Verifying a plaftorm for digital imaging: a multi-tool strategy*

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Calculemus 2013

July 8, 2013

*Partially supported by Ministerio de Educación y Ciencia, project MTM2009-13842-C02-01, and by European Commission FP7, STREP project ForMath, n. 243847

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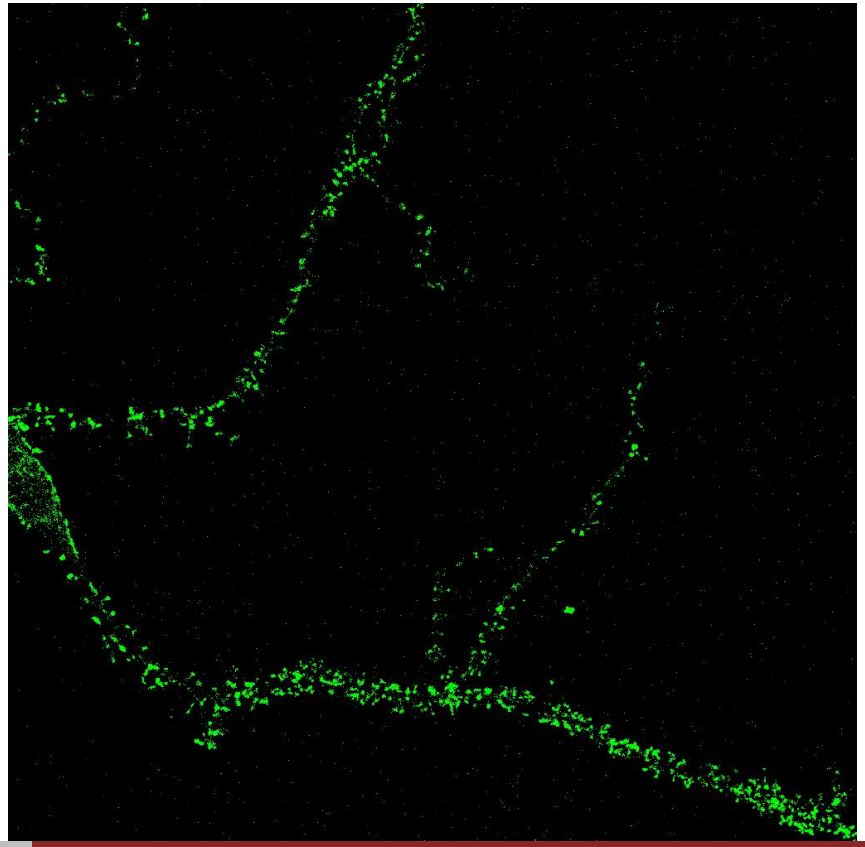

