Let The Compiler Help You: How To Make The Most Of Scala's Typesystem

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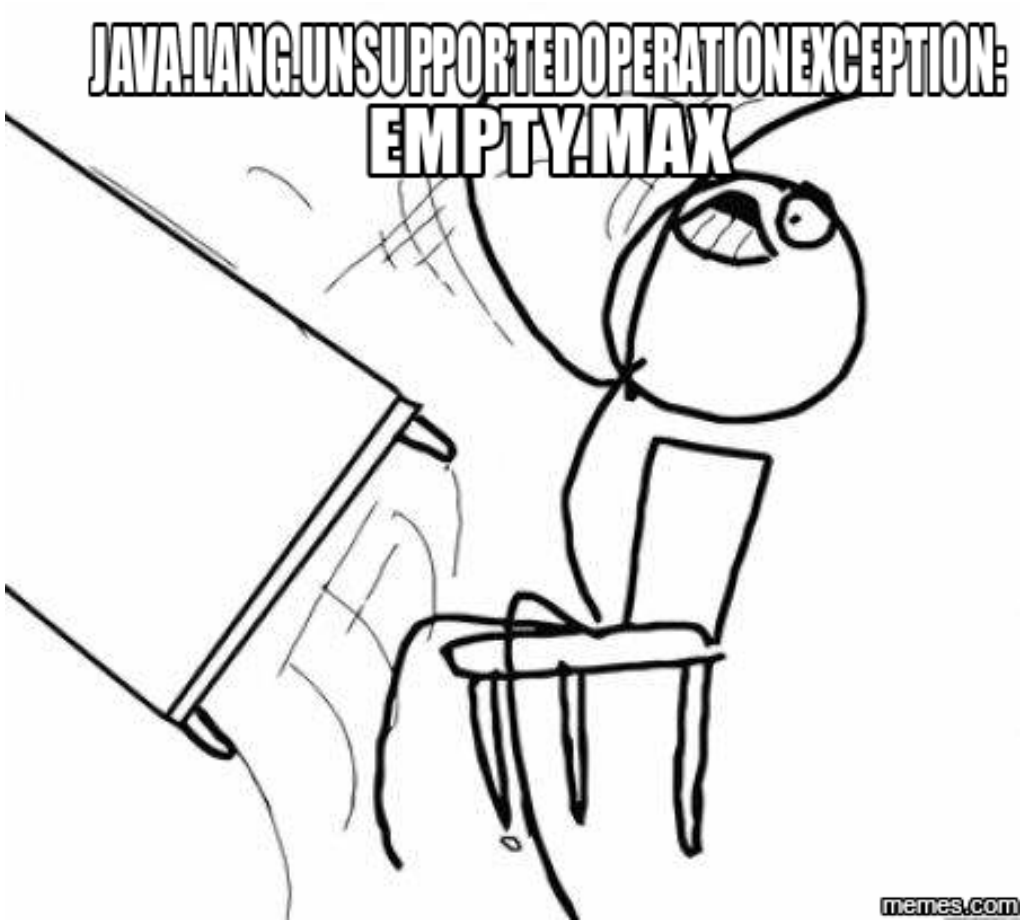
Scala.IO 2017

