A Scala API for Runtime Verification

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A Scala API for Runtime Verification DSL

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understanding complex systems
by analyzing their execution

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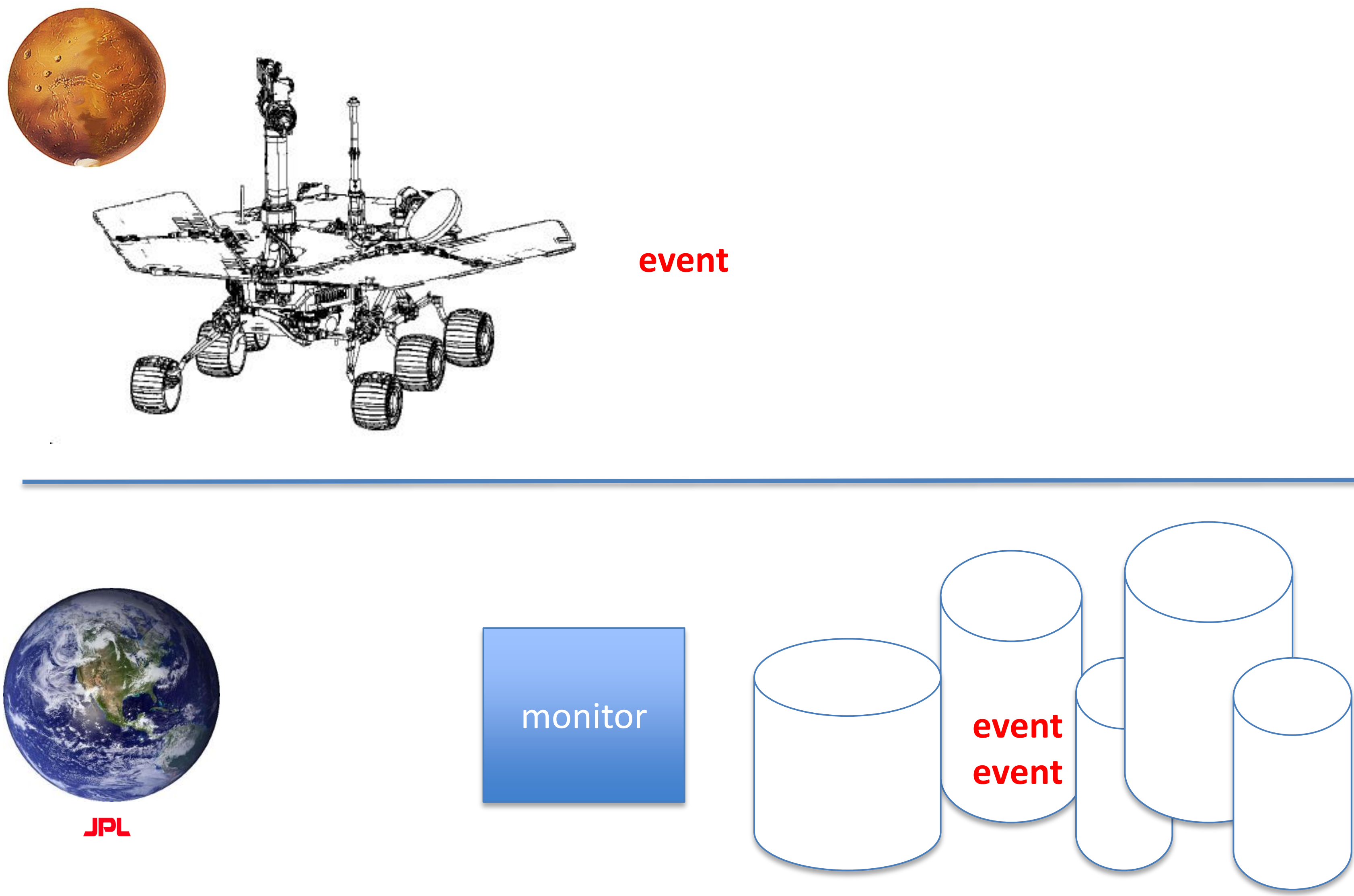
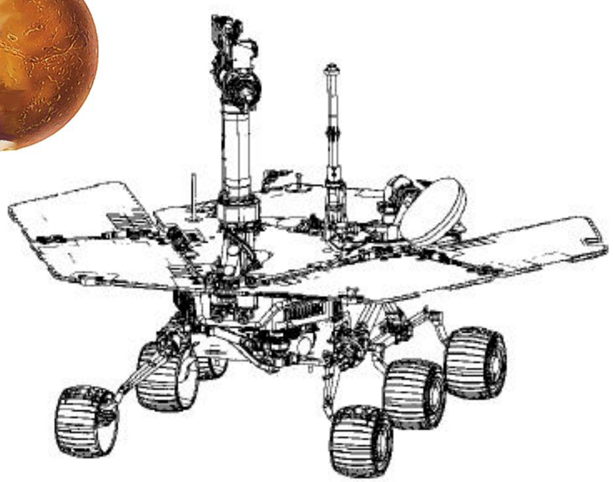
log analysis



