Teaching with Logika

Conceiving and Constructing Correct Software

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Context, Approach and Evolution

Use and Significance of Slang and Logika

Feedback

Discussion

Next Steps

Software Engineering Curriculum

- Development of *new BSc/MSc curriculum* at Aarhus University (Engineering, Fall 2018)
- *Problem solving*, *modelling*, *reasoning*, and *verification* are woven into "common" courses

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  - Software Architecture (BSc 5 ECTS – informal)
  - Discrete Mathematics (BSc 5 ECTS – informal)
  - *Programming and Modelling* (BSc 10 ECTS – formal)
  - Declarative Programming (BSc&MSc 10 ECTS – informal/formal)
  - **Software Correctness** (MSc 5 ECTS – formal)

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- Local students are prepared for formal methods thinking
- They see **Slang** and **Logika** in *Programming and Modelling* and **Software Correctness**
  - **Slang**: Scala dialect with verification support
  - **Logika**: Interactive support for programming and verifying with Slang

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  - **Slang**: Scala dialect with verification support
  - **Logika**: Interactive support for programming and verifying with Slang
- Cohort on MSc level is mixed – **background at MSc level varies**
  - Slang and Logika are well-suited for this situation

Evolution of the Course

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- In 2023 the **new course** Software Correctness was established

Content and Objectives

- Schedule:
  - **Week 1: Introduction** – Reasoning about software (and **tool** installation)
  - **Week 2: Tracing Facts** – Pick up the students **reasoning in familiar ways**
  - **Week 3: Conditionals** – **Progress slowly** discussing different approaches
  - **Week 4: Contracts (Test)** – Ensure **students see benefit** for their programming skills
  - **Week 5: Contracts (Proof)** – Based on preceding week but using compositional **proof**
  - **Week 6: Loops and Recursion** – Some theory: programs are just another kind of formula
  - **Week 7: Unfolding and Fixpoints** – More theory with large and complex formulas
  - **Week 8: Loops and Recursion Testing** – Ensure **students see benefit**
  - **Week 9: Sequences and Arrays** – Increase complexity of programs
  - **Finally: Verification Examples and Practice** – Provide **methodology** backed by examples

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- Objectives:
  - Improve **programming** skills, **testing** skills, **documentation** skills, **reasoning** skills
  - Do not limit students' vision to Slang,
    so the material becomes relevant **beyond the course**

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A Quick Tour of Slang and Logika

The User Interface

- Week3
  - absvalue_nn.sc
  - boolor.sc
  - maximum_diff.sc
  - maximum_diff_ded.sc
  - maximum_simple.sc
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- Week4
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- Week7
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// #Sireum #Logika
import org.sireum._
val x: Z = randomInt()
val y: Z = randomInt()

