Trends in Languages

2009 Edition

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About me

- Independent Consultant for itemis
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  - Software Architecture
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CONTENTS

Trends in Languages 2010

CONTENTS

Why this talk?

- Language World **is changing**
  - Mainstream Languages evolve (Java, C#)
  - Diverisfication: Ruby, Erlang, Scala, Groovy, …
- I want to illustrate interesting **trends**
- Explain some of the **controversy** and **backgrounds**.

C O N T E N T S

- Intro and Overview
- **Typing**
- OO +/vs. Functional
- Metaprogramming & DSLs
- Contracts
- Concurrency
- Platforms
- Tools
- Summary

Strongly Typed vs. Weakly Typed

- Does a language **have types** at all?
- Are those typed **checked** at all?
- **C weakly typed:**
  - *(void*)*
  - Interpret string as a number, and vice versa
  - The compiler has a „hole"
- Community agrees that **weak typing is bad.**
- **Opposite:** Strongly Typed.
  - When are types checked?

Strongly Typed: Dynamic vs. Static

- A strongly typed language **can check types at**
  - Compile time: **Statically** Typed Language
  - Runtime: **Dynamically** Typed Language
- Most **mainstream** languages use **static** typing:
  - Java
  - C#
  - (C++)
- Dynamic Typing associated with **„scripting languages"**
  - What is a „scripting language"
  - Is Smalltalk a scripting language? It is dynamically typed!
  - Term is not very useful!
- **Static Backdoor:** Casting
  - Defers type check to runtime

Strongly Typed: Dynamic vs. Static II

- „**Static is better**, because the compiler finds more errors for you"
- „**Dynamic is better**; more expressive code, and you have to test anyway."
- **XOR?** No, context dependent:
  - Safety Critical Software: Static Typing
  - Agile Web Applications: Dynamic Typing
- But there's **more**...

Duck Typing

- A form of **Dynamic Typing**
  "if it walks like a duck and quacks like a duck,
  I would call it a duck"
  - where **not the declared type** is relevant
  - but the **ability** at runtime **to handle** messages/method calls
- A handler for a message (method implementation) can be
  - Defined by its type
  - Be object-specific
  - Added at runtime via meta programming
- A **predefined callback** („doesNotUnderstand") is invoked in case a message cannot be handled.
- **Examples:** Smalltalk, Ruby

Structural Types: Duck Typing for Static Languages

- **Compiler** checks, whether something can satisfy context requirements.
  - Formal type is not relevant
- **Example I:** C++ Templates
- **Example II:** Scala

Scala

```
class Person(name: String) {
  def getName(): String = name
  …
}

def printName(o: { def getName(): String }) {
  print(o.getName)
}

printName( new Person("markus") )  // prints "markus"
```


Type Inference: Omit unnecessary type specs

- **Compiler Smarts:** You only have to write down those types the compiler cannot derive from the context
- **Example:** (Hypothetical) Java

Java

```
// valid Java
Map<String, MyType> m = new HashMap<String, MyType>();
// Hypothetical Java with Type inference
var m = new HashMap<String, MyType>();
```

Scala

```
// valid Scala
var m = new HashMap[String, MyType]();
```

- **Example II:** C# 3.0, LINQ

C# 3

```
Address[] addresses = …

var res = from a in addresses
          select new {     name = a.name(),
                           tel = a.telephoneNo()    };

foreach (var r in res) {
  Console.WriteLine("Name: {0}, Num: {1}", r.name, r.tel);
}
```

Dynamic Typing in static languages? Maybe!

- One **could add dynamic (runtime) dispatch** to static languages with the following approach (discussion with Anders Hejlsberg for SE Radio)

```
// language-predefined interface, like Serializable
interface IDynamicDispatch {
  void attributeNotFound(AttrAccessInfo info)
  void methodNotFound(MethodCallInfo info
}
```

Java?

```
class MyOwnDynamicClass implements IDynamicDispatch {
  // implement the …notFound(…) methods and
}

val o = new MyOwnDynamicClass

o.something() // compiler translates this into an
              // invocation via reflection. If it fails,
              // call methodNotFound(…)
```

Java?

