

# Experiments in Formal Verification of Scala Code

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Problems Verifying Bitcoin-S

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- Pure Scala
- Pre- and Postcondition
- Outcome: valid, invalid, unknown

## Example: max

```
1 def max(x: Int, y: Int): Int = {  
2   val d = x - y  
3   if (d > 0) x  
4   else y  
5 }
```

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<https://epfl-lara.github.io/stainless/tutorial.html#warm-up-max>

## Example: max

```
1 def max(x: Int, y: Int): Int = {  
2   val d = x - y  
3   if (d > 0) x  
4   else y  
5 } ensuring (res =>  
6   x <= res && y <= res && (res == x || res == y))
```

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<https://epfl-lara.github.io/stainless/tutorial.html#warm-up-max>

## Example: max

```
[...      ]  
[ Info    ] - Result for 'postcondition' VC for max @2:3:  
[Warning  ] => INVALID  
[Warning  ] Found counter-example:  
[Warning  ]   x: Int -> -2147483648  
[Warning  ]   y: Int -> 2147483647  
[...      ]
```

## Example: max

```
1  def max(x: Int, y: Int): Int = {  
2    require(0 <= x && 0 <= y)  
3    val d = x - y  
4    if (d > 0) x  
5    else y  
6  } ensuring (res =>  
7    x <= res && y <= res && (res == x || res == y))
```

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<https://epfl-lara.github.io/stainless/tutorial.html#warm-up-max>



# Properties

- Bitcoin-S
- No-Inflation Property
- Addition-with-Zero Property

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# Turning Object into Case Object

This:

```
1 object Satoshi extends BaseNumbers[Satoshi] {  
2   val zero = Satoshi(Int64.zero)  
3   val one = Satoshi(Int64.one)  
4 }
```

Becomes this:

```
1 case object Satoshi extends BaseNumbers[Satoshi] {  
2   val zero = Satoshi(Int64.zero)  
3   val one = Satoshi(Int64.one)  
4 }
```

# Getting Rid of Abstract Type Member

This:

```
1 sealed abstract class CurrencyUnit {  
2   type A  
3  
4   protected def underlying: A  
5 }  
6  
7 sealed abstract class Satoshi extends CurrencyUnit {  
8   override type A = Int64  
9 }
```

Becomes this:

```
1 sealed abstract class CurrencyUnit {  
2   protected def underlying: Int64  
3 }  
4  
5 sealed abstract class Satoshi extends CurrencyUnit
```

# BigInt &-Function to Bound Check

This:

```
1 sealed abstract class Number {  
2   def andMask: BigInt  
3   def checkResult(result: BigInt): BigInt = {  
4     require((result & andMask) == result)  
5     result  
6   }  
7 }
```

Becomes this:

```
1 sealed abstract class Number {  
2   def checkResult(result: BigInt): BigInt = {  
3     require(  
4       result <= BigInt("9223372036854775807") &&  
5       result >= BigInt("-9223372036854775808")  
6     )  
7     result  
8   }  
9 }
```

# Formal Specification

```
1 def +(c: CurrencyUnit): CurrencyUnit = {  
2   require(c.satoshis == Satoshis.zero)  
3   Satoshis(  
4     satoshis.underlying + c.satoshis.underlying  
5   )  
6 } ensuring(res => res.satoshis == this.satoshis)
```

# Output of Stainless

```
[Warning] The Z3 native interface is not available. Falling back onto smt-z3.
[ Info] - Checking cache: 'cast correctness' VC for underlying @59:30...
[ Info] - Checking cache: 'cast correctness' VC for inv @59:30...
[ Info] - Checking cache: 'cast correctness' VC for inv @59:30...
[ Info] Cache hit: 'cast correctness' VC for inv @59:30...
[ Info] Cache hit: 'cast correctness' VC for inv @59:30...
[ Info] Cache hit: 'cast correctness' VC for underlying @59:30...
[ Info] - Checking cache: 'cast correctness' VC for underlying @43:33...
[ Info] Cache hit: 'cast correctness' VC for underlying @43:33...
[ Info] - Checking cache: 'precond. (call checkResult(thiss, underlying(thiss) + u ...)' VC for + @22:11...
[ Info] - Checking cache: 'precond. (call +(@unchecked ( ...))' VC for + @4:3...
[ Info] Cache hit: 'precond. (call checkResult(thiss, underlying(thiss) + u ...)' VC for + @22:11...
[ Info] Cache hit: 'precond. (call +(@unchecked ( ...))' VC for + @4:3...
[ Info]
[ Info] stainless summary
[ Info]
[ Info] +      precondition. (call +(@unchecked ( ...))      valid from cache      BasicArithmetic.scala:4:3      0.022
[ Info] +      precondition. (call checkResult(thiss, underlying(thiss) + u ...) valid from cache      NumberType.scala:22:11      0.021
[ Info] inv      cast correctness      valid from cache      NumberType.scala:59:30      0.249
[ Info] inv      cast correctness      valid from cache      NumberType.scala:59:30      0.247
[ Info] underlying cast correctness      valid from cache      CurrencyUnits.scala:43:33    0.010
[ Info] underlying cast correctness      valid from cache      NumberType.scala:59:30      0.849
[ Info]
[ Info] -----
[ Info] total: 6      valid: 6      (6 from cache) invalid: 0      unknown: 0      time: 1.398
[ Info]
[ Info] Shutting down executor service.
```

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# Conclusion

- Write verifiable code
- We verified not original Bitcoin-S code
- Provided feedback to Stainless developers
- Found a bug in Bitcoin-S

# Found Bug in Bitcoin-S

```
▼ 6 core-test/src/test/scala/org/bitcoins/core/protocol/transaction/TransactionTest.scala ...  
@@ -294,6 +294,12 @@ class TransactionTest extends FlatSpec with MustMatchers {  
294 294     }  
295 295     }  
296 296  
297 + it must "check transaction with two out point referencing the same tx with different indexes" in {  
298 +   val hex = "0200000002924942b0b7c12ece0dc8100d74alcd29acd6cfc60698bfc3f07d83890eac20b6000000006a47304402202831  
299 +   val btx = BaseTransaction.fromHex(hex)  
300 +   ScriptInterpreter.checkTransaction(btx) must be(true)  
301 +   }  
302 +  
297 303   private def findInput(  
298 304     tx: Transaction,  
299 305     outPoint: TransactionOutPoint): Option[(TransactionInput, Int)] = {  
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```
▼ 4 core/src/main/scala/org/bitcoins/core/script/interpreter/ScriptInterpreter.scala ...  
@@ -779,8 +779,8 @@ sealed abstract class ScriptInterpreter {  
779 779     val totalSpentByOutputs: CurrencyUnit =  
780 780     outputValues.fold(CurrencyUnits.zero) (_ + _)  
781 781     val allOutputsValidMoneyRange = validMoneyRange(totalSpentByOutputs)  
782 -   val prevOutputTxIds = transaction.inputs.map(_.previousOutput.txId)  
783 -   val noDuplicateInputs = prevOutputTxIds.distinct.size == prevOutputTxIds.size  
784 +   val prevOutputs = transaction.inputs.map(_.previousOutput)  
785 +   val noDuplicateInputs = prevOutputs.distinct.size == prevOutputs.size  
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