var z: Z = 0
if (x < y) {


  z = y


} else {


  z = x


}
assert(z ≡ x ∨ z ≡ y)
assert(y ≤ z ∧ x ≤ z)
```

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Slang is a dialect of the **Scala programming language**

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Functional and imperative programming

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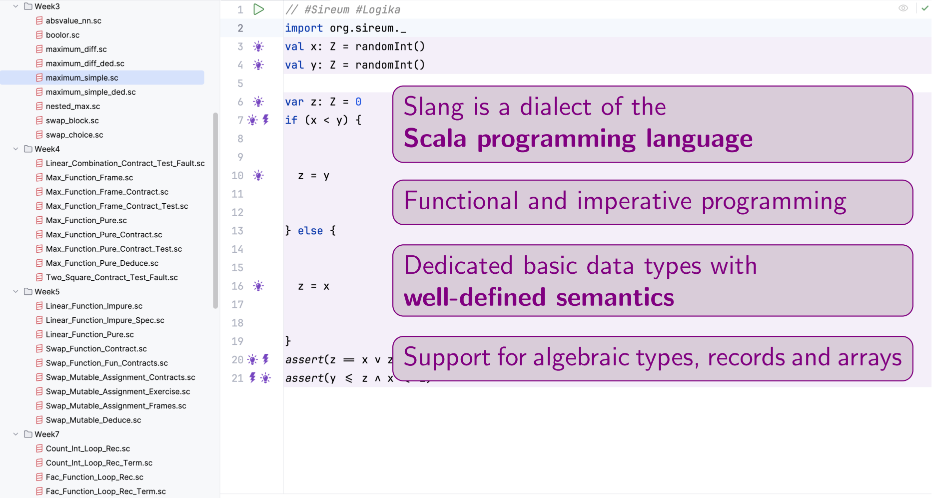
Functional and imperative programming

Dedicated basic data types with **well-defined semantics**

A Quick Tour of Slang and Logika

The User Interface



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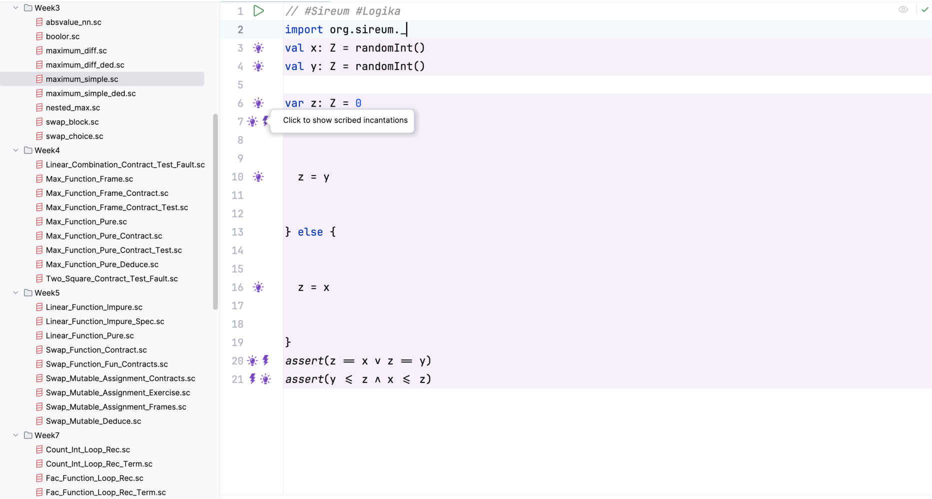
Functional and imperative programming

Dedicated basic data types with **well-defined semantics**

Support for algebraic types, records and arrays

A Quick Tour of Slang and Logika

The User Interface