- Combine this, eg. with load-time meta programming…

Optional / Pluggable Types

- Fundamentally, types are checked **at runtime**
- However, optionally one can add **type annotations** that are checked statically by a type checker
  - Why should types be treated differently than any other form of meta data that is worth checking? Concurrency, Timing, …
- Types are just **meta data** for which a checker is available
- Several **different kinds of meta data** (i.e. type systems) can be optionally overlayed over the same program
- Like **static analysis** tools that rely on custom annotations in Java (*@CanBeNull*)
- **Example:** Newspeak / Gilad Braha

CONTENTS

OO and Functional

- OO is clearly **mainstream**.
- That is changing (very) slowly … especially **functional programming** is taking up speed.
- What is functional programming (as in Erlang, Lisp, F#)
  - Function Signatures are **types**
  - Function **Literals** are available (lambda expressions)
  - Functions are **values**: assignable to variables and parameters → Higher Order Functions
- You can find **elements** of this in Ruby, Groovy, C# 3 and Scala
- Scala's primary goal is to unify OO and functional
- (also: **side-effect free;** important later wrt concurrency)

From Primitive To Workable

- **Primitive** functional programming can be done with
  - Function pointers (as in C/C++)
  - Delegates (C# < 3)
  - Command Pattern/Inner Classes in Java
- Better solution: **Closures**
  (aka lamda expressions, blocks, anonymous functions)

```
[1,2,3,4,5,6].each { |element| puts (element * 2) }
```

Ruby

- **Anonymous Functions** (Function Literals)

```
x: Int => x + 1
```

Scala

Higher Order Functions

- **Function Signatures** (Function Types)

```
Int => Int    // Int Parameter, Return Type Int
(Int, Int) => String   // Two Int Parameter, returns String
```

Scala

- Function Signatures/Types are important for **Higher Order Functions:**
  - Functions that take other functions as arguments
  - … or return them

```
def apply(f: Int => String, v: Int) => f(v)
```

Scala

Currying

- Functions called with fewer arguments than they formally expect **return new functions** with the given parameters bound

```
> let add a b = a + b;;
val add : int -> int -> int
```
F#

```
> let add10 = add 10;;
val add10 : int -> int
```
F#

```
> add10 5;;
15
```
F#

- Name „currying“ based on **Haskell Curry** (yes, his first name was used for the Haskell language)

Pattern Matching

- Checking for and extracting the **structure** of data

```
> let t = (42, „text");;
val tuple : int * string

> let (num, str) = tuple;;
val num : int  // 42
val str : string  // „text“
```
F#

- Especially useful for **discriminated unions** (F#) or **case classes** (Scala) to decompose tree structures (e.g. expression trees)

```
> type Expr =
  | Op of string * Expr * Expr
  | Var of string
  | Const of int;;
(…)

> // y*42
let expr = Op("+", Var "x", Const 10);;
val v : expr
```
F#

Pattern Matching II

- A simple evaluator for the expressions using **pattern matching**

```
> let rec eval x = match x with
    | Op(op, l, r) -> let (lv, rv) = (eval l, eval r)
      if (op = "+") then lv + rv
      elif (op = "-") then lv - rv
      else failwith "Unknonw operator!"
    | Var(var) -> getFromSymbolTable var
    | Const(n) -> n;;
val eval : Expr -> int
```

F#

- Patterns can **deconstruct** the composition structure of complex data structures and **assign local variables** to the parts of the data structure.

?

```
(defn move-to [shape x y] (merge shape {:x x :y y}))
(defn r-move-to [shape x y] (move-to shape (+ (shape :x) x) (+ (shape :y) y)))
(derive ::rectangle ::shape)
(derive ::circle ::shape)
(defn rectangle [x y w h] (with-meta {:x x :y y :width w :height h} {:type
::rectangle}))
(defn circle [x y r] (with-meta {:x x :y y :radius r} {:type ::circle}))
(defmulti draw (fn [shape] ((meta shape) :type)))
(defmethod draw ::rectangle [rect]
  (println (str "Draw a Rectangle at:(" (rect :x) ", " (rect :y)
       "), width " (rect :width) ", height " (rect :height))))
(defmethod draw ::circle [circle]
  (println (str "Draw a Cicrle at:(" (circle :x) ", " (circle :y)
       "), radius " (circle :radius))))

(def scribble [(rectangle 10 20 5 6) (circle 15 25 8)])

(doseq [shape scribble]
  (draw shape)
  (let [s (r-move-to shape 100 100)]
    (draw s)))

(draw (assoc (rectangle 0 0 15 15) :width 30))
```

?