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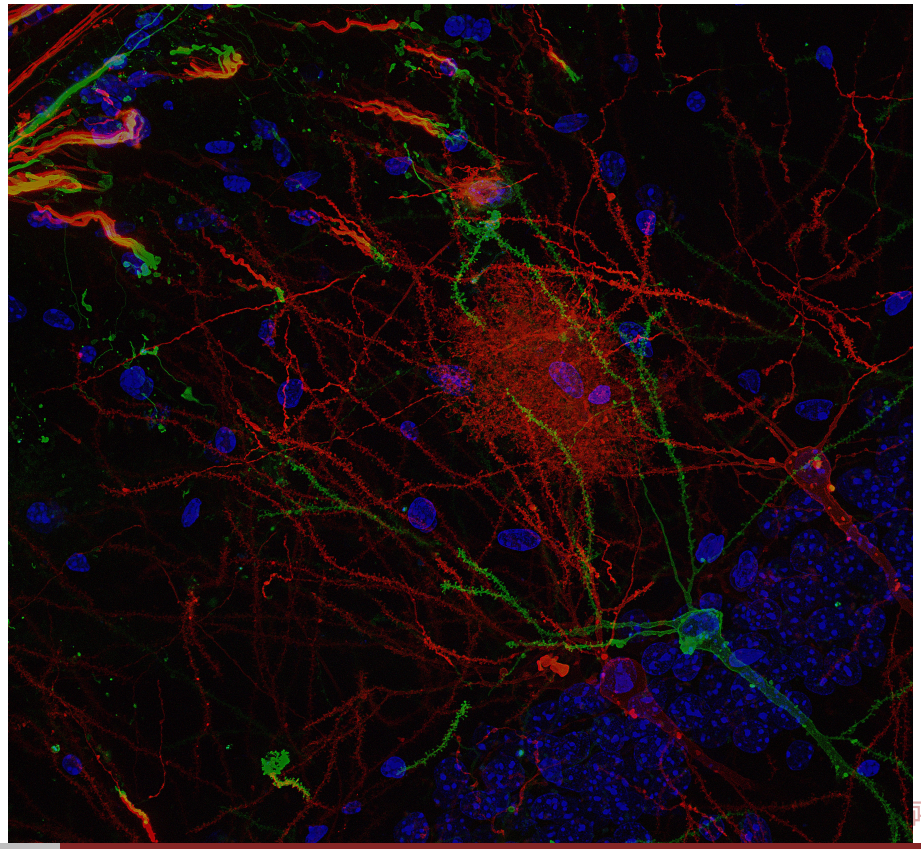
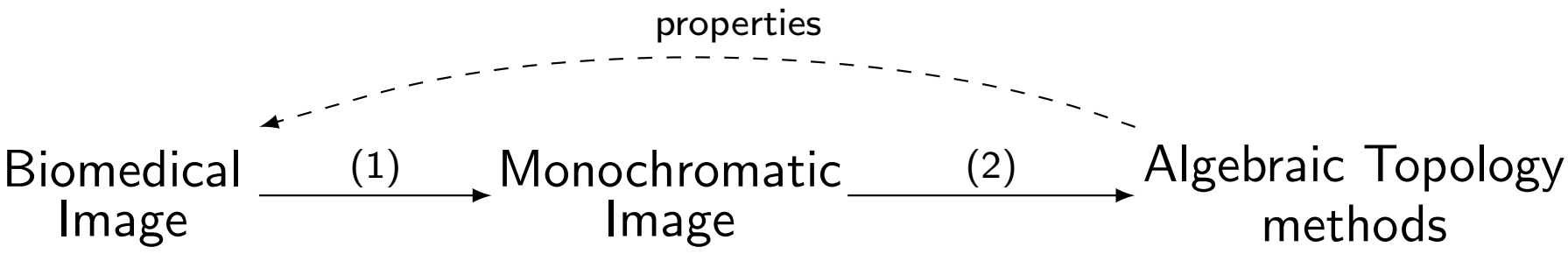


Our approach



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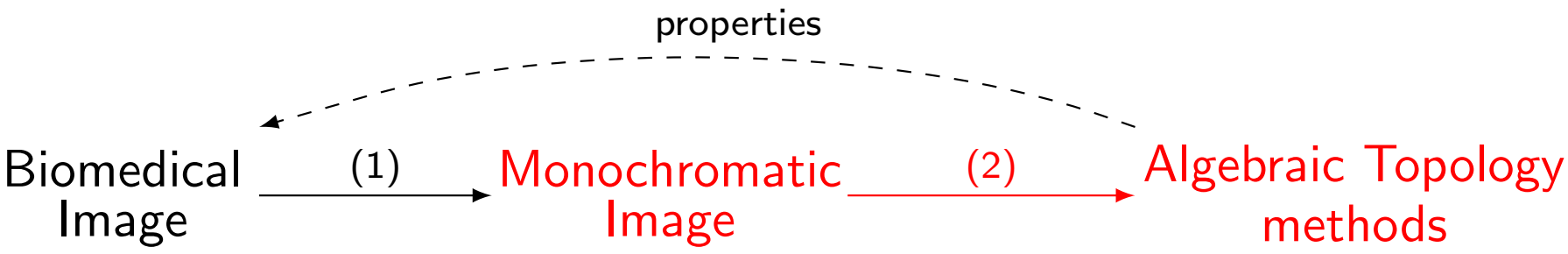