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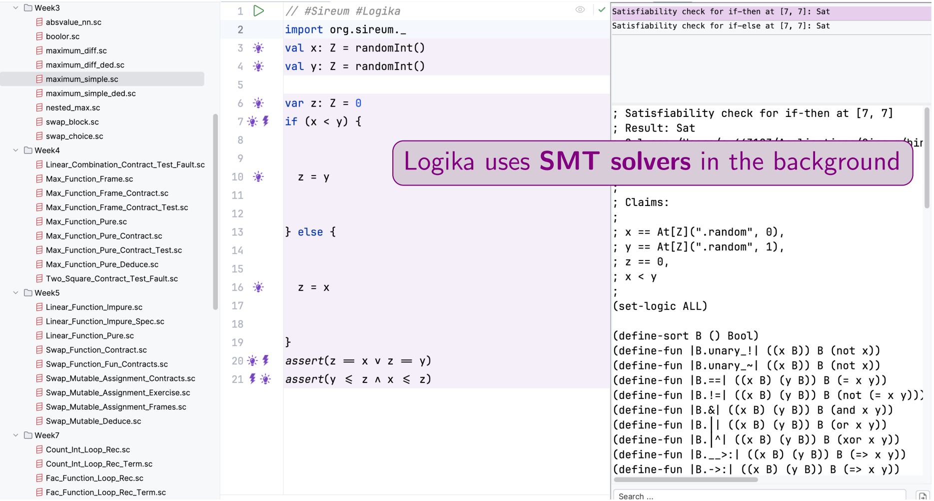

Logika uses **SMT solvers** in the background

A Quick Tour of Slang and Logika

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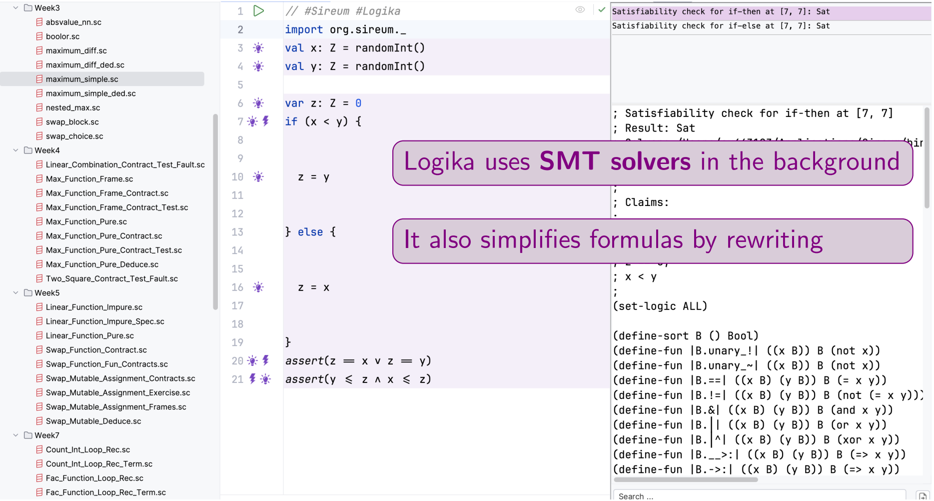

Logika uses **SMT solvers** in the background

It also simplifies formulas by rewriting

A Quick Tour of Slang and Logika

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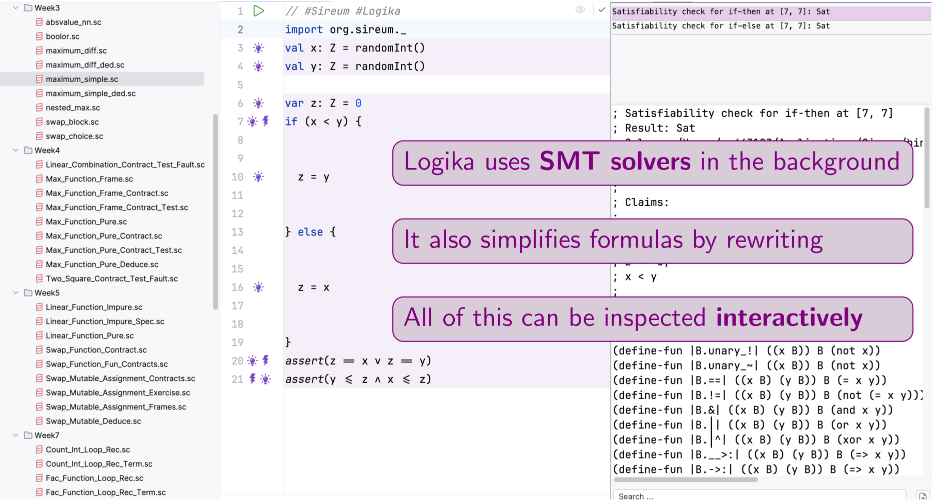

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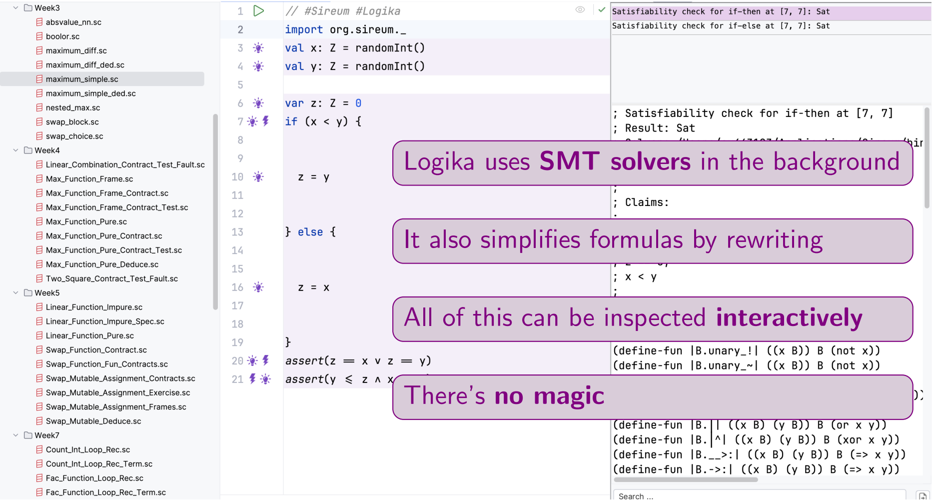

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There's **no magic**

A Quick Tour of Slang and Logika

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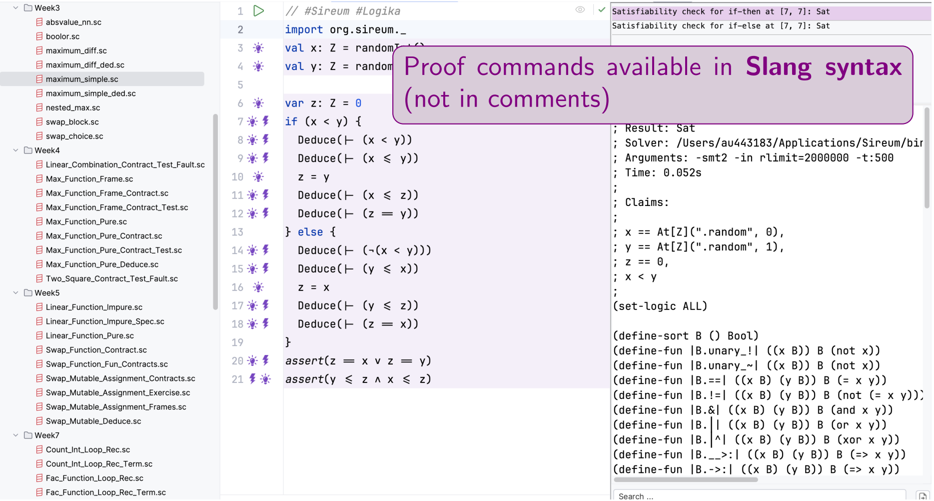

Proof commands available in **Slang syntax** (not in comments)

A Quick Tour of Slang and Logika

Contracts & Proof