One Evening

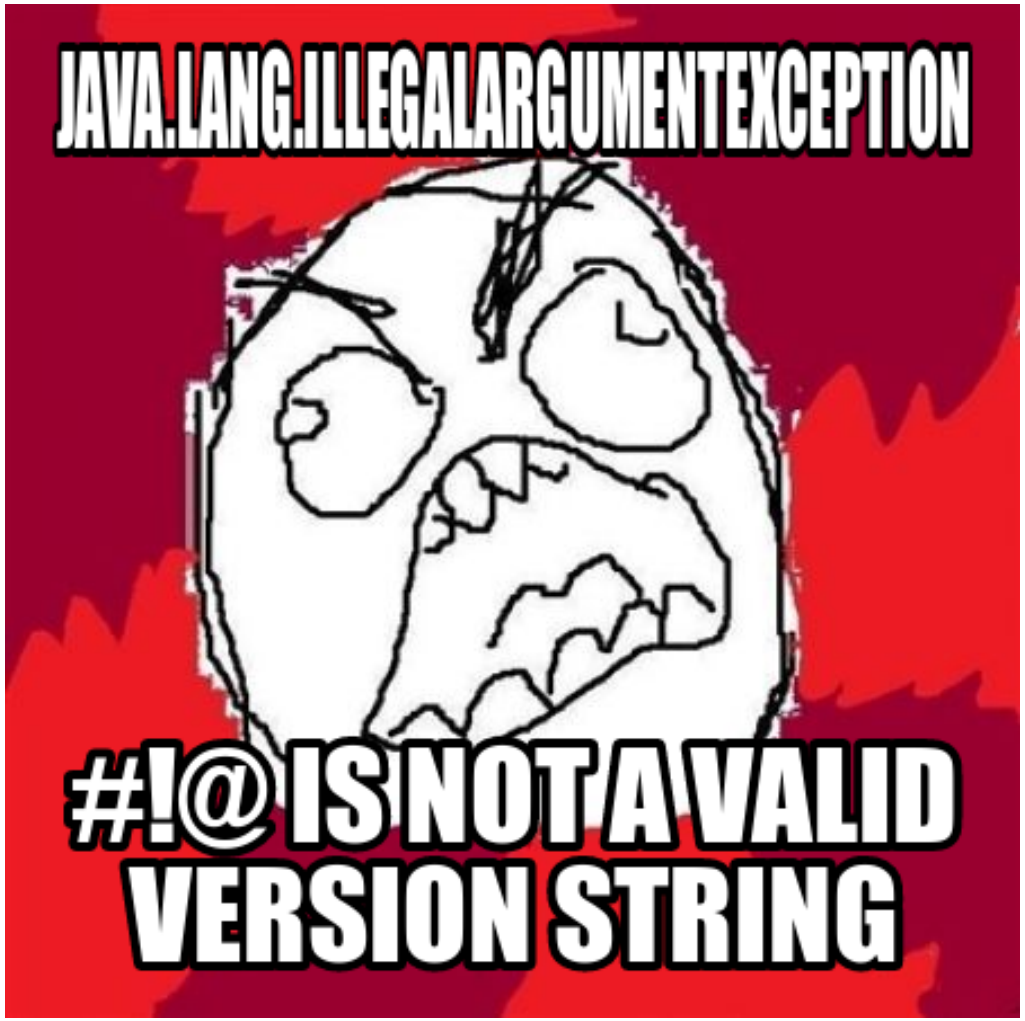
Done!?

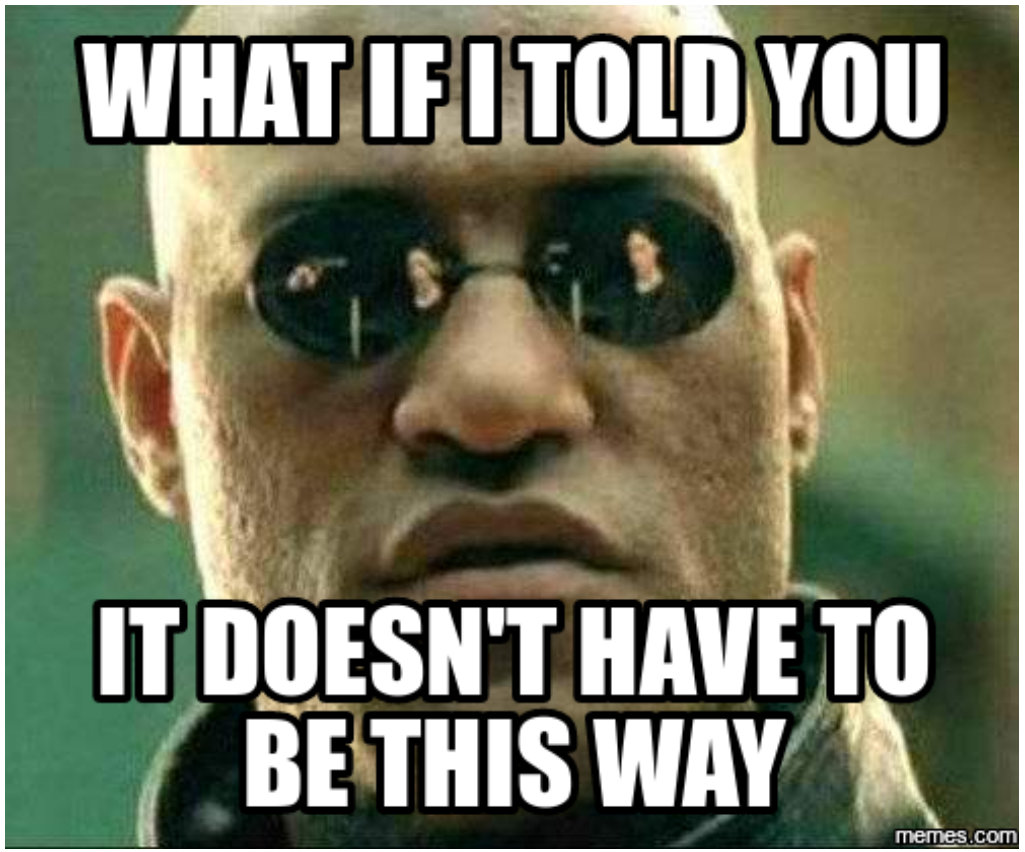
```
> compile
[success] Total time: 42s, completed Nov 2 14:05:42
> run
...
```


JAVA.LANG.UNSUPPORTEDOPERATIONEXCEPTION:
EMPTY.MAX
memes.com

Done!?

```
> compile
[success] Total time: 42s, completed Nov 2 14:05:42
> run
...
```


