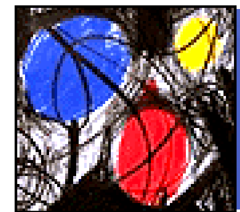

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Jartege : a Tool for Random Generation of Unit Tests for Java Classes

Catherine Oriat
LSR/IMAG, Grenoble, France
(presented by Yves Ledru)

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The need for automatic test generation

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- Testing usually estimated to 40% of the total development cost
- Agile methods favour continuous testing

⇒The need for a large number of tests

⇒The need for automatic generation

Sources of test generation

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- Automatic generation can be systematic:
  - From the structure of the code (white box structural testing)
  - From the structure of the specification (black box functional testing)
  - From knowledge on the input (combinatorial testing)
- Automatic generation can be random
  - Usually presented as the poorest approach for selecting test data [Myers94]
  - But cheap and able to detect a large number of errors

Conformance testing

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- Testing to compare an implementation to a reference specification

- We focus on
  - Java programs
  - JML specifications

Java Modelling Language

- www.jmlspecs.org
- Several verification tools
(testing tools, static checkers, proof tools)
- JML specifications:
  - Based on the « Design by Contract™ » principle
  - Executable specifications
  - Automated oracle for the tests
- JML-Junit :
  - A combinatorial testing tool
  - Yoonsik Cheon and Gary T. Leavens.
A Simple and Practical Approach to Unit Testing: The JML and JUnit Way.
In ECOOP 2002 Proceedings. Vol. 2374 of LNCS,
Springer, 2002.

A case study : bank accounts

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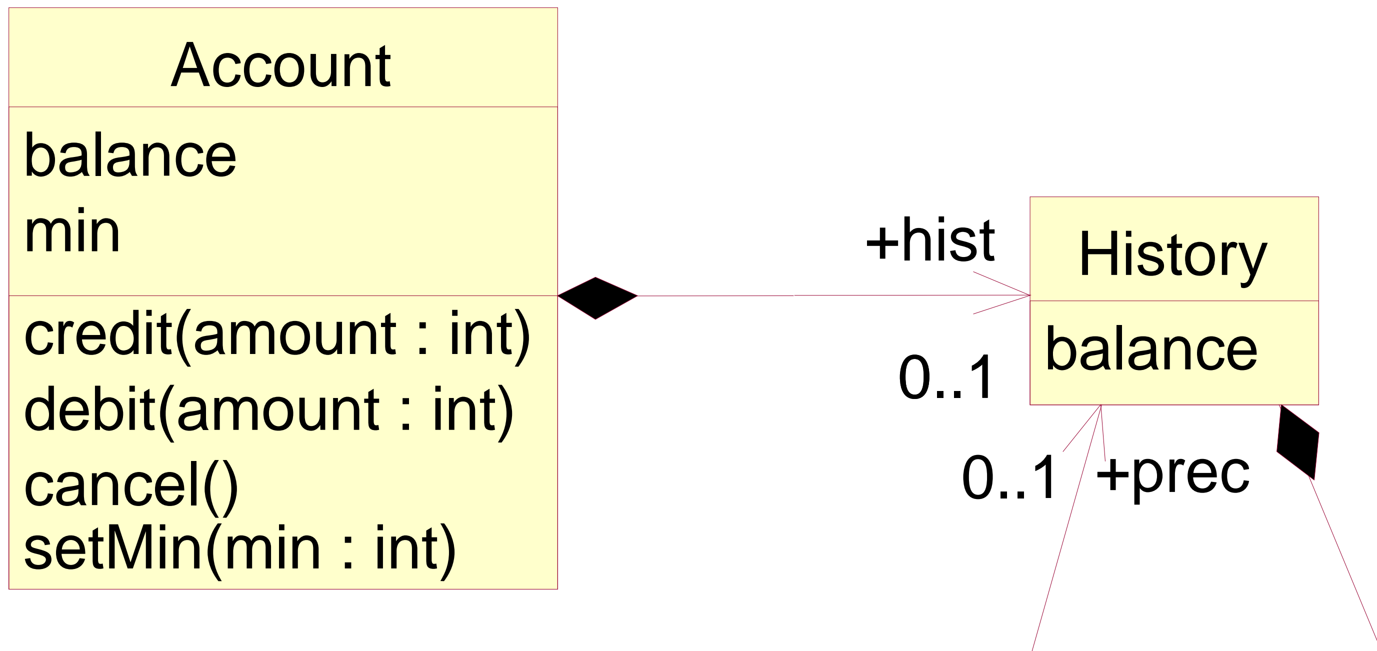