```
// #Sireum #Logika
import org.sireum._

def swap(a: ZS, i:Z, j: Z) : Unit = {
  Contract(
    Requires(0 ≤ i, i < a.size, 0 ≤ j, j < a.size),
    Modifies(a),
    Ensures(
      a(i) ≡ In(a)(j),
      a(j) ≡ In(a)(i),
      ∀(a.indices)(k ⇒ k ≡ i ∨ k ≡ j ∨ a(k) ≡ In(a)(k)),
      a.size ≡ In(a).size
    )
  )
  val t: Z = a(i)
  Deduce(⊢ (t ≡ In(a)(i)))
  a(i) = a(j)
  Deduce(⊢ (t ≡ In(a)(i)))
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Contracts for **compositional reasoning**

A Quick Tour of Slang and Logika

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Hoare-style reasoning about imperative commands

A Quick Tour of Slang and Logika

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Contracts for **compositional reasoning**

Hoare-style reasoning about imperative commands

Proof in Slang as close as possible to **programming**

A Quick Tour of Slang and Logika

Contracts & Proof

Familiar Interface for students

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k: Z

Example

A Quick Tour of Slang and Logika

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k: Z

Example

Familiar Interface for students

Interactive inspection of all elements, including formulas and proof

A Quick Tour of Slang and Logika

Proof Information

```
@pure def sorted(seq: ISZ[Z]): B = {
  Contract(
    Ensures(Res == All(1 until seq.size)(i ⇒ seq(i-1) ≤ seq(i)))
  )
  var res: B = true
  var k: Z = 1
  while (k < seq.size) {
    Invariant(
      Modifies(k, res),
      k ≥ 1,
      k-1 ≥ 0,
      k-1 ≤ seq.size,
      seq.size ≥ 2 || res == true,
      seq.size < 2 v k ≤ seq.size,
      seq.size < 2 || res == All(1 until k)(i ⇒ seq(i-1) ≤ seq(i))
    )
    Deduce(⊢ (seq.size ≥ 2))
    if (seq(k - 1) > seq(k)) {
      res = false
    }
    k = k + 1
  }
  Deduce(⊢ (seq.size ≥ 2 || res == All(1 until seq.size)(i ⇒ seq(i-1) ≤ seq(i))))
  Deduce(⊢ (seq.size < 2 || res == All(1 until seq.size)(i ⇒ seq(i-1) ≤ seq(i))))
  return res
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Proof information available **interactively**

A Quick Tour of Slang and Logika

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      seq.size ⩾ 2 || res ≡ true,
      seq.size < 2 ∨ k ⩽ seq.size,
      seq.size < 2 || res ≡ All(1 until k)(i ⇒ seq(i-1) ⩽ seq(i))
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    if (seq(k - 1) > seq(k)) {
      res = false
    }
    k = k + 1
  }
  Deduce(⊢ (seq.size ⩾ 2 || res ≡ All(1 until seq.size)(i ⇒ seq(i-1) ⩽ seq(i))))
  Deduce(⊢ (seq.size < 2 || res ≡ All(1 until seq.size)(i ⇒ seq(i-1) ⩽ seq(i))))
  return res
}
```