JAVA.LANG.ILLEGALARGUMENTEXCEPTION
#!@ IS NOT A VALID VERSION STRING


WHAT IF I TOLD YOU
IT DOESN'T HAVE TO BE THIS WAY
memes.com

A Better Way

```
> compile
[info] Compiling 1 Scala source to
  /home/brain/world-domination/target/scala-2.12/classes ...
[error] ConquerWorld.scala:1337:42: type mismatch;
[error]  found   : Int(-42)
[error]  required: PositiveInt
[error]   requiredAssets(-42)
[error]                  ^
[error] one error found
[error] (compile:compileIncremental) Compilation failed
```


NO NEED TO RUN
YOU HAVE AN ERROR THERE

Introduction

- currently: programming as a fight against the compiler
- soon: work **together** with the compiler
- tests: **evidence** it works
- types: **proof** it works
- you need to communicate with the compiler

The Road Ahead

- Preparations
- Be Honest
- Forbid it
- No Garbage
- Only Valid Ops

Become Friends

- by default the compiler is a little shy
- but once you get friends, you don't want to go back
- first thing: unmute him!
  - `-deprecation`
  - `-unchecked`
  - `-Xfuture`
  - `-Xlint:-unused`
  - `-Ywarn-unused:imports,privates,locals`
- sometimes false positives, see
  - `scalac -X`
  - `scalac -Y`

Not: Documentation

- documentation is not for the compiler
- it is meant for humans (which are bad at it)
- avoid: **context sensitive** reasoning
- think: I **know** this can't happen
- use a language that the compiler understands: types

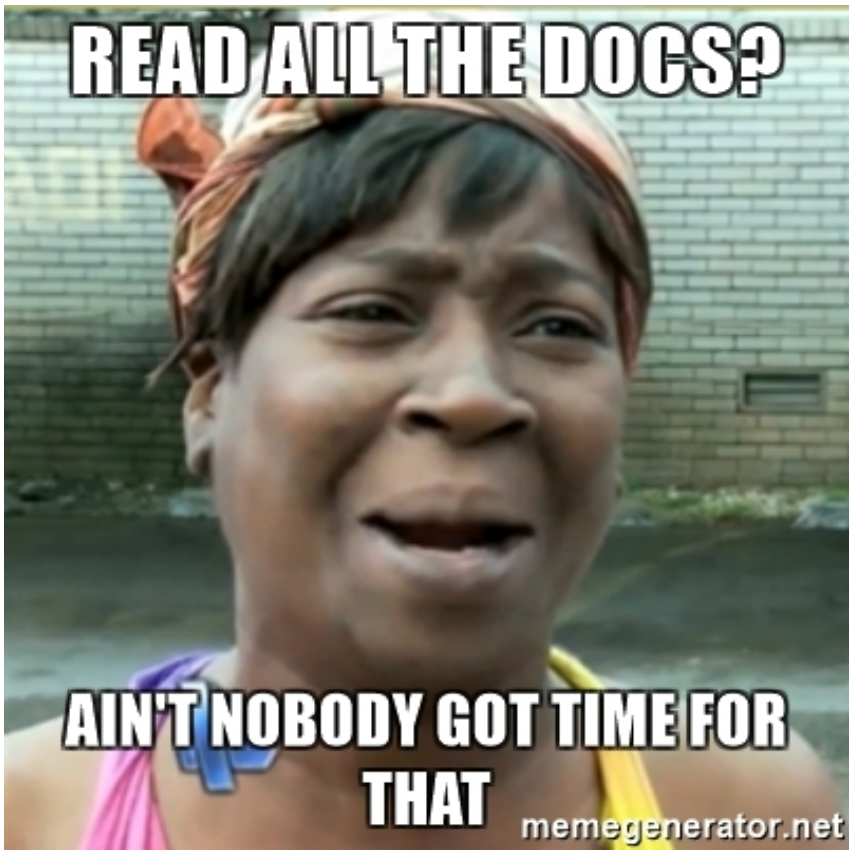
Case Study: Vending Machine

- insert coin (50 cents or 1 euro)
- push button for drink
- abort the transaction and return money

```
final class VendingMachine(id: Int) {
  require(id > 0 && id < 100, "Invalid identifier")
  private[this] var amount: Int = 0

  def insertMoney(cents: Int): Unit = cents match {
    case 50 | 100 => amount += cents
    case _ => throw new IllegalArgumentException("...")
  }

  def pushButton(): Unit = if (amount == 100) {
    () // eject
  } else {
    throw new IllegalStateException("...")
  }

  def abort(): Int = if (amount > 0) {
    val res = amount; amount = 0; res
  } else {
    throw new IllegalStateException("...")
  }
}
```

A First Design

- what does the compiler know?
- what do you as a user of this class know without docs?