- The balance must always be greater than the minimum
- The history is the list of successive balances
- The minimum may be changed

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The invariant is a property that must be true on entry and exit of all methods of the class

```
public class Account {
/*@ public invariant getBalance( ) >= getMin( ); */
private int balance;  // The balance of this account
private int min;      // The minimum balance
private History hist; // The history list of this
                      // account

/* The balance of this account. */
public /*@ pure */ int getBalance( )
         { return balance; }

/* The history list of this account. */
public /*@ pure */ History getHist( )
         { return hist; }

/* The minimum balance of this account. */
public /*@ pure */ int getMin( )
         { return min; }
```

Pure methods may not modify the object

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```
/* Constructs an account with the specified balance and
 * minimum balance. */

/*@ requires balance >= min; */
public Account (int balance, int min) {
     this.balance = balance;
     this.min = min;
     this.hist = null;
}
```

Requires expresses a pre-condition, i.e. a condition that must be true at the entry of the method

If the precondition is false, the method should not be called

```
/* Sets the minimum balance to the specified value. */
/*@ requires getBalance ( ) >= min; */
public void setMin (int min) {
     this.min = min;
}
```

Credit method

```
/* Credits this account with the specified amount. */
/*@ requires amount >= 0;
```

You may only credit positive amounts

The balance is updated

```
  *@ ensures
  *@ getBalance() == \old (getBalance()) + amount &&
  *@ \fresh (getHist()) &&
```

Ensures expre
i.e. a predicate

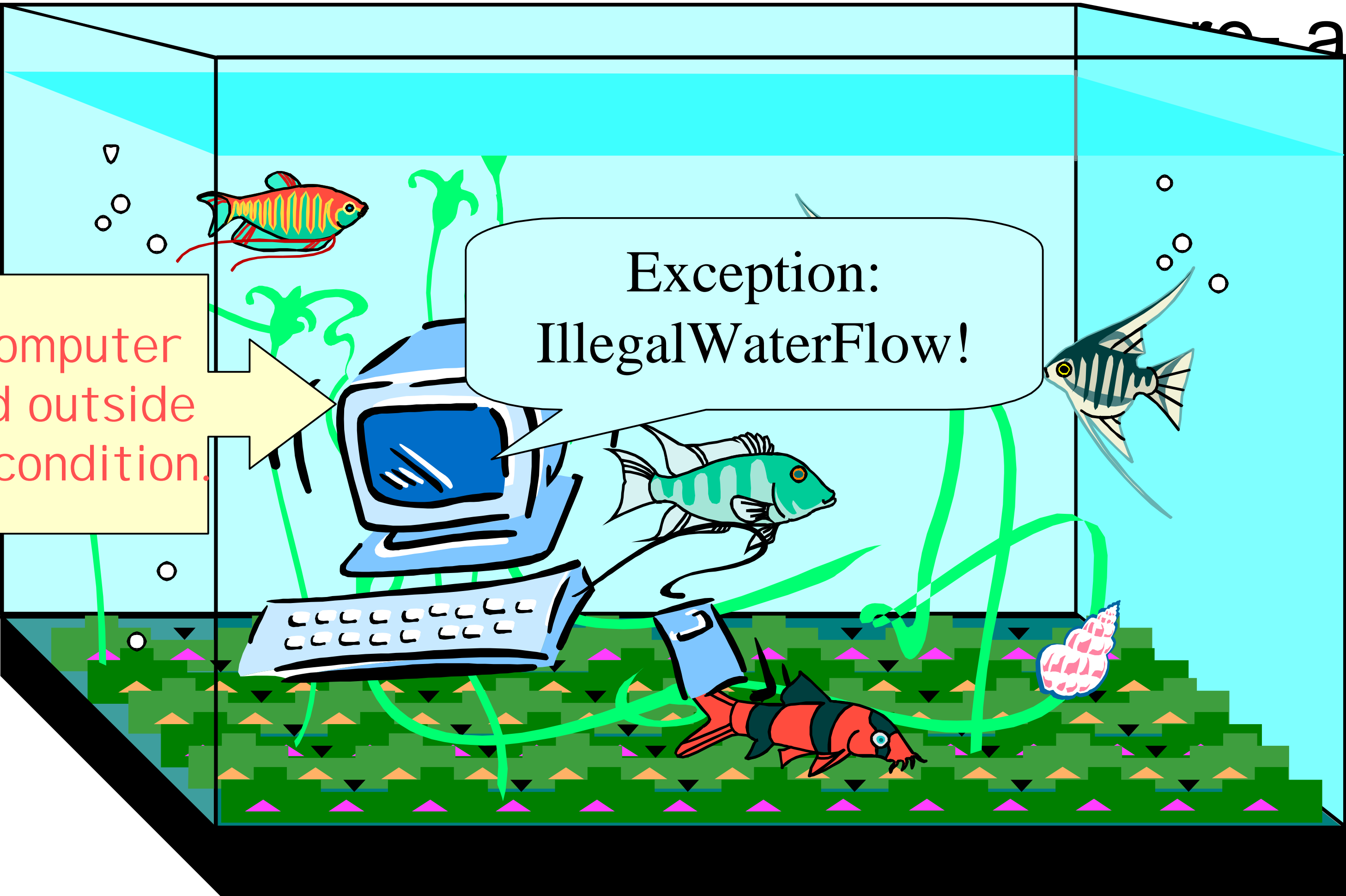
\old(expr) refers to the value of « expr »
at the start of the operation

The history is updated

raise exceptions