Click to show some hints

Proof information available **interactively**

"Click the *light bulb*"

A Quick Tour of Slang and Logika

Proof Information

```
@pure def sorted(seq: ISZ[Z]): B = {
  Contract(
    Ensures(Res ≡ All(1 until seq.size)(i ⇒ seq(i-1) ≤ seq(i)))
  )
  var res: B = true
  var k: Z = 1
  while (k < seq.size) {
    Invariant(
      Modifies(k, res),
      k ≥ 1,
      k-1 ≥ 0,
      k-1 ≤ seq.size,
      seq.size ≥ 2 || res ≡ true,
      seq.size < 2 v k ≤ seq.size,
      seq.size < 2 || res ≡ All(1 until k)(i ⇒ seq(i-1) ≤ seq(i))
    )
    Deduce(⊢ (seq.size ≥ 2))
    if (seq(k - 1) > seq(k)) {
      res = false
    }
    k = k + 1
  }
  Deduce(⊢ (seq.size ≥ 2 || res ≡ All(1 until seq.size)(i ⇒ seq(i-1) ≤ seq(i))))
  Deduce(⊢ (seq.size < 2 || res ≡ All(1 until seq.size)(i ⇒ seq(i-1) ≤ seq(i))))
  return res
}
```

```
{ // State claims at line 23
  At(res, 0) ≡ T;
  At(k, 0) ≡ 1;
  k < seq.size;
  k ≥ 1;
  k - 1 ≥ 0;
  k - 1 ≤ seq.size;
  seq.size ≥ 2;
  seq.size < 2 v
    k ≤ seq.size;
  ¬(seq.size < 2);
  res ≡ ∀(1 until k)(i ⇒ seq(i - 1) ≤ seq(i));
  seq(k - 1) > seq(k)
}
```

Filter claims ...

A Quick Tour of Slang and Logika

Proof Information

```
@pure def sorted(seq: ISZ[Z]): B = {
  Contract(
    Ensures(Res ═ All(1 until seq.size)(i ⇒ seq(i-1) ⩽ seq(i)))
  )
  var res: B = true
  var k: Z = 1
  while (k < seq.size) {
    Invariant(
      Modifies(k, res),
      k ⩾ 1,
      k-1 ⩾ 0,
      k-1 ⩽ seq.size,
      seq.size ⩾ 2 || res ═ true,
      seq.size < 2 v k ⩽ seq.size,
      seq.size < 2 || res ═ All(1 until k)(i ⇒ seq(
    )
    Deduce(⊢ (seq.size ⩾ 2))
    if (seq(k - 1) > seq(k)) {
      res = false
    }
    k = k + 1
  }
  Deduce(⊢ (seq.size ⩾ 2 || res ═ All(1 until seq.size)(i ⇒ seq(i-1) ⩽ seq(i))))
  Deduce(⊢ (seq.size < 2 || res ═ All(1 until seq.size)(i ⇒ seq(i-1) ⩽ seq(i))))
  return res
}
```

```
{ // State claims at line 23
  At(res, 0) ═ T;
  At(k, 0) ═ 1;
  k < seq.size;
  k ⩾ 1;
  k - 1 ⩾ 0;
  k - 1 ⩽ seq.size;
  seq.size ⩾ 2;
  seq.size < 2 v
    k ⩽ seq.size;
  ¬(seq.size < 2);
  res ═ ∀(1 until k)(i ⇒ seq(i - 1) ⩽ seq(i));
  seq(k - 1) > seq(k)
}
```

Filter claims ...