Clojure – a Lisp for the JVM

```
(defn move-to [shape x y] (merge shape {:x x :y y}))
(defn r-move-to [shape x y] (move-to shape (+ (shape :x) x) (+ (shape :y) y)))
(derive ::rectangle ::shape)
(derive ::circle ::shape)
(defn rectangle [x y w h] (with-meta {:x x :y y :width w :height h} {:type
::rectangle}))
(defn circle [x y r] (with-meta {:x x :y y :radius r} {:type ::circle}))
(defmulti draw (fn [shape] ((meta shape) :type)))
(defmethod draw ::rectangle [rect]
  (println (str "Draw a Rectangle at:(" (rect :x) ", " (rect :y)
       "), width " (rect :width) ", height " (rect :height))))
(defmethod draw ::circle [circle]
  (println (str "Draw a Cicrle at:(" (circle :x) ", " (circle :y)
       "), radius " (circle :radius))))

(def scribble [(rectangle 10 20 5 6) (circle 15 25 8)])

(doseq [shape scribble]
  (draw shape)
  (let [s (r-move-to shape 100 100)]
    (draw s)))

(draw (assoc (rectangle 0 0 15 15) :width 30))
```

Clojure

Example from *http://onestepback.org/articles/poly/oo-clojure.html*

- Lisp is the grand daddy of functional programming.
- Clojure is a new **Lisp for the VM** with good **Java interop** and very nice **support for concurrency** (see later)

CONTENTS

What is Metaprogramming?

- A program can **inspect** and **modify** itself or other **programs**.
- **Not** a **new** concept: Lisp, CLOS
  - But returning to fame these days…
- Two different **flavours**:
  - **Static/Compile Time** metaprog. : handled by compiler
  - **Dynamic** metaprog.: done at runtime
    (fits well with Duck Typing … you can call what's there)
- Static Meta Programming is a relative **niche concept** (aka hygienic macro system) … see section on DSLs
  - C++ Template Metaprogramming (aargh!)
  - Template Haskell
  - Converge
  - Boo

Dynamic Metaprogramming

- Is available in **many dynamic OO languages**, such as Smalltalk, Ruby, Groovy
- Dynamically **add a new method** to a class:

Ruby

```
class SomeClass
    define_method(“foo”){ puts "foo" }
End

SomeClass.new.foo // prints “foo“
```

- What happens in Duck languages, if you call a **method** that's **not available**? Remember, no compiler type check!

Groovy

```
class Sammler {
   def data = [:]
   def propertyMissing =
      {String name, value-> data [name] = value }
   def propertyMissing =
      {String name-> data [name] }
}
```

```
def s = new Sammler()
s.name = "Voelter"
s.vorname = „Markus“
s.name  // is „Voelter“
```

Meta Object Protocols

- MOPs support „overwriting" the interpreter typically via the concept of **meta classes**.
- Here we **overwrite** what it means to **call a method**:

```
class LoggingClass {
  def invokeMethod(String name, args) {
    println "just executing "+name
    // execute original method definition
  }
}
```

Groovy

- Yes, this looks like the **AOP** standard example ☺
- In fact, AO has **evolved from MOPs** (in CLOS)
- And now we're **back to MOPs** as a way for „simple AO"… strange world …

Macro systems

- Macros are **transformations of program code** that are executed by the compiler during compilation.
  - Quotation (and unquotation) is used

```
(defmacro with-connection [& body]
 `(binding [*conn* (get-connection)]
    (let [ret# (do ~@body)]
      (.close *conn*)
      ret#
    )
  )
)

(with-connection (str *conn*))
```

Clojure

- Powerful way to define **new language syntax** (Growing a Language, Guy Steele)
- Works especially well for „**syntaxless" languages**.

What are DSLs?

A DSL is a **focused**, **processable language** for describing a **specific concern** when building a **system** in a specific **domain**. The **abstractions** and **notations** used are **tailored** to the **stakeholders** who specify that particular concern.

- Domain can be **business** or **technical** (such as architecture)
- The „program" needs to be **precise** and **processable**, but not necessarily **executable**.
  - Also called **model** or **specification**

Internal DSLs vs. External DSLs

- **Internal DSLs** are defined as part of a host language.
  - DSL „program" is **embedded** in a host language program
  - It is typically **interpreted** by facilities in the host language/program (→ metaprogramming)
  - DoF for syntax customization is **limited by host language**
    - Only useful in languages with a **flexible syntax** (such as Ruby) or no syntax (Lisp ☺)
- **External DSLs** are defined independent of any programming language
  - A program **stands on its own.**
  - It is either **interpreted** by a custom-build interpreter, or **translated** into executable code
  - DoF for syntax customization **only limited by custom editor** (i.e. not really limited at all: graphical, textual, tables, combinations of those...)