```
  *@ signals (Exception e) false;
*/
public void credit(int amount) {
     hist = new History (balance, getHist ( ));
     balance = balance + amount;
}
```

The contract



- But if the program is called outside its precondition, anything may happen…

Cancel method

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```
/* Cancels the last credit or debit operation. */
/*@ requires getHist() != null;
```

Cancel only makes sense if there is some history

The last record is deleted from the history

```
 *@ ensures
 *@ getHist() == \old (getHist().getPrec()) &&
 *@ getBalance() == \old (getHist().getBalance());
```

The previous balance is restored

```
 *@ signals (Exception e) false;
*/

public void cancel ( ) { balance = hist.getBalance ( );
hist = hist.getPrec ( );
}
} // End of class Account
```

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```
public class History {
    private int balance;  // The balance of this history.
    private History prec; // The preceding history.

/* Constructs a history with the specified balance and
   preceding history. */
public History (int balance, History prec) {
    this.balance = balance;
    this.prec = prec;
}

/* The balance of this history. */
public /*@ pure */ int getBalance ( )
    { return balance; }

/* The preceding history. */
public /*@ pure */ History getPrec ( )
    { return prec; }
}
```

No JML assertion here!

Jartege

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- Java framework for random test generation
- Mainly unit tests
- Principles
  - Discovers the methods of the class using Java introspection/reflection
  - Randomly generates objects and parameters for the method
  - Builds sequences of calls
  - Takes advantage of the JML specification:
    - Pre-conditions filter irrelevant calls
    - Invariant and post-conditions as test oracle

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```
/** Jartege test cases generator for classes Account and
   History. */
class TestGen { public static void main (String[] args){

   ClassTester t = new ClassTester();
                  // Creates a class tester

   t.addClass ("Account"); // Adds the specified classes
   t.addClass ("History"); // to the set of classes
                           // under test

// Generates a test class TestBank,
// made of 100 test cases.
// For each test case,
// the tool tries to generate 50 method calls.
   t.generate ("TestBank", 100, 50);
}}
```