Proof information shown to student
close to the program text

A Quick Tour of Slang and Logika

Proof Information

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5  @pure def sorted(seq: ISZ[Z]): B = {
6    Contract(
7      Ensures(Res == All(1 until seq.size)(i ⇒ seq(i-1) ⩽ seq(i)))
8    )
9    var res: B = true
10   var k: Z = 1
11   while (k < seq.size) {
12     Invariant(
13       Modifies(k, res),
14       k ⩾ 1,
15       k-1 ⩾ 0,
16       k-1 ⩽ seq.size,
17       seq.size ⩾ 2 || res == true,
18       seq.size < 2 ∨ k ⩽ seq.size,
19       seq.size < 2 || res == All(1 until k)(i ⇒ seq(
20     )
21     Deduce(⊢ (seq.size ⩾ 2))
22     if (seq(k - 1) > seq(k)) {
23       res = false
24     }
25     k = k + 1
26   }
27   Deduce(⊢ (seq.size ⩾ 2 || res == All(1 until seq.size)(i ⇒ seq(i-1) ⩽ seq(i))))
28   Deduce(⊢ (seq.size < 2 || res == All(1 until seq.size)(i ⇒ seq(i-1) ⩽ seq(i))))
29   return res
30 }
31
```

```
{ // State claims at line 23
  At(res, 0) == T;
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  ¬(seq.size < 2);
  res == ∀(1 until k)(i ⇒ seq(i - 1) ⩽ seq(i));
  seq(k - 1) > seq(k)
}
```

Filter claims ...

Proof information shown to student **close to the program text**

Easy to match program text to formulas (also large formulas)

A Quick Tour of Slang and Logika

Informal vs Formal

```
// #Sireum #Logika
import org.sireum._

val m: Z = randomInt();
val n: Z = randomInt()
val z: Z = m + n
// deduce z == m + n  (consequence of assignment)
val y: Z = z - n
// deduce z == m + n  (old fact)
// deduce y == z - n  (consequence of assignment)
// deduce y == m      (proof by algebra)
//                    (y == z - n
//                       == (m + n) - n
//                       == m)
val x: Z = z - y
// deduce z == m + n  (old fact)
// deduce y == m      (old fact)
// deduce x == z - y  (consequence of assignment)
// deduce x == n      (proof by algebra)
//                    (x == z - y
//                       == (m + n) - m
//                       == n)
assert(x == n & y == m)
```

Informal proofs in comments useable **without tool support**

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Informal proofs in comments useable **without tool support**

Also used on **white board**

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// deduce x ≡ n      (proof by algebra)
//                   (x ≡ z - y
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//                      ≡ n)
assert(x ≡ n ∧ y ≡ m)
```

Logika can do **many proofs fully automatic**

Logika Verified
Proof is accepted

A Quick Tour of Slang and Logika

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Beginning students benefit from this

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Logika can do **many proofs fully automatic**

Beginning students benefit from this

If **they know that it can be proved**,
Logika confirms or refutes their deductions

Logika Verified
Proof is accepted

A Quick Tour of Slang and Logika

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assert(x == n ∧ y == m)

```

Logika Verified
Proof is accepted

Logika can do **many proofs fully automatic**

Beginning students benefit from this

If **they know that it can be proved**, Logika confirms or refutes their deductions

The students can use Logika **like a teacher**

Student Feedback

It was nice with a little mini–project to use some of the techniques learned in the course

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I am not sure if I am going to use what if have learned

Discussion

- A good **user-friendly tool** that the students are familiar with is **essential**
- Students look for the **benefit** they get out of a course
- They **don't** have a strong background in maths and logics
- It's better if taught material **does not look like formal methods**
- Concerning proof, **in-class attention** by teacher is required
- Using theorem provers directly **did not work well**
- Notation and methodology should be as close to **programming** as possible
- The students rate this course **very high**: 4.4 out of 5
  (but response rate needs to be improved)
- **Despite its title** "Software Correctness" high number of inscriptions
  (20 students)
- Lecture materials for the course are **publicly available**
  (`https://github.com/santoslab/software-correctness-course-materials`)

Much More Material Available From Kansas State University

S 301: Logical Foundations of Programming

earch...

- ropositional Logic Proofs
- redicate Logic Translations
- redicate Logic Proofs
- lathematical Induction
- ntro to Programming Logic
- unctions and Loops
  - 9.1. Functions
  - 9.2. Recursion
  - 9.3. Loops
  - 9.4. Logika Facts
  - 9.5. Summary
- Sequences, Globals, and mination

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Functions and Loops > Loops

A lot of material **available online**