Dynamic Internal DSL Examples: Ruby

- **Ruby** is currently the **most suitable language** for internal DSLs.

```
class Person < ActiveRecord::Base
  has_one :adress
  has_many :telecontact
end

class Address < ActiveRecord::Base
end
```

Ruby

- *has_one* and *has_many* are actually **invocations of class methods** of the *ActiveRecord::Base* super class.

- Alternative Syntax:

```
has_one(„adress“)
```

Ruby

- The original notation is an example of **Ruby‘s flexible syntax** (optional parens, symbols)

Dynamic Internal DSL Examples: Ruby II

- The *has_one* and *has_many* invocations dynamically **create accessors for properties** of the same name:

```
p = Person.new
a = Adress.new
p.adress = a
p.adress == a
```

Ruby

- The methods are implemented via **meta programming**.

- They do all kinds of magic wrt. to the database backend used in Rails.

Static Internal DSL Examples: Scala

- The following uses *loop/unless* as if it were a Scala language feature (which it is not!)

```
var i = 10;
loop {
  Console.println("i = " + i)
  i = i-1
} unless (i == 0)
```

Scala

- In fact, it is implemented as a library relying on **automatic closure construction** and the use of **methods in operator notation**.

```
def loop(body: => Unit): LoopUnlessCond =
  new LoopUnlessCond(body);

private class LoopUnlessCond(body: => Unit) {
  def unless(cond: => Boolean): Unit = {
    body
    if (!cond) unless(cond);
  }
}
```

Scala

Static Internal DSL Examples: Boo

- Boo has a full **hygienic macro system** (open compiler)

```
public interface ITransactionable:
     def Dispose(): pass
     def Commit(): pass
     def Rollback(): pass
```

Boo

```
macro transaction:
     return [|
          tx as ITransactionable =  $(transaction.Arguments[0])
          try:
               $(transaction.Body)
               tx.Commit()
          except:
               tx.Rollback()
               raise
          finally:
               tx.Dispse()
     |]
```

Boo

- Use it like **native language syntax!**

```
transaction GetNewDatabaseTransaction():
          DoSomethingWithTheDatabase()
```

Boo

Static Internal DSL Examples: Boo

- Boo has a full **hygienic macro system** (open compiler)

```
public interface ITransactionable:
     def Dispose(): pass
     def Commit(): pass
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Boo

```
macro transaction:
     return [|
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         try:
              $(transaction.Body)
              tx.Commit()
         except:
              tx.Rollback()
              raise
         finally:
              tx.Dispse()
     |]
```

Boo

- Use it like **native language syntax!**

```
transaction GetNewDatabaseTransaction():
         DoSomethingWithTheDatabase()
```

Boo

Static Internal DSL Examples: Boo II

- See how the *Expression* type is used to **pass in AST / syntax elements** (in this case, an expression)

```
[ensure(name is not null)]
class Customer:
         name as string
         def constructor(name as string): self.name = name
         def SetName(newName as string): name = newName
```

Boo