Step 1: Be Honest

Get The Max Out Of Your List

```
def max: A
```

[use case]

Finds the largest element.

returns the largest element of this list.

Definition Classes TraversableOnce → GenTraversableOnce

Full Signature

Get The Max Out Of Your List

```
> List[Int](1, 2, 3).max
res0: Int = 3
```

```
> List[Int]().max
java.lang.UnsupportedOperationException: empty.max
```

Be Honest

- not honest ⇒ no help
- `max` pretends to always return something, which is not the case!
- tell the compiler this operation can fail
- Option: if no result is a result
- Either: if there can be errors
- Custom ADT:if `Either` doesn't cut it

Be Honest

- how does this apply to our case study?
- `insertMoney` can fail
- `pushButton` can fail
- `abort` can fail

- we will fix this later

Step 2: If not allowed, forbid it

Step 2: If not allowed, forbid it

- **every** project has domain classes with invariants
- how to verify those invariants?

```
if (input.isValid) {
  ???
} else {
  throw new Exception("whoopsie")
}
```

```
class ImportantStuff(stuff: Stuff) {
  require(stuff.isImportant, "Not important!")
}
```

- but the compiler (and others) does not know this!

If not allowed, forbid it

```
case class Email(value: String) extends AnyVal {
  require(isValidEmail(value))
}
```

```
> Email("markus.hauck@codecentric.de")
res1: Email = ...

> Email("Hello World!")
java.lang.IllegalArgumentException:
  Not a valid email address
```

If not allowed, forbid it

- how can we improve?
- for methods, the **return type** changed
- instantiation doesn't have one?
- one solution: smart constructors / factories

If not allowed, forbid it

```scala
abstract case class Email private (...)

object Email {
  def fromString: Either[ValidationError, Email] =
    ??? // exercise
}
```

```scala
> Email.fromString("markus.hauck@codecentric.de")
res1: Either[ValidationError, Email] =
  Right("markus.hauck@codecentric.de")

> Email.fromString("Hello World")
res2: Either[ValidationError, Email] =
  Left(InvalidEmail)
```

Case Study

- Okay, back to our case study
- we want to fix:
  - methods that are not honest
  - forbid invalid instantiation

```scala
final class VendingMachine private (id: Int) {
  private[this] var amount: Int = 0

  def insertMoney(cents: Int): Either[InvalidCoin, Unit] =
    cents match {
      case 50 | 100 =>
        amount += cents
        Right(())
      case _ =>
        Left(InvalidCoin)
    }

  def pushButton(): Either[InsufficientFunds, Unit] =
    if (amount == 100) { Right(()) }
    else { Left(InsufficientFunds) }

  def abort(): Either[NoChange, Int] = if (amount > 0) {
    val res = amount; amount = 0; Right(res)
  } else Left(NoChange)
}
```

```
object VendingMachine {
  def create(id: Int): Either[InvalidId, VendingMachine] =
    if (id > 0 && id < 100) {
      Right(new VendingMachine(id))
    } else {
      Left(InvalidId)
    }
}

// define left sides of eithers
```

Case Study: Review

- we got rid of all exceptions
- no way to "forget" that something can fail
- compiler (coworkers?) now knows quite a bit more
- what else can we improve?

Step 3: Don't accept garbage

Don't accept garbage input

- another everyday example:

```
> List(1, 2, 3).take(-42)
```

- Quiz: what happens?

Don't accept garbage input

- another everyday example:

```
> List(1, 2, 3).take(-42)
```

- Quiz: what happens?

```
res1: List[Int] = List()
```

Don't accept garbage input

- our constructor and methods are quite liberal
- they take almost everything!
- does the validation really belong in our vending machine?
- actually it is the **caller**'s fault!
- better: don't accept garbage and let the caller to the work
- push validation to the boundaries of your system
- avoid doing it over and over again in program flow

Putting It Into Practice

```
class MailService {
  def sendEmail(mail: String):
    Either[MailValidationError, MailStatus]
}
```

```
class MailService {
  def sendEmail(mail: Email): MailStatus
}
```

Putting It Into Practice

```
> List(1, 2, 3).head
res1: Option[Int] = Some(1)
```

```
> NonEmptyList.of(1, 2, 3).head
res1: Int = 1
```

Putting It Into Practice

```
sealed abstract class List[+A] {
  def apply(index: Int): A
}
```

```
sealed abstract class List[+A] {
  def apply(index: Natural): A
}
```

How To Validate

- okay seems like it makes sense to do this
- goal: make core logic more focused, factor out error handling
- how?
  - use a wrapper with smart constructors
  - use phantom types as “tags”

Validation With Smart Constructors

```
abstract case class Email private (...)

object Email {
  def fromString: Either[ValidationError, Email] =
    ??? // exercise
}
```

- that works, but becomes cumbersome pretty quick
- I **know** it will succeed!

```
> Email.fromString("foo@bar.de")
```