fault protection



response

monitor

event

JPL

a DSL for log analysis

Log Scope

```
COMMAND("STOP_CAMERA",1,22:50.00)
COMMAND("ORIENT_ANTENNA_TOWARDS_GROUND",2,22:50.10)
SUCCESS("ORIENT_ANTENNA_TOWARDS_GROUND",3,22:52.02)
COMMAND("STOP_CAMERA",4,22:55.01)
SUCCESS("ORIENT_ANTENNA_TOWARDS_GROUND",5,22:56.19)
COMMAND("STOP_ALL",6,23:01.10)
FAIL("ORIENT_ANTENNA_TOWARDS_GROUND",7,23:02.02)
```

a LogScope property

CommandMustSucceed:

"An issued command must succeed, without a failure to occur before then".

```
monitor CommandMustSucceed {
  always {
    COMMAND(n,x) => RequireSuccess(n,x)
  }

  hot RequireSuccess(name,number) {
    FAIL(name,number) => error
    SUCCESS(name,number) => ok
  }
}
```

```
rule_schema ::=
    modifier+ "{" transition+ "}"
  | modifier* ident ["(" ident,* ")"] ["{" transition+ "}"]

modifier ::=
    "init" | "always" | "step" | "next" | "hot"

transition ::= pattern,* "=>" pattern,*

pattern ::= ["!"] ident ["(" constraint,* ")"]

constraint ::=
   ident ":" range
 | range
```

user reaction

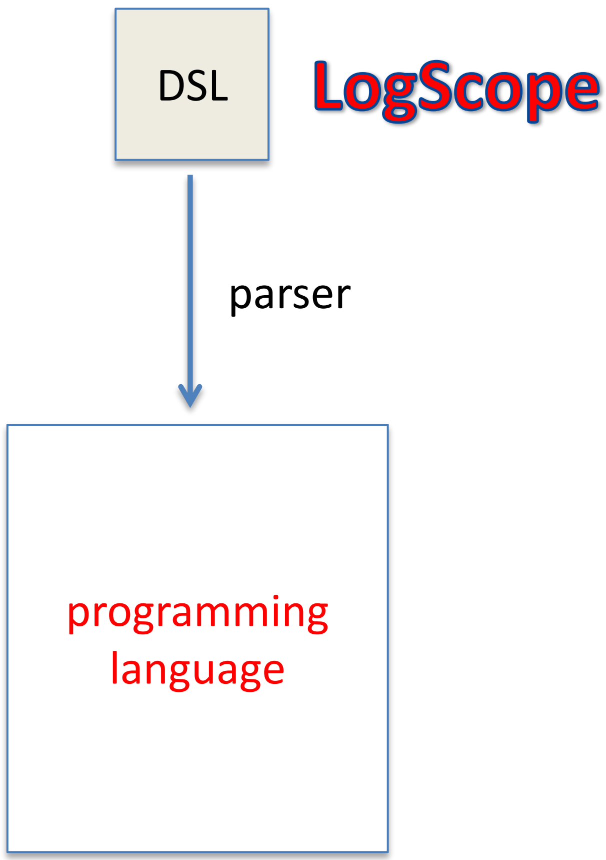
excellent

- I read the manual and was up an running, all before lunch
- my first spec had no errors and just worked