```
[AttributeUsage(AttributeTargets.Class)]
class EnsureAttribute(AbstractAstAttribute):
         expr as Expression
         def constructor(expr as Expression):
             self.expr = expr
         def Apply(target as Node):
             type as ClassDefinition = target
             for member in type.Members:
                   method = member as Method
                   block = method.Body
                   method.Body = [|
                       block:
                             try:
                                 $block
                             ensure:
                                 assert $expr
                   |].Block
```

Boo

Boo examples taken from Ayende Rahien and Oren Eini's InfoQ article *Building Domain Specific Languages on the CLR*

More legal characters: useful for DSLs

- Most languages still basically use 7-bit ASCII.
- A **larger set of legal characters** provides more degress of freedom for expressing domain-specific concepts.
- To be able to enter these characters Fortress provides a **Wiki-like** syntax (like Tex, or Mathematica)

$$
\begin{array}{l}
\mathit{conjGrad}[\![\mathrm{Elt}\ \mathbf{extends}\ \mathrm{Number},\ \mathbf{nat}\ \mathrm{N}, \\
\quad\quad \mathrm{Mat}\ \mathbf{extends}\ \mathrm{Matrix}[\![\mathrm{Elt}, N \times N]\!], \\
\quad\quad \mathrm{Vec}\ \mathbf{extends}\ \mathrm{Vector}[\![\mathrm{Elt},\mathrm{N}]\!] \\
\quad\quad]\!](A:\mathrm{Mat},\ x:\mathrm{Vec}):(\mathrm{Vec},\ \mathrm{Elt}) \\
\quad \mathit{cgit}_{\max} = 25 \\
\quad z:\mathrm{Vec} = 0 \\
\quad r:\mathrm{Vec} = x \\
\quad p:\mathrm{Vec} = r \\
\quad \rho:\mathrm{Elt} = r^{\mathrm{T}} r \\
\quad \mathbf{for}\ j \leftarrow \mathbf{seq}(1:\mathit{cgit}_{\max})\ \mathbf{do} \\
\quad\quad q = A\,p \\
\quad\quad \alpha = \dfrac{\rho}{p^{\mathrm{T}} q} \\
\quad\quad z := z + \alpha\,p \\
\quad\quad r := r - \alpha\,q \\
\quad\quad \rho_0 = \rho \\
\quad\quad \rho := r^{\mathrm{T}} r \\
\quad\quad \beta = \dfrac{\rho}{\rho_0} \\
\quad\quad p := r + \beta\,p \\
\quad \mathbf{end} \\
\quad (z,\ \|x - A\,z\|)
\end{array}
$$

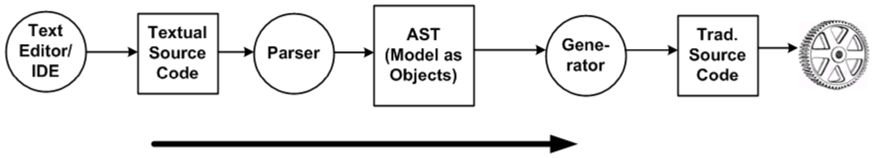
Fortress

External DSLs

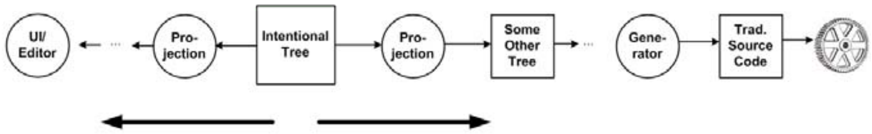
- Aka **Model-Driven Software Development**.
- **Notation:**
  - Textual (antlr, Xtext)
  - Graphical (GMF, MetaEdit+)
  - Or even a mixture (Intentional)
- **Execution:** Interpretation vs. Code Generation
  - Or even a mixture?
- Other advantages:
  - Language Specific Tooling (syntax coloring and completion)
  - Domain Specific Constraints
- But this is another talk…

Language Workbenches à la Fowler

- Traditionally, the **AST (Abstract Syntax Tree) is the result** of a parsing process – ascii text is the master



- In Projectional Editors, **the tree is the master**, and the editor, as well as the (potentially) generated code follows from **projections** (i.e. model-2-model transformations)



Benefits of Projectional Editing

- Syntax can be **ambiguous**
- **Language Modularization** becomes much simpler – because see above
- Language modules can be **composed at the site of use** – no explicit grammar composition necessary.
- A much **larger range of symbols** can be used
- **Textual** can **graphical** notations can be treated similarly
  - Simplifies mixing
  - Semi-graphical notations (mathematical symbols) can be used
- **NB:** Parser technology also evolves, scannerless parsers can do *some* of the same things.

Disadvantages of Projectional Editing

- **You edit a tree** – depending on the tool this can be a pain (or at least take some getting used to)
- **Storage** based on **abstract syntax** (maybe XML), i.e. text-based tooling won't work anymore.
- Everything will be **tool-dependent**... no standards as of now.

Long Range Vision: Modular Languages

- We won't have **large, general purpose languages** anymore, and use **modeling** for all the stuff where the GPLs are lacking.
- Instead we will have **modular languages**,
  - with **standardized modules** for technical concerns
    - Remoting, persistence, state machines, ...
  - And the ability to **build custom modules** for our own domains
- Realistic? Absolutely.

MPS as a Language Workbench

- jetbrains.com/mps
- **Open Source,** Apache 2.0
- **Java as a Base Language** – can be extended!
- Tree editing ok (takes getting used to)
- Released as 1.0

MPS: Java with Lock Statement

