Formal verification of Scala programs with Stainless

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June 14th, 2019

Who am I?

What is Stainless?

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Stainless is a verification framework for higher-order programs written in a (now fairly substantive) subset of Scala.

We currently support the following features:



What Stainless verifies

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Stainless supports verifying:

- ▶ Assertions which should hold at the place where they are stated, but are checked statically
- Postconditions using ensuring function: assertions for return values of functions
- Preconditions using require function: assertions on function parameters
- ▶ Loop invariants: inductive assertions that hold in each loop iteration after the while condition check passes
- ▶ ADT/Class invariants: assertions on immutable parameters of constructors (which remain true for all constructed values)

Stainless also automatically performs automatic checks for the absence of runtime failures:

- completeness of pattern matching
- b division by zero, array bounds checks
- map domain checks

Moreover, Stainless prevents *PureScala* programs from:

overflows and underflows on sized integer types

- creating null values or unininitalized local variables or fields
- explicitly throwing an exception



Verifying typeclasses

```
Seq(1, 2, 3, 4).par.fold(10)(_ - _)

// ((((10 - 1) - 2) - 3) - 4) => 0

// (10 - 1) - (2 - (3 - 4)) => 6
```

```
Seq(1, 2, 3, 4).par.fold(0)(_ + _)
```

$$// ((((10 + 1) + 2) + 3) + 4) \Rightarrow 10$$

 $// (10 + 1) + (2 + (3 + 4)) \Rightarrow 10$

```
abstract class Semigroup[A] {
  def combine(x: A, y: A): A

@law def law_assoc(x: A, y: A, z: A) =
```

combine(x, combine(y, z)) == combine(combine(x, y), z)

```
abstract class Monoid[A]
  extends Semigroup[A] {
  def empty: A
    @law def law_identity(x: A) =
    combine(empty, x) == x
```

@law def law_rightIdentity(x: A) =

combine(x, empty) == x

```
case class Sum(get: BigInt)
```

```
implicit def sumMonoid = new Monoid[Sum] {
  def empty = 0
  def combine(x: Sum, y: Sum) = Sum(x.get + y.get)
}
```

```
implicit def optionMonoid[A](implicit val S: Semigroup[A])
 new Monoid[Option[A]] {
   def empty: Option[A] = None()
   def combine(x: Option[A], y: Option[A]) =
     x match {
        case None() => y
        case Some(xv) => y match {
          case None() => x
          case Some(yv) => Some(S.combine(xv, yv))
```

```
def lemma_optionCombineAssoc(x: Option[A], y: Option[A], z
```

// TODO

```
implicit def optionMonoid[A](implicit val S: Semigroup[A])
  new Monoid[Option[A]] {
    // ...
```

override def law_assoc(x: Option[A], y: Option[A], z: 0
super.law_assoc(x, y, z) because lemma_optionCombine.

// ...

}

```
implicit def optionMonoid[A](implicit val S: Semigroup[A])
  new Monoid[Option[A]] {
    // ...
```

```
override def law_assoc(@induct x: Option[A], y: Option
```

super.law_assoc(x, y, z)

```
def foldMap[M, A](xs: List[A])(f: A => M)(implicit M: Monor
    xs.map(f).fold(M.empty)(M.append)

@extern
def parFoldMap[M, A](xs: List[A])(f: A => M)(implicit M: Monor
    xs.toScala.par.map(f).fold(M.empty)(M.append)
```

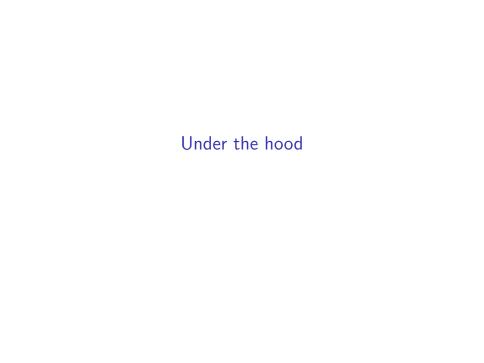
} ensuring { res =>

res == foldMap(xs, f)



Termination checking

A *verified* function in stainless is guaranteed to never crash, however, it can still lead to an infinite evaluation. Stainless therefore provides a termination checker that complements the verification of safety properties.



Case studies

ConcRope

Parellel Map-Reduce pipeline

```
Actor systems
     case class Primary(backup: ActorRef, counter: Counter) es
       require(backup.name == "backup")
       def processMsg(msg: Msg)(implicit ctx: ActorContext): 1
         case Inc =>
           backup! Inc
           PrimBehav(backup, counter.increment)
         case => this
     case class Backup(counter: Counter) extends Behavior {
       def processMsg(msg: Msg)(implicit ctx: ActorContext): 1
         case Inc => BackBehav(counter.increment)
         case _ => this
```

Smart contracts verification

We also maintain a fork of Stainless, called *Smart* which supports:

- Writing smart contracts in Scala
- Specifiybg and proving properties of such programs, including precise reasoning about the Uint256 data type
- Generating Solidity source code from Scala, which can then be compiled and deployed using the usual tools for the Ethereum software ecosystem

For example, we have modeled and verified a voting smart contract developed by SwissBorg.

[0] https://github.com/epfl-lara/smart

Bonus: Refinement and dependent function types

Refinement types

```
def sortedInsert(
   xs: { List[Int] => xs.nonEmpty },
   x: { Int => x <= xs.head }
): { res: List[Int] => isSorted(res) } = {
   x :: xs // VALID
}
```

Dependent function types

```
trait Entry {
  type Key
  val key: Key
}
def extractKey(e: Entry): e.Key = e.key
def extractor: (e: Entry) => e.Key = extractKey(_)
```

```
case class IntEntry() extends Entry {
  type Key = Int
  val key: Int = 42
}
```

assert(extractor(entry) == 42) // VALID

Coming up

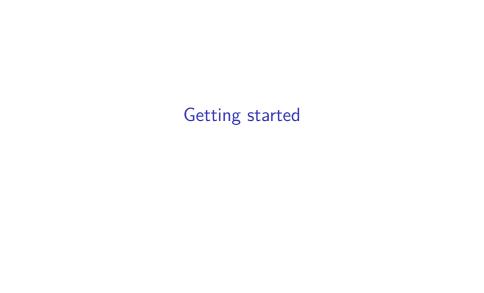
Coming up

- VC generator via bidirectional typechecker for System FR (TODO: ref)
- Higher-kinded types
- Better support for GADTs
- Indexed recursive types
- WebAssembly backend
- Actually working compiler and sbt plugin
- Better metals/IDE integration



Further work

- ▶ Reasoning about I/O and concurrency (via ZIO?)
- Support for exceptions
- Scala 2.13 / latest Dotty / TASTY support
- Standalone front-end for a verification friendly input language
- ► Eta / Frege front-end
- ► GraalVM/Truffle back-end





References I