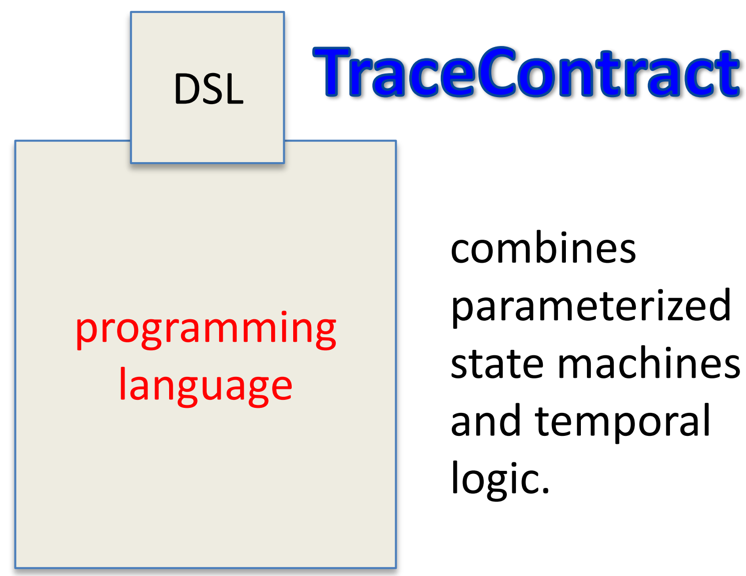
but (2 days later)

- can I define a function and call it in a formula?
- is it possible to re-use formulas?

external versus internal DSL



external DSL



internal DSL

combines parameterized state machines and temporal logic.