```
public class Test extends <none> implements <none> {
   <<static fields>>

   <<static initializer>>
   private LockHelper helper = new LockHelper();
   <<properties>>
   <<initializer>>
   public Test() {
      <no statements>
   }

   private int m() {
      int j = 0;
      int j = 0;
      lock ( this.helper.getLock() )
         int i = 1;
         j = i * 2;
         <statement>
      }
      return j;
   }

   <<static methods>>

   <<static inner classifiers>>
}
```

- **translated** to „normal“ Java for compilation
- ca. **15 minutes of work** to extend Java with the *LockStatement*.

MPS: Concept Definition

LockStatement

```
concept LockStatement extends     Statement
                      implements <none>

  instance can be root: false

  properties:
  << ... >>

  children:
  StatementList body           1 specializes: <none>
  Expression    lockExpression 1 specializes: <none>

  references:
  << ... >>

  concept properties:
  alias = lock

  concept links:
  << ... >>

  concept property declarations:
  << ... >>

  concept link declarations:
  << ... >>
```

Structure | Editor | Constraints | Behavior | Typesystem | Intentions | Find Usages | Data Flow | Generator

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MPS: Editor Definition

LockStatement

```
editor for concept LockStatement
  node cell layout:
    [/
      [> lock ( % lockExpression % ) { <]
      [> ---> % body % <]
      }
    /]

  inspected cell layout:
    <choose cell model>
```

Structure | Editor | Constraints | Behavior | Typesystem | Intentions | Find Usages | Data Flow | Generator

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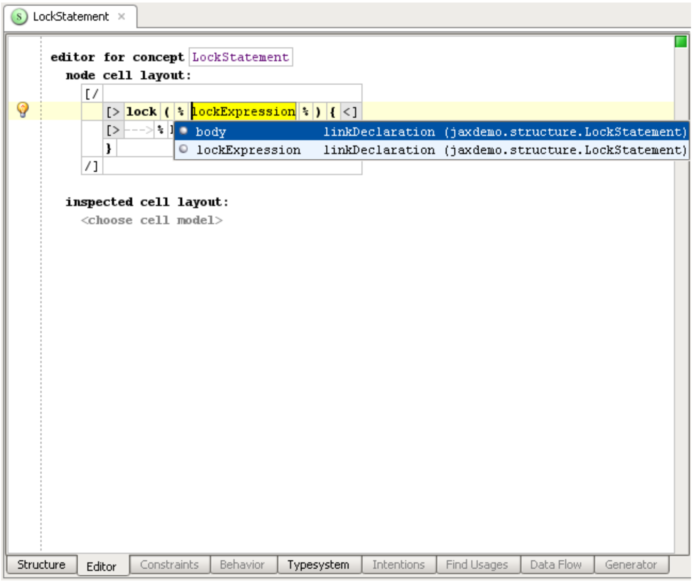
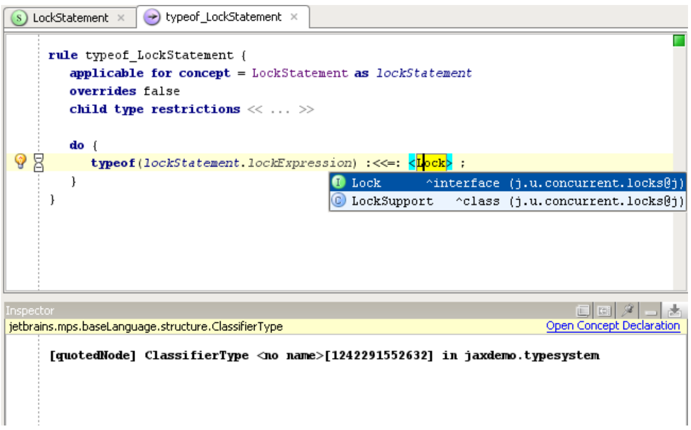
MPS: Editor Definition



Trends in Languages 2010

MPS: Type System Definition



MPS: Generator Definition

main

```
conditional root rules:
   << ... >>

mapping rules:
   << ... >>

weaving rules:
   << ... >>

reduction rules:
   [concept     LockStatement] --> reduce_LockStatement
   [inheritors false         ]
   [condition  <always>      ]

abandon roots:
   << ... >>

pre-processing scripts:
   << ... >>
```


Trends in Languages 2010

MPS: Generator Definition II

reduce_LockStatement

```
content node:
public class someclass extends <none> implements <none> {
    <<static fields>>