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```
// Test case number 1
public void test1 ( ) throws Exception {
  try {
    Account ob1 = new Account (1023296578, 223978640);
    ob1.debit (152022897);
    History ob2 = new History(1661966075,(History)null);
    History ob3 = new History (-350589348, ob2);
    History ob4 = ob2.getPrec ( );
    int ob5 = ob3.getBal
    ob1.cancel ( );
// ...
    } catch (Throwable except) { error ( except, 1);}
}
```

Here cancel appears when its precondition is true!

Discovers the methods of the class

Randomly generates objects and parameters

Takes advantage of the JML specification:

- Pre-conditions filter irrelevant calls
- Invariant and post-conditions as test oracle

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During test case number 2

The invariant was broken

```
1) Error detected in class TestBank by method test2:
   JMLInvariantError:
By method ”credit@posthAccount.java:79:18i” of class
   ”Account”
for assertions specified at Account.java:11:32 [...]
at TestBank.test2(TestBank.java:138)
[...]
Number of tests: 100
Number of errors: 71
Number of inconclusive tests: 0
```

At the exit of method « credit »

- The test suite includes 100 test cases
- 71 tests ended with an error

Controlling random generation

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« if we leave everything to chance, Jartege might not produce interesting sequences of calls »

A typical problem: how to handle strong preconditions?

e.g. a random debit will not satisfy the pre-condition if balance is close to min.

Jartege features several mechanisms to define an « *operational profile* »

Controlling the creation of objects

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- When a method call needs an object, we can
  - Either create a new one
  - Or reuse an existing one
- A creation probability function controls the creation of objects:
  - $F(0) = 1$
  - $F(n) \in [0,1] \ \forall n > 0$
- For example:
  - It does not make sense to create multiple bank accounts in our case study
  - $F(0) = 1, F(n) = 0 \ \forall n > 0$

```
t.changeCreationProbability("Account",
                            new ThresholdProbability(1));
```

Parameter generation

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- Instead of using the full range of a parameter, we can provide our own generation function.

```
public class JRT_Account {
private Account theAccount; // The current account
/* Constructor. */
public JRT_Account (Account theAccount) {
   this.theAccount = theAccount; }

/** Generator for the first parameter
    of operation debit (int). */
public int JRT_debit_int_1 ( ) {
   return RandomValue.intValue (0,
        theAccount.getBalance() - theAccount.getMin());
}}
```

The parameter of debit is generated with respect to the current values of balance and min.
It is more likely to meet the precondition!

Other features

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- Weights
  - On the choice of classes
  - On the choice of methods
  - (allows to forbid the test of a given method)
- Test fixtures (like JUnit)
  - Additional attributes for the test class
  - setUp and tearDown methods

Errors found on the case study

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- 71 test sequences ended with a failure.
- Analysis of these failures leads to two basic errors
- The test cases have been reduced manually to the minimal sequence that reveals the error
- The errors were unknown from us.

- First error:

```
public void test1 ( ) {
Account ob1 = new Account (250000000, 0);
ob1.credit (2000000000); // Produces a negative balance,
}                        // below the minimum balance.
```

Credit produces an overflow of balance which becomes a negative value under min

Error #2

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```
public void test11 ( ) {
Account ob1 = new Account (-50, -100);
ob1.credit (100);
ob1.setMin (0);
ob1.cancel ( ); // Restores the balance to a value
}                // inferior to the minimum balance.
```

- The precondition of setMin only takes into account the current balance.
- Restoring a previous balance with cancel may lead to it to be under the new minimum

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- Summary:
  - A framework for random testing
  - Of java programs
  - Specified in JML
  - Using operational profiles
- The tool has been applied to several case studies:
  - Small banking application from Gemplus (ASE'04)
  - Jartege itself (use your own medecine!)
- Experiments confirmed the expected advantages of the tool:
  - Low cost of test generation
  - The tool helps findings errors

Future work

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- Generation of method parameters
  - Currently done by hand
  - Could be generated from preconditions
  - Corresponds to the extraction of range constraints
- Once a test case reveals a failure
  - Identification of the smallest sequence that leads to an error
  - Currently manual, could be automated
- Operational profiles may help to evaluate reliability of a given software.