

Test-Data Generation

- Observation: "all other cases" ... were represented by the clauses still containing recursive predicates.
- Logically: we used a regularity hypothesis, i.e ...

$$(\forall X.\ |X|<k \Rightarrow X.sum() \equiv Y) \Rightarrow (\forall X.\ X.sum() \equiv Y)$$

where we choose as "complexity mesure" |X| just X.lgth and k (the number of unfoldings) was 2 ...

16/02/18 B. Wolff - Ingé. 2 - Test 76

Test-Data Generation

- Observation: "all other cases" ... were represented by the clauses still containing recursive predicates.
- Logically: we used a regularity hypothesis, i.e ...

$$(\forall X.\ |X|<k \Rightarrow X.sum() \equiv Y) \Rightarrow (\forall X.\ X.sum() \equiv Y)$$

where we choose as "complexity mesure" |X| just X.lgth and k (the number of unfoldings) was 2 ...

16/02/18 B. Wolff - Ingé. 2 - Test 76

Test-Data Generation

- Coverage Criterion for a Test:

  DNF_k

  For all data up to structural complexity k, we constructed abstract test-cases and generated a test.

  In our example, the “complexity measure” is just the length of the LLists. It could be the depth in trees or ...

Test-Data Generation

- Coverage Criterion for a Test:

  DNF_k

  For all data up to structural complexity k, we constructed abstract test-cases and generated a test.

  In our example, the “complexity measure” is just the length of the LLists. It could be the depth in trees or ...

16/02/18 B. Wolff - Ingé. 2 - Test 77

Test-Data Generation

- Coverage Criterion for a Test:

  DNF_k

  For all data up to structural complexity k, we constructed abstract test-cases and generated a test.

  In our example, the “complexity measure” is just the length of the LLists. It could be the depth in trees or ...

16/02/18 B. Wolff - Ingé. 2 - Test 77

Test-Data Generation

- Coverage Criterion for a Test:

  DNF_k

  For all data up to structural complexity k, we constructed abstract test-cases and generated a test.

  In our example, the “complexity measure” is just the length of the LLists. It could be the depth in trees or ...

16/02/18 B. Wolff - Ingé. 2 - Test 77

Test-Data Generation

- What are the alternatives to symbolic test-case generation ?

  Must this really be so complicated ???

  Well, think about the probability to "guess" input with a complex invariant and precondition, if you use "blind" random-generation procedure ...

Test-Data Generation

- What are the alternatives to symbolic test-case generation ?

  Must this really be so complicated ???

  Well, think about the probability to "guess" input with a complex invariant and precondition, if you use "blind" random-generation procedure ...

16/02/18 B. Wolff - Ingé. 2 - Test 78

Test-Data Generation

- What are the alternatives to symbolic test-case generation ?

  Must this really be so complicated ???

  Well, think about the probability to "guess" input with a complex invariant and precondition, if you use "blind" random-generation procedure ...

16/02/18 B. Wolff - Ingé. 2 - Test 78

Test-Data Generation

- What are the alternatives to symbolic test-case generation ?

  Must this really be so complicated ???

  Well, think about the probability to "guess" input with a complex invariant and precondition, if you use "blind" random-generation procedure ...

16/02/18 B. Wolff - Ingé. 2 - Test 78

Test-Data Generation

- Summary
  - We have (sketched) a symbolic Test-Case Generation Procedure for UML/MOAL Specifications
  - It takes into account:
    - object orientation
    - data invariants (recursive predicates)
    - recursive functions (via unfolding)
  - The process can be tool-supported (HOL-TestGen)
  - The process is intended for automation.

Test-Data Generation

- Summary
  - We have (sketched) a symbolic Test-Case Generation Procedure for UML/MOAL Specifications
  - It takes into account:
    - object orientation
    - data invariants (recursive predicates)
    - recursive functions (via unfolding)
  - The process can be tool-supported (HOL-TestGen)
  - The process is intended for automation.

16/02/18 B. Wolff - Ingé. 2 - Test 79

Test-Data Generation

- Summary
  - We have (sketched) a symbolic Test-Case Generation Procedure for UML/MOAL Specifications
  - It takes into account:
    - object orientation
    - data invariants (recursive predicates)
    - recursive functions (via unfolding)
  - The process can be tool-supported (HOL-TestGen)
  - The process is intended for automation.

16/02/18 B. Wolff - Ingé. 2 - Test 79

Test-Data Generation

- Summary
  - We have (sketched) a symbolic Test-Case Generation Procedure for UML/MOAL Specifications
  - It takes into account:
    - object orientation
    - data invariants (recursive predicates)
    - recursive functions (via unfolding)
  - The process can be tool-supported (HOL-TestGen)
  - The process is intended for automation.

16/02/18 B. Wolff - Ingé. 2 - Test 79

Test-Data Generation

- Summary
  Key-Ingredients are:
  - Unfolding predicates up to a given depth k
  - computing the Disjunctive Normal Form (DNF_k)
  - Adequacy:
    Pick for each test-case (a conjoint in the DNF_k) one test, i.e. one substitution for the free variables satisfying the test-case !

Test-Data Generation

- Summary
  Key-Ingredients are:
  - Unfolding predicates up to a given depth k
  - computing the Disjunctive Normal Form (DNF_k)
  - Adequacy:
    Pick for each test-case (a conjoint in the DNF_k) one test, i.e. one substitution for the free variables satisfying the test-case !

16/02/18 B. Wolff - Ingé. 2 - Test 80

Test-Data Generation

- Summary
  Key-Ingredients are:
  - Unfolding predicates up to a given depth k
  - computing the Disjunctive Normal Form (DNF_k)
  - Adequacy:
    Pick for each test-case (a conjoint in the DNF_k) one test, i.e. one substitution for the free variables satisfying the test-case !

16/02/18 B. Wolff - Ingé. 2 - Test 80

Test-Data Generation

- Summary
  Key-Ingredients are:
  - Unfolding predicates up to a given depth k
  - computing the Disjunctive Normal Form (DNF_k)
  - Adequacy:
    Pick for each test-case (a conjoint in the DNF_k) one test, i.e. one substitution for the free variables satisfying the test-case !

16/02/18 B. Wolff - Ingé. 2 - Test 80