    <<static initializer>>
    <<fields>>
    <<properties>>
    <<initializer>>
    public someclass() {
       <no statements>
    }

    public void somemethod() {
       Lock l = null;
       <TF [try {
          $COPY_SRC$[l].lock();
          $LOOP$[$COPY_SRC$[null;]]
       } finally {
          $COPY_SRC$[l].unlock();
       }] TF>
    }

    <<static methods>>

    <<static inner classifiers>>
}
```

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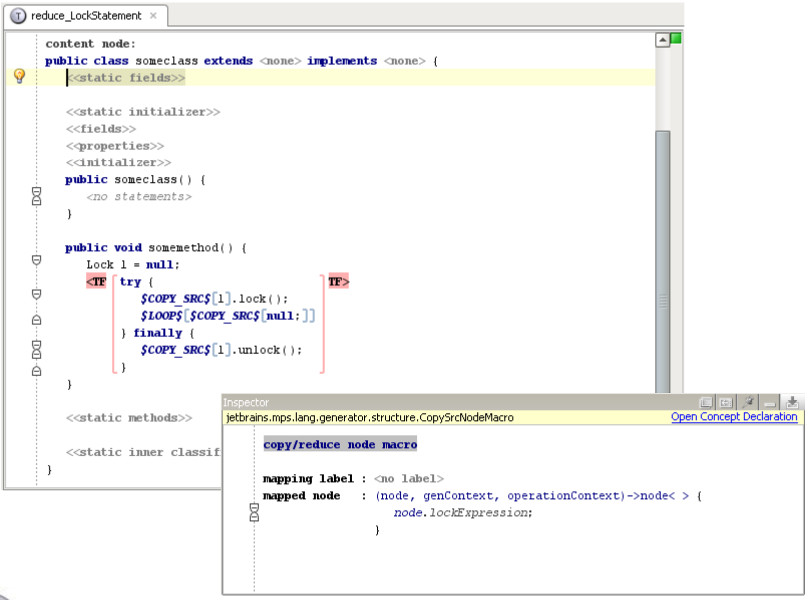
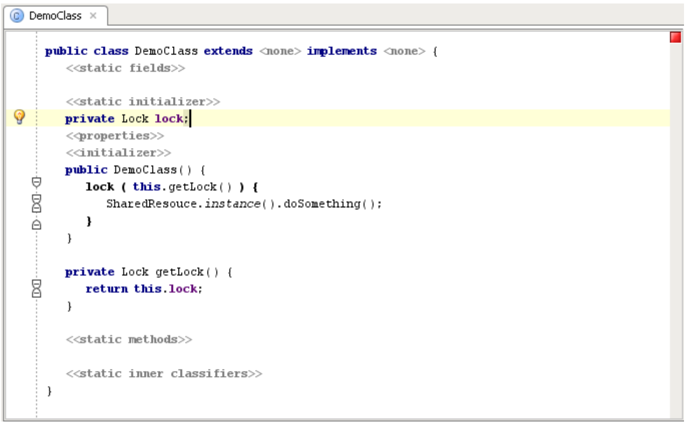
MPS: Generator Definition II



MPS: Using the new Construct



MPS: Using the new Construct

DemoClass

```
public class DemoClass extends <none> implements <none> {
  <<static fields>>

  <<static initializer>>
  private Lock lock;
  <<properties>>
  <<initializer>>
  public DemoClass() {
    lock ( 1 ) {
      SharedResouce.instance().doSomething();
    }   Typesystem error: int is not a subtype of Lock
  }

  private Lock getLock() {
    return this.lock;
  }

  <<static methods>>

  <<static inner classifiers>>
}
```


CONTENTS

Invented by Eiffel

- As part of an interface or class, specify (declaratively) the **pre- and postconditions** of an operation.

Eiffel

```
class ACCOUNT
  feature -- Access
    balance: INTEGER
    deposit_count: INTEGER is
    do … somehow calculate number of deposits … end
  feature
    deposit( sum: INTEGER) is
      require
        non_negative: sum>= 0
      do … implementation …
      ensure
        one_more_deposit:
                deposit_count= old deposit_count + 1
        updated: balance= old balance + sum
    end
  feature { NONE} -- Implementation
    all_deposits: DEPOSIT_LIST
  invariant
    consistent_balance: ( all_deposits /= Void) implies
       ( balance = all_deposits.total)
    zero_if_no_deposits: ( all_deposits = Void) implies
       ( balance= 0)
end -- class ACCOUNT
```


Spec#, an extension of C#

- It provides pre- and postconditions for methods (in classes and interfaces!)
- It also provides additional assertions, eg **Non-Nullness:**

Spec#