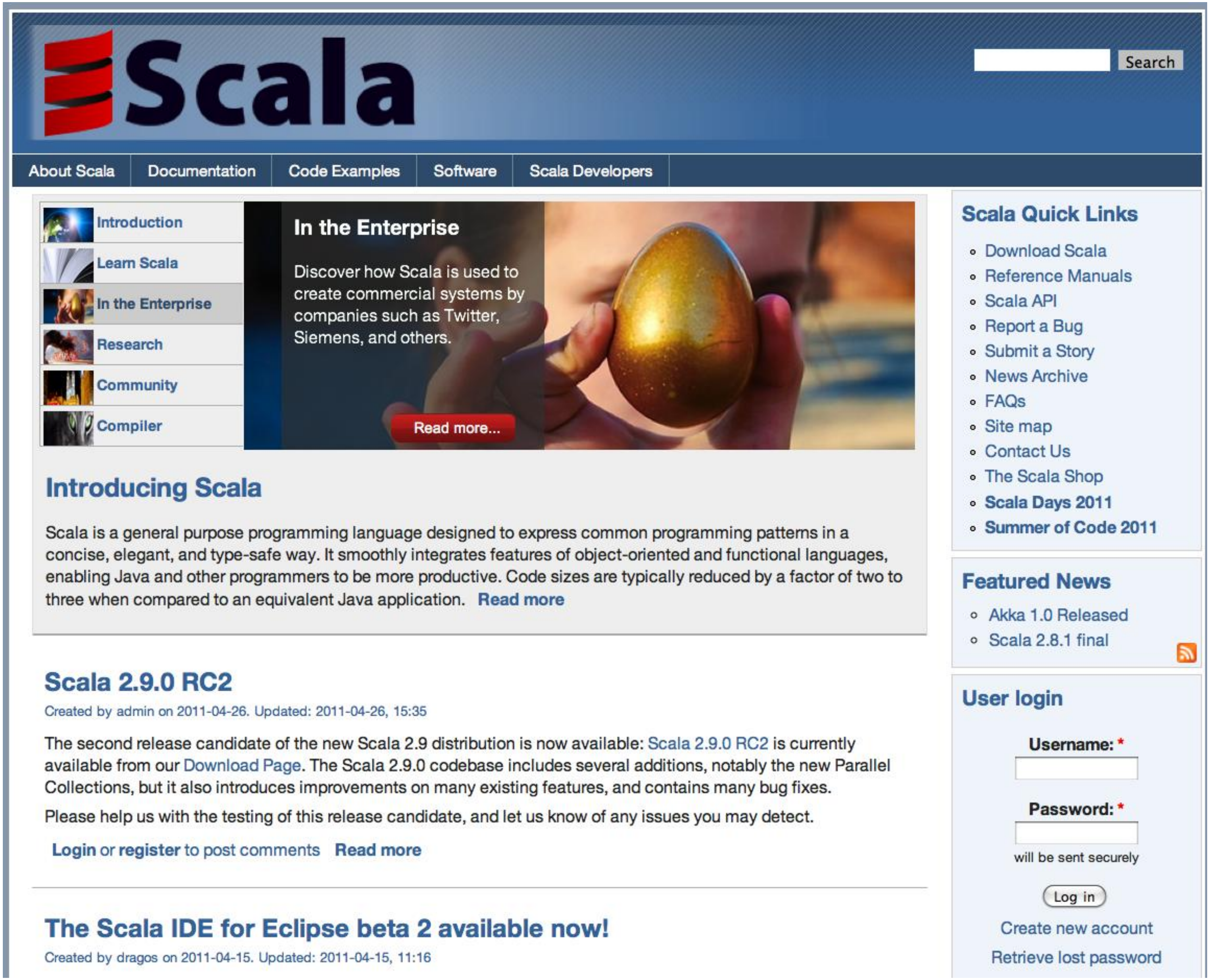
pros and cons for internal DSL

pros

- decreases development effort
- increases expressiveness
- allows use of existing IDE, debuggers, etc.

cons

- steep learning curve
- limited analyzability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In the Enterprise
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Introducing Scala
Scala is a general purpose programming language designed to express common programming patterns in a concise, elegant, and type-safe way. It smoothly integrates features of object-oriented and functional languages, enabling Java and other programmers to be more productive. Code sizes are typically reduced by a factor of two to three when compared to an equivalent Java application. Read more
Scala 2.9.0 RC2
Created by admin on 2011-04-26. Updated: 2011-04-26, 15:35
The second release candidate of the new Scala 2.9 distribution is now available: Scala 2.9.0 RC2 is currently available from our Download Page. The Scala 2.9.0 codebase includes several additions, notably the new Parallel Collections, but it also introduces improvements on many existing features, and contains many bug fixes.
Please help us with the testing of this release candidate, and let us know of any issues you may detect.
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Username: *
Password: *
will be sent securely
Log in
Create new account
Retrieve lost password

Scala as a unifier

script-like

object oriented

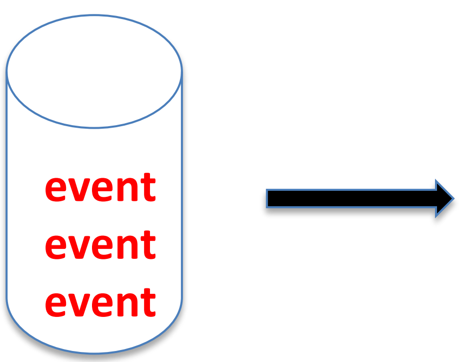
functional

high performance
with strong typing

events

```
abstract class Event

case class  COMMAND(name: String, nr: Int)  extends  Event
case class  SUCCESS(name: String, nr: Int)      extends  Event
case class  FAIL(name: String, nr: Int)            extends  Event
```




```
val trace : List[Event] =
   List(
      COMMAND("STOP_DRIVING", 1),
      COMMAND("TAKE_PICTURE", 2),
      SUCCESS("TAKE_PICTURE", 2),
      SUCCESS("TAKE_PICTURE", 2)
   )
```

```
monitor CommandMustSucceed {
  always {
    COMMAND(n,x) => RequireSuccess(n,x)
  }

  hot RequireSuccess(name,number) {
    FAIL(name,number) => error
    SUCCESS(name,number) => ok
  }
}
```

LogScope

```
class CommandMustSucceed extends Monitor[Event] {
  always {
    case COMMAND(n,x) => RequireSuccess(n,x)
  }

  def RequireSuccess(name: String, number: Int) =
    hot {
      case FAIL(`name`, `number`) => error
      case SUCCESS(`name`, `number`) => ok
    }
}
```