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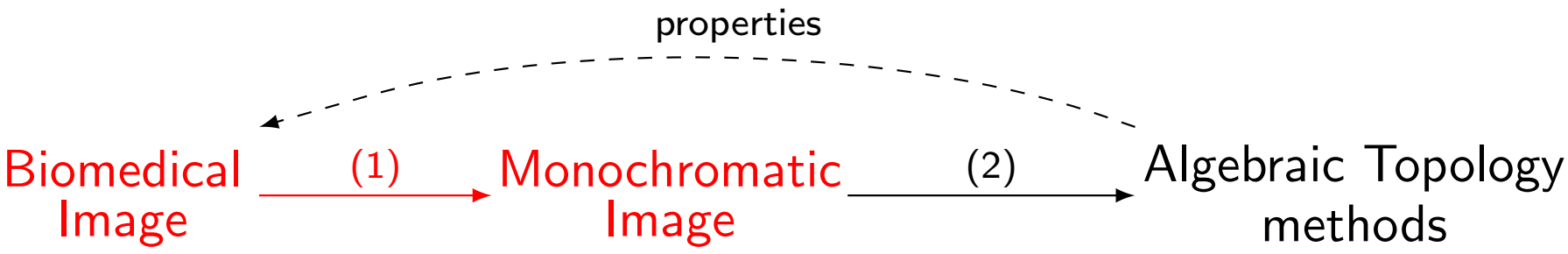

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In this talk: towards a formal verification of Step (1).

Table of Contents

1. Tools and method
2. Verification of actual imaging code
3. Conclusions and Further work

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Fiji/ImageJ

Fiji/ImageJ:

- Java programs used in life-science and biomedicine.
- Process and analyse biomedical images.
- Extensible by means of plugins.
- Functionality: binarise images, application of filters, maximum projection of stack of images, ...

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Our plugins:

- SynapCountJ: count number of synapses.
- NeuronPersistentJ: detect neuronal structure.

Why/Krakatoa

Why/Krakatoa:

- Environment for proving the correctness of Java programs annotated with JML.
- Three components:
  - Krakatoa: annotated Java program $\rightarrow$ Why input.
  - Why tool: compute proof obligations.
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. . . but some proof obligations cannot be automatically discharge. In those cases, Why generates Coq (and other proof assistants) code.

Coq – ACL2

Coq:

- Interactive proof assistant.
- Constructive higher-order logic based on the CoC.
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ACL2:

- A Computational Logic for Applicative Common Lisp.
- Automated-Interactive prover.
- Applied in formal methods projects of industrial and commercial interest.

The method

Our method to verify the correctness of Fiji/ImageJ code:

1. Fiji code $\rightarrow$ compilable Krakatoa code.

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6. Extract Coq code.

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   - No Are other specifications needed? Yes, Goto 2. No . . .

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1. Tools and method
2. Verification of actual imaging code
   - Challenges to formalise Fiji code
   - Transforming Fiji/Java to Krakatoa/Java
   - Specifying programs for digital imaging
   - The role of ACL2
   - Demo
3. Conclusions and Further work

Challenges to formalise Fiji code

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- Fiji is a big software system not devised to be formalised.
- Why/Krakatoa does not support the complete Java programming language.
- Specification of programs.
- ATPs does not automatically discharge all proof obligations.
- ITPs lack automation.

Transforming Fiji-Java to Krakatoa-Java

Making Fiji/Java programs compilable in Krakatoa:

1. Delete annotations.
2. Move the classes that are referenced into Why folder.
3. Reproduce the behaviour of the class that we want to compile.
4. Remove import clauses.
5. Remove package declarations.
6. Rebuild native methods.
7. Add a clause in if-else structures in order to remove "Uncaught exceptions".
8. Remove debugging useless references.
9. Modify the declaration of some variables to avoid syntax errors.
10. Change the way that Maximum and Minimum float numbers are written.

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Java allows the use of native methods written in C/C++ (dependent on hardware/OS).
Methods in the class *Math*: exponential, logarithm, square root, trigonometric functions, ...
Native methods cannot be verified in Krakatoa $\Longrightarrow$ Rewrite them.

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10. Change Maximum and Minimum float numbers format.

Used to avoid overflow errors.
They generate an error due to the eP exponent.
Conversion from `0x1.fffffeP+127d` to `3.4028235e+38f`.

Specifying programs for digital imaging

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Specification of preconditions and postconditions using JML to certify the correctness of the programs.

- Precondition: `requires`.
- Postcondition: `ensures`.
- Notations: `\result` and `old`.