Phantom Types

- phantom type: not associated to any value
- only exists at compile time
- attach information to values
- example: validation of user input
- instead of repeated validation “to be sure”, enforce with types

Phantom Types: The Idea

```
sealed trait Validation
final abstract class Valid extends Validation
final abstract class Unknown extends Validation

abstract case class UserInput[A <: Validation]
  (value: String)

object UserInput {
  def unknown(s: String): UserInput[Unknown] =
    new UserInput[Unknown](s) {}

  def validate(input: UserInput[Unknown]):
    Option[UserInput[Valid]] = ???
}
```

Phantom Types for Tags

- Creating new classes for invariants works, but very cumbersome
- But: Whenever input enters your system: require validation
- Avoid validation again and again because of different flows through system and refactorings (context-free!)
- annoying: static input requires validation
- *skipping*: `Tagged` to avoid wrappers

Refined

- the refined library to the rescue
- in essence: a **Refined[T, P]**
- actual value `T` + phantom type for predicate `P`
- no wrapper, no custom phantom type (ADT)
- only define your predicate or use the builtin ones
- killer feature: perform validation for literals as input at compile time

Refined: Predicates

- DSL to define predicates
- many builtins: link
- useful as documentation as well

```
String Refined Uri
String Refined Uuid
String Refined MatchesRegex[W.‘"[0-9]+"‘.T]

type ZeroToOne = Not[Less[W.‘0.0‘.T]]
  And Not[Greater[W.‘1.0‘.T]]

type ValidChar =
  AnyOf[Digit :: Letter :: Whitespace :: HNil]
```

Using Refined

```scala
object Refined {
  def index[A](xs: List[A])(
    i: Int Refined Positive): A = xs(i)

  index(List(1, 2, 3))(2)

  index(List(1, 2, 3))(-1)
}
```

```
[error] UserInput.scala:15: Predicate failed: (-1 > 0).
[error]   index(List(1, 2, 3))(-1) // compile error
[error]                        ^
[error] one error found
```

Refined: Dynamic Input

- but the macro works only for literal input
- dynamic values: you still have to take care

```
> refineV[Positive](fortyTwo)
res1: Either[String, Int Refined Positive] =
  Right(...)
> refineV[Positive](negativeInt)
res2: Either[String, Int Refined Positive] =
  Left(...)
```

Case Study

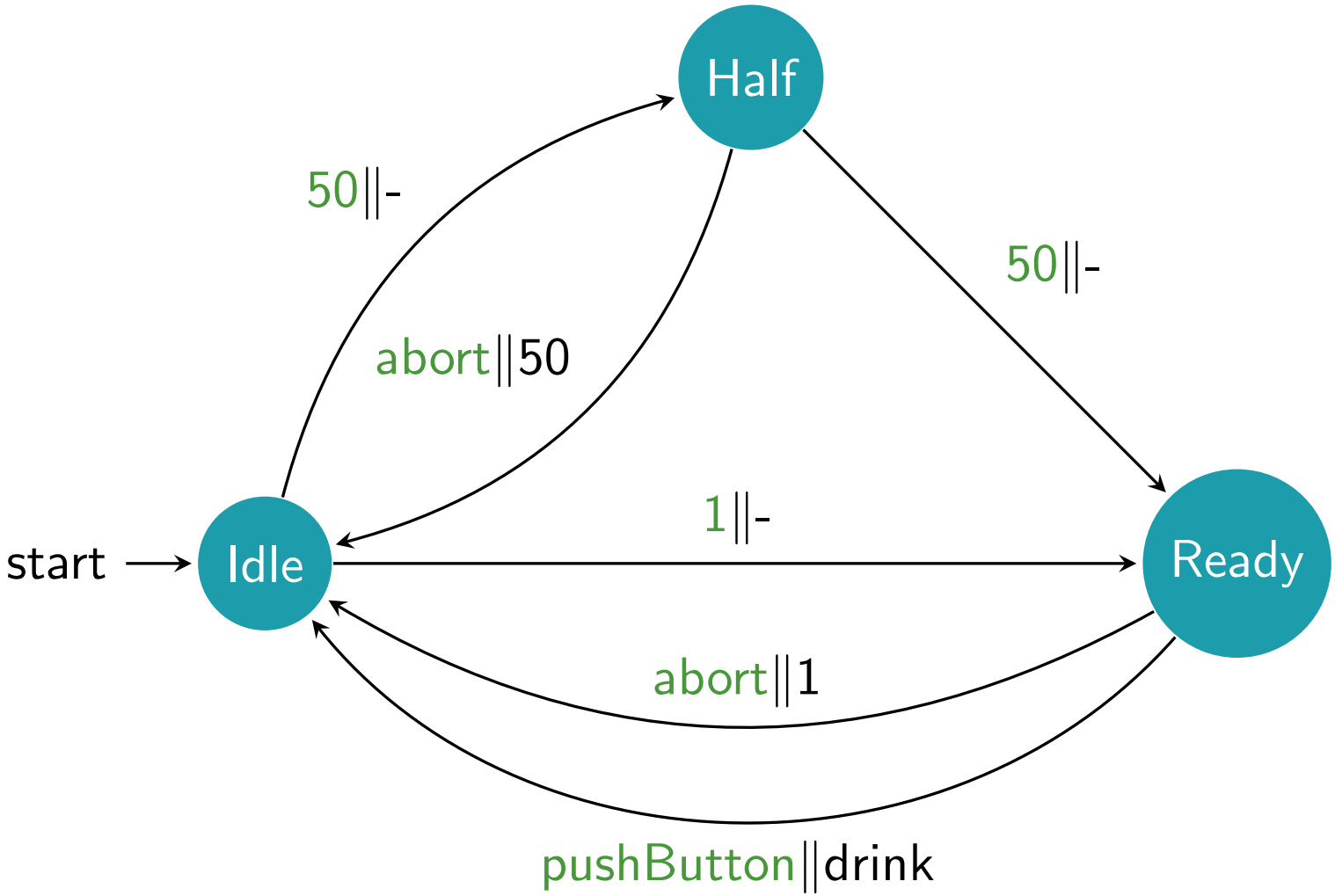
```
final class VendingMachine(id: Identifier) {
  private[this] var amount: Int = 0
  def insertMoney(cents: Coin): Unit = ???
  def pushButton(): Either[InsufficientFunds, Unit] = ???
  def abort(): Either[NoChange, Int] = ???
}

object VendingMachine {
  type Identifier = Int Refined
    Interval.Closed[W.‘1‘.T, W.‘100‘.T]
}

sealed trait Coin
case object FiftyCents extends Coin
case object OneEuro extends Coin
```