TraceContract

LogScope

```
monitor CommandMustSucceed {
  always {
    COMMAND(n,x) => RequireSuccess(n,x)
  }

  hot RequireSuccess(name,number) {
    FAIL(name,number) => error
    SUCCESS(name,number) => ok
  }
}
```

inlining a state

```
class CommandMustSucceed extends Monitor[Event] {
  always {
    case COMMAND(n, x) =>
      hot {
        case FAIL(`n`, `x`) => error
        case SUCCESS(`n`, `x`) => ok
      }
  }
}
```

TraceContract

```
monitor CommandMustSucceed {
  always {
    COMMAND(n,x) => RequireSuccess(n,x)
  }

  hot RequireSuccess(name,number) {
    FAIL(name,number) => error
    SUCCESS(name,number) => ok
  }
}
```

LogScope

linear temporal logic

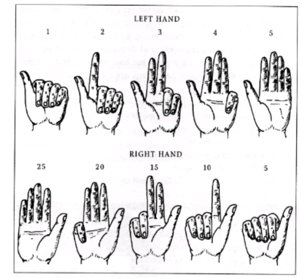
```
class CommandMustSucceed extends Monitor[Event] {
  always {
    case COMMAND(n, x) =>
      not(FAIL(n, x)) until (SUCCESS(n, x))
  }
}
```

TraceContract

LogScope

```
monitor CommandMustSucceed {
  always {
    COMMAND(n,x) => RequireSuccess(n,x)
  }

  hot RequireSuccess(name,number) {
    FAIL(name,number) => error
    SUCCESS(name,number) => ok
  }
}
```



first 10 commands must succeed

```
class CommandMustSucceed extends Monitor[Event] {
  var count = 0
  always {
    case COMMAND(n, x) if count < 10 =>
      count += 1
      not(FAIL(n, x)) until (SUCCESS(n, x))
  }
}
```

TraceContract

```
class Monitor[Event] {
  ...
  type Block = PartialFunction[Event, Formula] (*\label{type-block}*)

  // states:
  def always(block: Block): Formula
  def state(block: Block): Formula
  def hot(block: Block): Formula
  def step(block: Block): Formula
  def strong(block: Block): Formula
  def weak(block: Block): Formula

  // future time temporal logic:
  def not(formula: Formula): Formula
  def globally(formula: Formula): Formula
  def eventually(formula: Formula): Formula
  def strongnext(formula: Formula): Formula
  def matches(predicate: PartialFunction[Event, Boolean]): Formula
  def within(time: Int)(formula: Formula): Formula
}
```

the state function

CommandMustSucceed:

"An issued command can succeed at most once".

```
class MaxOneSuccess extends Monitor[Event] {
 always {
  case SUCCESS(_, number) =>
   state {
    case SUCCESS(_, `number`) => error
   }
 }
}
```

analyzing a trace

```
class Requirements extends Monitor[Event] {
  monitor(
    new CommandMustSucceed,
    new MaxOneSuccess
  )
}
```

compose

run

```
object Apply {
  def readLog(): List[Event] = {...}

  def main(args: Array[String]) {
    val monitor = new Requirements
    val log = readLog()
    monitor.verify(log)
  }
}
```