```
val x: Z = Z.read()
val y: Z = Z.read()

var sum: Z = 0
var count: Z = 0

//prove the invariant before the loop begins
Deduce(
    1 (     sum == 0        )  by Premise,          //from the "sum = 0" assignment
    2 (     count == 0      )  by Premise,          //from the "count = 0" assignment
    3 (     sum == count*x  )  by Algebra*(1, 2)    //proved EXACTLY the loop invariant
)

while (count != y) {
    Invariant(
        Modifies(sum, count),
        sum == count * x
    )

    Deduce(
        1 (     sum == count*x      )   by Premise,     //the loop invariant holds
                                                        //at the beginning of an iteration
    )

    sum = sum + x

    Deduce(
        1 (     sum == Old(sum) + x     )  by Premise,        //from "sum = sum + x" assignment
        2 (     Old(sum) == count*x     )  by Premise,        //loop invariant WAS true, but su
        3 (     sum == count*x + x      )  by Algebra*(1,2)   //current knowledge without using
    )

    count = count + 1

    Deduce(
        1 (     count == Old(count)+ 1  )  by Premise,        //from "count = count + 1" assign
        2 (     sum == Old(count)*x + x )  by Premise,        //from previous "sum = count*x + 
                                                              //but count has changed

        3 (     sum == (count-1)*x + x  )  by Algebra*(1,2),
        4 (     sum == count*x - x + x  )  by Algebra*(3),
        5 (     sum == count*x          )  by Algebra*(4)     //loop invariant holds at end of 
    )
}
```

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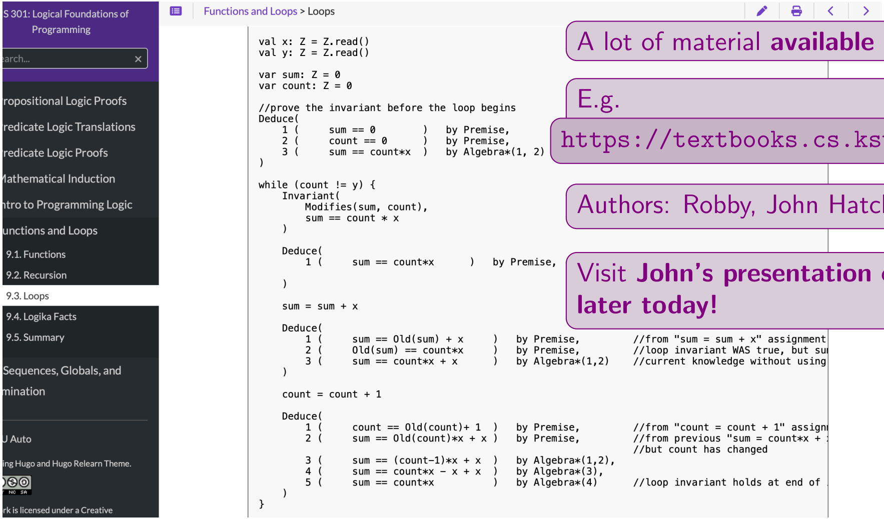
Authors: Robby, John Hatcliff, Julie Thorton

Much More Material Available From Kansas State University



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Authors: Robby, John Hatcliff, Julie Thorton

Visit **John's presentation** on Logika **later today!**

Context, Approach and Evolution

Use and Significance of Slang and Logika

Feedback

Discussion

Next Steps

Next Steps

- Extend the number of **examples**
- Improve support for **self-study**
- improve presentation of **more advanced verification**
- Improve presentation of **proof methodology**
- Rely on discussion and **feedback from students** for improvements
- The course **evolves gradually** – material, tool and students change