Case Study

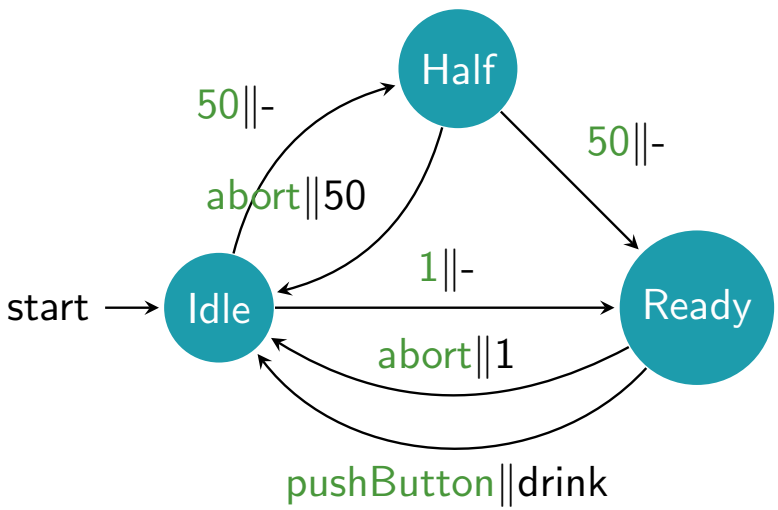
- the `Identifier` is checked by `refined`
- `insertMoney` only allows valid coins by design
- we can get rid of the `Either` in `insertMoney`
- what else?

Step 4: Restrict Valid Operations

Vending State Machine



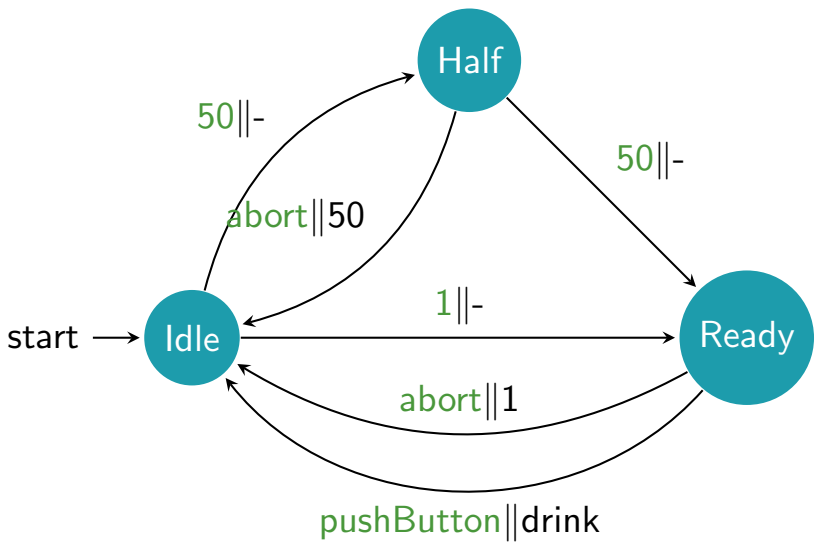
Vending State Machine



- possible:
  - 50 → 50 → pushbutton
  - 50 → abort
  - 1 → pushbutton
  - 1 → abort
- available actions depend on the **implicit state**
- methods can return **different types** depending on the state, e.g., abort
- so we need to check those two invariants (via types)!