result

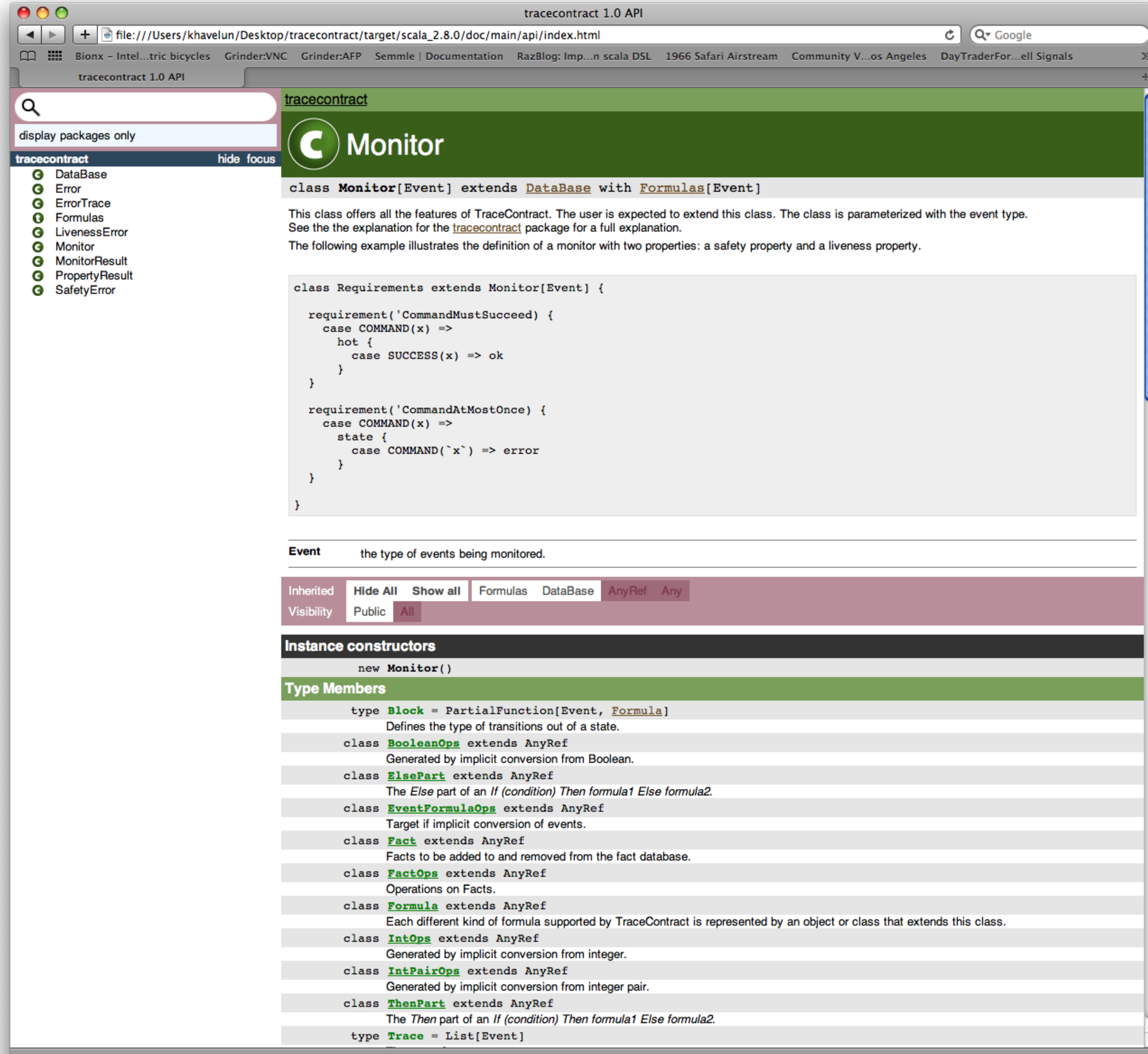
```
Monitor: CommandMustSucceed

Error trace:
  1=COMMAND(STOP_DRIVING,1)


--------------------------------


Monitor: MaxOneSuccess

Error trace:
  2=COMMAND(TAKE_PICTURE,2)
  3=SUCCESS(TAKE_PICTURE,2)
  4=SUCCESS(TAKE_PICTURE,2)
```