Example 1: Translating an object

```
 private double x;
 private double y;

 /*@ ensures x == \old(x) + dx && y == \old(y) + dy; @*/

 public void translate(final double dx, final double dy) {
    this.x += dx; this.y += dy;
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Small demo in Krakatoa.

Example 2: x^n

```
static double power(double x, int n){
  int i=0;
  double pot=1;
  while (i<n) {
     pot=pot*x;
     i++;
     }
  return pot;
  }
```

Example 2: x^n

```
/*@ axiomatic Power {
  @ logic real lpower(real x, integer n);
  @
  @ axiom power_zero: \forall real x; lpower(x,0) == 1.0;
  @
  @ axiom power_one: \forall real x; lpower(x,1) == x;
  @
  @ axiom power_two: \forall real x; lpower(x,2) == x*x;
  @
  @ axiom power_sum:
  @ \forall real x, integer i j; lpower(x,i+j) == lpower(x,i)+lpower(x,j);
  @
  @ axiom power_sum2:
  @ \forall real x, integer i j; lpower(x,i*j) == lpower(lpower(x,i),j);
  @
  @ axiom power_multi:
  @ \forall real x y, integer i; lpower(x*y,i) == lpower(x,i) * lpower(y,i);
  @
  @ axiom power_general1:
  @    \forall real x , integer i;x > 1 && i%2 == 1
  @ ==> lpower(x,i) == lpower(lpower(x,2),i/2)*x;
  @  ... }
  @*/
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/*@ requires n >=0;
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  static double power(double x, int n){
     int i=0;
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     /*@ loop_invariant
       @ i <= n && pot==lpower(x,i) ;
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Coq2ACL2 – a Proof General extension.

- Transforms Coq statements generated by Why to ACL2.
- Automatically sends the ACL2 statements to ACL2.
- Displays the proof attempt generated by ACL2.

The I2EA framework

Original aim:

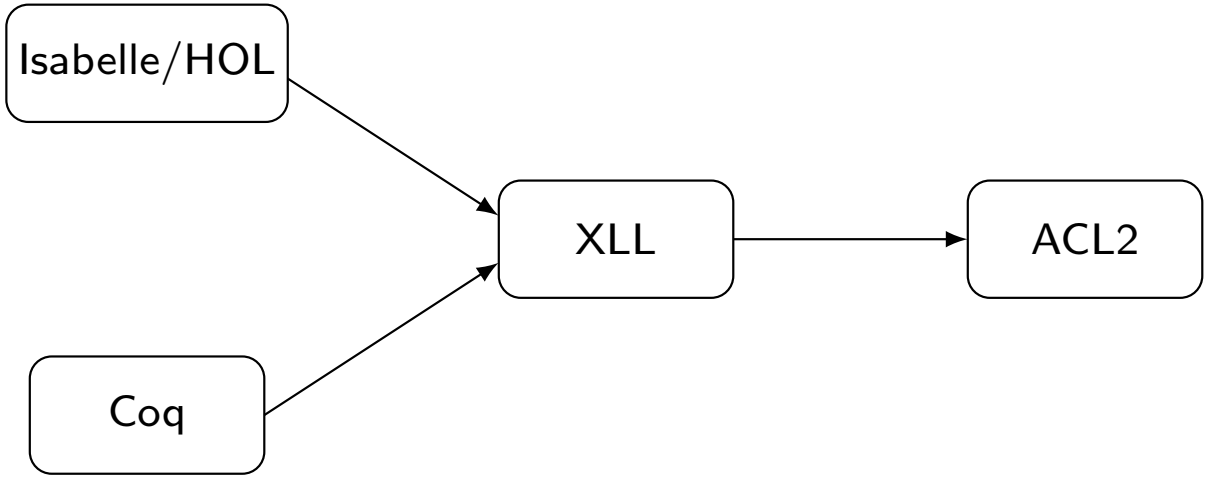
- Isabelle/HOL theories $\rightarrow$ ACL2.
- Isabelle/HOL first-order expressions $\rightarrow$ schema of the proof in ACL2.

The I2EA framework

XLL (Xmall Logical Language):

- Intermediate language to port Isabelle/HOL theories to ACL2 and Ecore (UML + OCL).
- Transformations are done by means of XSLT.

The I2EA framework



Integration of Coq in this framework.

- Reuse XLL and XSLT transformations.
- Coq statements $\rightarrow$ ACL2.
- Coq2ACL2:

$$\text{Coq} \xrightarrow{\text{Lisp program}} \text{XLL} \xrightarrow{\text{XSLT}} \text{ACL2}$$

Demo

Motivation:

- Images acquired by microscopy techniques.
- Different planes from the same sample (same XY plane different Z levels).
- Maximum projection of the stack of images.
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Demo: correctness of the calculateStdDev method.