State Machine: States

```
sealed trait VState
final abstract class Idle extends VState
final abstract class Half extends VState
final abstract class Ready extends VState
```



State Machine: Vending Machine

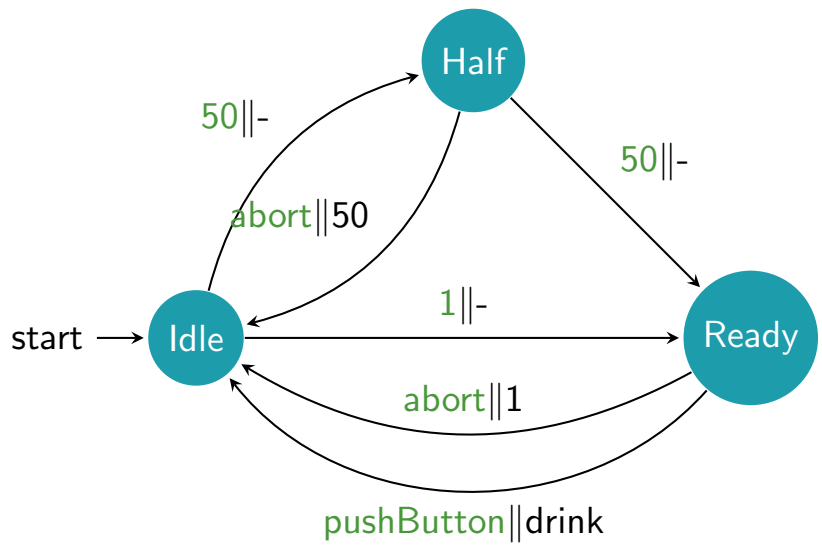
```
final class VendingMachine[S <: VState] private {
  def insertFirst50()(implicit ev: S =:= Idle):
      VendingMachine[Half] = new VendingMachine

  def insertSecond50()(implicit ev: S =:= Half):
      VendingMachine[Ready] = new VendingMachine

  def insertEuro()(implicit ev: S =:= Idle):
      VendingMachine[Ready] = new VendingMachine

  def pushButton()(implicit ev: S =:= Ready):
      (VendingMachine[Idle], Drink) =
        (new VendingMachine[Idle], Drink("Fizz"))

  def abort[T, O]()(implicit ev: Next.Aux[S, T, O]):
      (VendingMachine[T], O) =
        (new VendingMachine[T], ev.coin)
}
```

State Machine: Typeclass

```
sealed abstract class Next[S <: VState] {
  type Next <: VState
  type Out <: Coin
  def coin: Out
}

final object Next {
  type Aux[S0 <: VState, N0 <: VState, O0 <: Coin] =
    Next[S0] {
      type Next = N0
      type Out = O0
    }
```

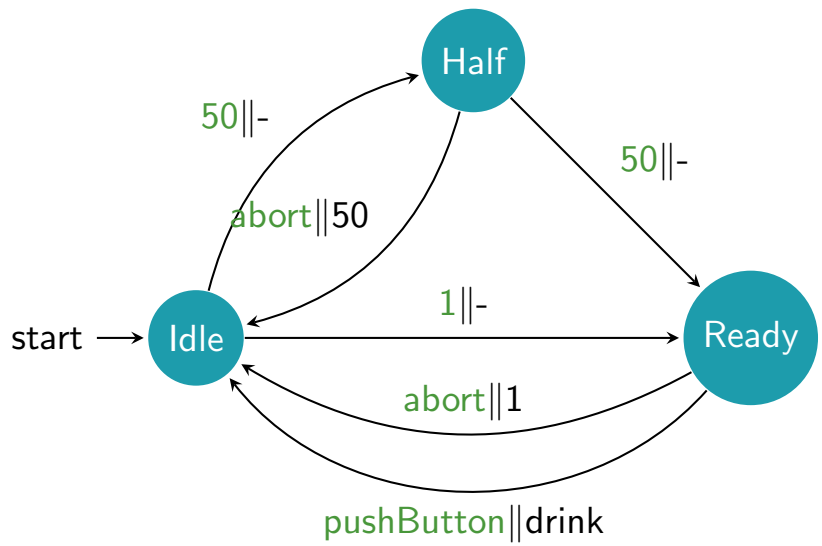
State Machine: Implicit Evidence

```
implicit val halfAbort:
    Next.Aux[Half, Idle, FiftyCents.type] = new Next[Half] {
  type Next = Idle; type Out = FiftyCents.type
  override val coin = FiftyCents
}
```