tracecontract 1.0 API
file:///Users/khavelun/Desktop/tracecontract/target/scala_2.8.0/doc/main/api/index.html
Google
Bionx – Intel...tric bicycles
Grinder:VNC
Grinder:AFP
Semmle | Documentation
RazBlog: Imp...n scala DSL
1966 Safari Airstream
Community V...os Angeles
DayTraderFor...ell Signals
tracecontract 1.0 API
display packages only
tracecontract
hide focus
DataBase
Error
ErrorTrace
Formulas
LivenessError
Monitor
MonitorResult
PropertyResult
SafetyError
tracecontract
Monitor
class Monitor[Event] extends DataBase with Formulas[Event]
This class offers all the features of TraceContract. The user is expected to extend this class. The class is parameterized with the event type.
See the the explanation for the tracecontract package for a full explanation.
The following example illustrates the definition of a monitor with two properties: a safety property and a liveness property.
class Requirements extends Monitor[Event] {
requirement('CommandMustSucceed) {
case COMMAND(x) =>
hot {
case SUCCESS(x) => ok
}
}
requirement('CommandAtMostOnce) {
case COMMAND(x) =>
state {
case COMMAND(`x`) => error
}
}
}
Event
the type of events being monitored.
Inherited
Hide All
Show all
Formulas
DataBase
AnyRef
Any
Visibility
Public
All
Instance constructors
new Monitor()
Type Members
type Block = PartialFunction[Event, Formula]
Defines the type of transitions out of a state.
class BooleanOps extends AnyRef
Generated by implicit conversion from Boolean.
class ElsePart extends AnyRef
The Else part of an If (condition) Then formula1 Else formula2.
class EventFormulaOps extends AnyRef
Target if implicit conversion of events.
class Fact extends AnyRef
Facts to be added to and removed from the fact database.
class FactOps extends AnyRef
Operations on Facts.
class Formula extends AnyRef
Each different kind of formula supported by TraceContract is represented by an object or class that extends this class.
class IntOps extends AnyRef
Generated by implicit conversion from integer.
class IntPairOps extends AnyRef
Generated by implicit conversion from integer pair.
class ThenPart extends AnyRef
The Then part of an If (condition) Then formula1 Else formula2.
type Trace = List[Event]

```
def error(message: String): Formula
```
Emits the error message provided as argument and evaluates to False.

```
def error: Formula
```
Emits an error message and evaluates to False.

```
def eventually(formula: Formula): Formula
```
Eventually true (an LTL formula).

```
def eventuallyBw(m: Int, n: Int, x: Int = 1)(formula: Formula): Formula
```
Eventually true between *m* and *n* steps.

```
def eventuallyEq(n: Int)(formula: Formula): Formula
```
Eventually true at step *n*.

```
def eventuallyGe(n: Int)(formula: Formula): Formula
```
Eventually true at or after minimally *n* steps.

```
def eventuallyGt(n: Int)(formula: Formula): Formula
```
Eventually true after *n* steps.

```
def eventuallyLe(n: Int)(formula: Formula): Formula
```
Eventually true in maximally *n* steps.

```
def eventuallyLt(n: Int)(formula: Formula): Formula
```
Eventually true in less than *n* steps.

```
def factExists(pred: PartialFunction[Fact, Boolean]): Boolean
```
Tests whether a fact exists in the fact database, which satisfies a predicate.

```
def getMonitorResult: MonitorResult[Event]
```
Returns the result of a trace analysis for this monitor.

```
def getMonitors: List[Monitor[Event]]
```
Returns the sub-monitors of a monitor.

```
def globally(formula: Formula): Formula
```
Globally true (an LTL formula).

```
def hot(m: Int, n: Int)(block: PartialFunction[Event, Formula]): Formula
```
A hot state waiting for an event to eventually match a transition (required) between *m* and *n* steps.

```
def hot(block: PartialFunction[Event, Formula]): Formula
```
A hot state waiting for an event to eventually match a transition (required).

```
def informal(name: Symbol)(explanation: String): Unit
```
Used to enter explanations of properties in informal language.

```
def informal(explanation: String): Unit
```
Used to enter explanations of properties in informal language.

```
def matches(predicate: PartialFunction[Event, Boolean]): Formula
```
Matches current event against a predicate.

```
def monitor(monitors: Monitor[Event]*): Unit
```
Adds monitors as sub-monitors to the current monitor.

```
def never(formula: Formula): Formula
```
Never true (an LTL-inspired formula).

```
def not(formula: Formula): Formula
```
Boolean negation.

```
def ok(message: String): Formula
```
Emits the message provided as argument and evaluates to True.

```
def ok: Formula
```
Equivalent to True.

`def eventuallyGt(n: Int)(formula: Formula): Formula`

Eventually true after *n* steps.

`def eventuallyLe(n: Int)(formula: Formula): Formula`

Eventually true in maximally *n* steps.

`def eventuallyLt(n: Int)(formula: Formula): Formula`

Eventually true in less than *n* steps.

`def factExists(pred: PartialFunction[Fact, Boolean]): Boolean`

Tests whether a fact exists in the fact database, which satisfies a predicate.

`def getMonitorResult: MonitorResult[Event]`

Returns the result of a trace analysis for this monitor.