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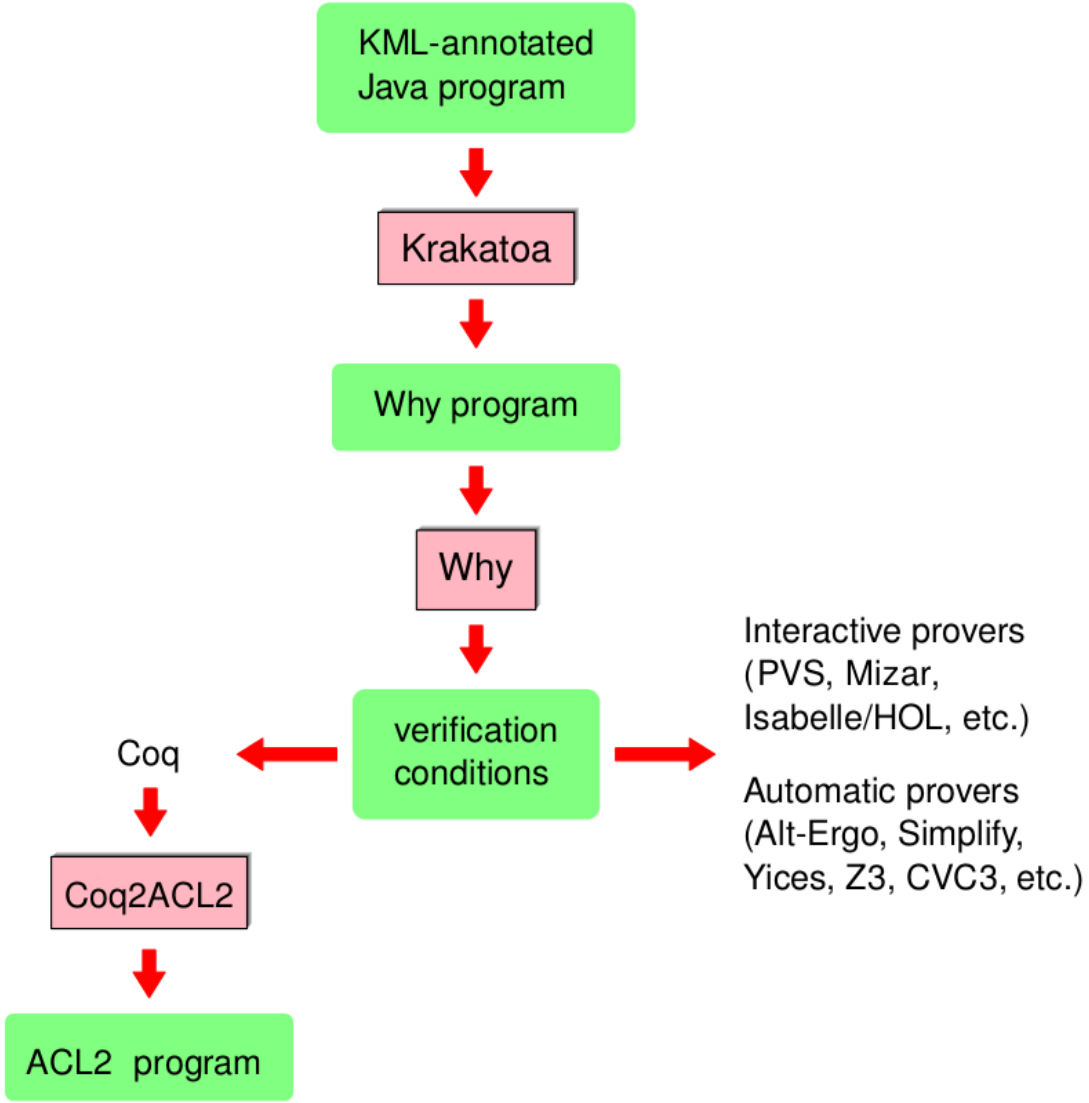

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  - Isolate relevant parts of programs to formalise them.
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  - Integration of several tools keeping transformations as simple as possible.
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- Further work:
  - Automatic transformation from Java code to Krakatoa code.
  - Automatic discovery of proof invariants.
  - Reconstruction of ACL2 proofs in Coq.
  - Full certification of SynapCountJ and NeuronPersistentJ.

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