State Machine: Implicit Evidence

```
implicit val readyAbort:
    Next.Aux[Ready, Idle, OneEuro.type] = new Next[Ready] {
  type Next = Idle; type Out = OneEuro.type
  override val coin = OneEuro
}
```



State Machines: Usage

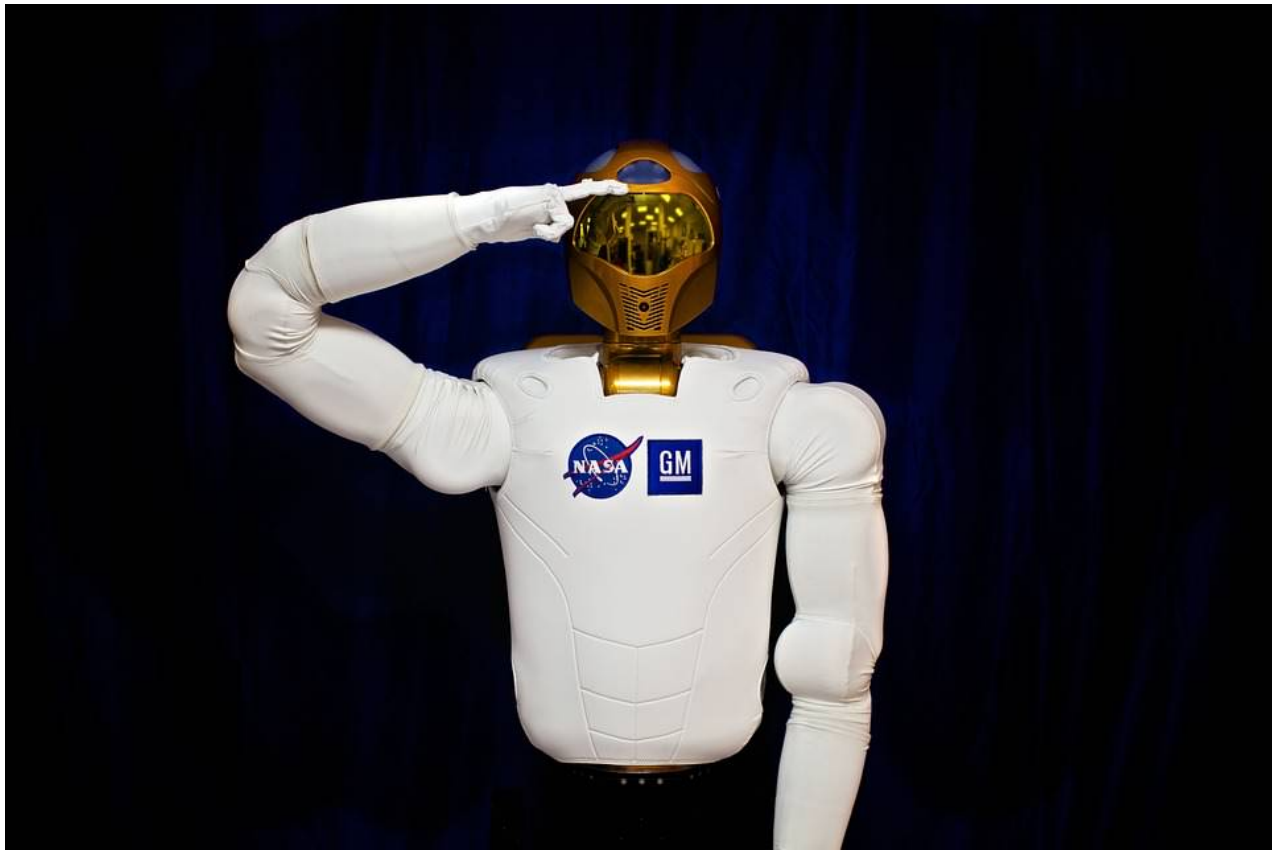
```
object VendingMachineExamples {
  val machine = VendingMachine.initial

  // machine.insertSecond50()
  // Cannot prove that
  //   de.codecentric.Idle =:= de.codecentric.Half.

  // machine.abort()
  // no implicit found for Next[Idle, ???, ???]

  machine.insertFirst50().insertSecond50().pushButton()
  machine.insertEuro().pushButton()
}
```

State Machines: Summary

- calling methods only compiles when it makes sense
- eliminates our **Either** return types
- but: restricted to immutability (change type parameters)
- potentially less code than inheritance (and less weird)


BE HONEST
FORBID IT
NO GARBAGE
ONLY VALID OPS
imgflip.com

The Compiler Is There To Help!



THANKS!

https://github.com/markus1189/scala-io-compiler-help

Bonus: Exercise

- our vending machine is still quite liberal

```
val machine: VendingMachine[Ready] =
  VendingMachine.initial.insertEuro()

val drink1 = machine.pushButton()._2
val drink2 = machine.pushButton()._2
// ...
```

- how could we restrict this **with types**?
- hint: limit access to the state machine