`def getMonitors: List[Monitor[Event]]`

Returns the sub-monitors of a monitor.

`def globally(formula: Formula): Formula`

Globally true (an LTL formula).

`def hot(m: Int, n: Int)(block: PartialFunction[Event, Formula]): Formula`

A hot state waiting for an event to eventually match a transition (required) between *m* and *n* steps.

`def hot(block: PartialFunction[Event, Formula]): Formula`

A hot state waiting for an event to eventually match a transition (required). The state remains active until the incoming event *e* matches the *block*, that is, until *block.isDefinedAt(e) == true*, in which case the state formula evaluates to *block(e)*.

At the end of the trace a *hot state* formula evaluates to False.

As an example, consider the following monitor, which checks the property: *"a command x eventually should be followed by a success"*:

```
class Requirement extends Monitor[Event] {
  require {
    case COMMAND(x) =>
      hot {
        case SUCCESS(`x`) => ok
      }
  }
}
```

block	partial function representing the transitions leading out of the state.
returns	the *hot state* formula.

definition classes: Formulas

`def informal(name: Symbol)(explanation: String): Unit`

Used to enter explanations of properties in informal language.

`def informal(explanation: String): Unit`

Used to enter explanations of properties in informal language.

`def matches(predicate: PartialFunction[Event, Boolean]): Formula`

Matches current event against a predicate.

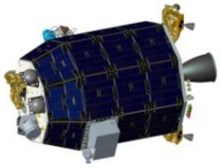
`def monitor(monitors: Monitor[Event]*): Unit`

Adds monitors as sub-monitors to the current monitor.

`def never(formula: Formula): Formula`

Never true (an LTL-inspired formula).

command verification in LADEE mission



verified
command
sequence

command
sequence

```
class R42  extends Monitor[Event] {
  always {
    case COMMAND("ACS_MODE", _, time1, _) =>
      state {
        case COMMAND("ACS", _, time2, _) =>
          (time1,time2) beyond (1 second)
      }
  }
}
```

TraceContract

implementation – formulas

```
abstract class Formula {
  def apply(event: Event): Formula
  def reduce(): Formula = this
  def and(that: Formula): Formula = And(this, that).reduce()
  def until(that: Formula): Formula = Until(this, that).reduce()
  ...
}
```

states

```
case class State(block: Block) extends Formula {
  override def apply(event: Event): Formula =
    if (block.isDefinedAt(event)) block(event) else this
}

case class Step(block: Block) extends Formula {
  override def apply(event: Event): Formula =
    if (block.isDefinedAt(event)) block(event) else True
}

case class Strong(block: Block) extends Formula {
  override def apply(event: Event): Formula =
    if (block.isDefinedAt(event)) block(event) else False
}
```

// Hot the same

// Weak the same

globally and eventually

```
case class Globally(formula: Formula) extends Formula {
  override def apply(event: Event): Formula =
    And(formula(event), this).reduce()
}

case class Eventually(formula: Formula) extends Formula {
  override def apply(event: Event): Formula =
    Or(formula(event), this).reduce()
}
```

and

```
case class And(formula1: Formula, formula2: Formula) extends Formula {
  override def apply(event: Event): Formula =
    And(formula1(event), formula2(event)).reduce()

  override def reduce(): Formula = {
    (formula1, formula2) match {
      case (False, _) => False
      case (_, False) => False
      case (True, _) => formula2
      case (_, True) => formula1
      case (f1, f2) if f1 == f2 => f1
      case _ => this
    }
  }
}
```

at the end

```
def end(formula: Formula): Boolean =
  formula match {
    case State(_)   => true
    case Hot(_)      => false

    case Strong(_) => false
    case Weak(_)   => true

    case Step(_)     => true
    ...
    case Globally(_)     => true
    case Eventually(_) => false
     ...
    case And(formula1, formula2) => end(formula1) && end(formula2)
  }
```

future plans

- optimization
  - internal DSL is not analyzable
  - indexing: map incoming events to monitors
- application within LADEE mission
  - feature refinement (expressiveness)
- trace analysis in a broader perspective:
  - trace monitoring for embedded systems
  - trace mining
  - trace visualization

understanding complex systems
by analyzing their execution