```
class Student : Person {
  Transcript! t ;
  public Student (string name, EnrollmentInfo! ei)
    : t (new Transcript(ei)), base(name) {
  }
}
```

- ... and **modification-specifications.**

Spec#

```
class C {
  int x , y;
  void M() modifies x ; { . . . }
```

- 56 -

Protocols in Axum

- Communication through **channels** in Axum is **asynchronous.**
  - It can be hard to track down what‘s happening.
- Solution: **Protocol State Machines**
  - associated with a channel/port

Axum

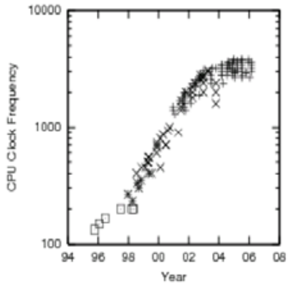
```
channel Adder {
  input int Num1;
  input int Num2;
  output int Sum;

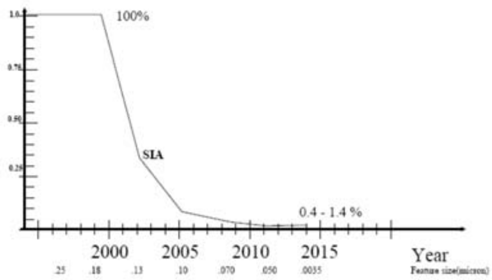
  Start: { Num1 -> GotNum1; }
  GotNum1: { Num2 -> GotNum2; }
  GotNum2: { Sum -> End; }
}
```


CONTENTS

Why?

- Systems need to **scale**: More and More machines
- **Machine performance** needs to improve: Multicore
  - Multicore system can provide **real concurrency** as opposed to „apparent“ concurrency on one core.
  - Multicore systems can only be utilized fully if the available set of cores is utilized effectively.





Diagrams © Joe Armstrong

The role of pure functional programming

- **Pure Functional Programming** uses
  - Only functions without sideeffects
  - No shared state
  - Immutable data structures
- If you share nothing (or the shared stuff is not mutable) there‘s **no need for locking** or other access coordination protocols → pure functional languages are a good fit
- The **call graph** is the **only dependency structure** in the system (no hidden dependencies using global/shared state)
  - makes the programs easier (or even feasible) to **analyze**
  - And makes **parallelization** simple (you can parallelize any set of sub-callgraphs)

Shared Memory Concurrency

- Mainstream languages use **shared memory**:
  - A process (address space) can host any numer of thread
  - Threads can share data
  - They need to coordinate via locking
- Locking has to be **implemented manually** by developers via an agreed **locking / coordination protocol**
  - Often very **complex** (non-local)
  - **Error prone**, because there‘s little language/tool support
  - **Overspecification:** „Acquire/Release Lock X“ vs. „Pretend this were sequential/atomic“
- Solution: **Express atomicity requirements** with language primitives as opposed to using locking protocol API → **Transactional Memory**

Shared Memory Concurrency: Transactional Memory

- Transactional Memory in Fortress:

```
atomic do
  // the stuff here is executed as if
  // there was only this thread
end
```

Fortress

- This formulation **says nothing about specific locks** and their allocation and release:
  - Less error prone
  - More potential for optimizations of compiler and RT system
- Similar in Spirit to **Garbage Collection** (Dan Grossman):
  - Rely on clever compiler and RT system
  - Solution might not always be optimal
  - … but good enough in 99% of cases
  - and much less (error prone) work.

STM in Clojure

- Define a ***ref***, an a „piece of transactional memory“

```
user => (def foo (ref 0))
#'user/foo
user => @foo // (deref foo) is similar
0
```

Clojure

- **Accessing** a *ref* has to happen in a **transaction**, otherwise an exception is thrown

```
user=> (dosync (ref-set foo 1))
1
user => @foo
1
```

Clojure

More bad overspecification

- Overspecification generally **prohibits** a compiler or runtime system from introducing **optimizations**.
- **Example:** Assume you want to do something **for each element** of a collection
- (Old) Java solution enforces total **ordering**. Intended?
  - Compiler cannot remove ordering

```
for ( int i=0; i < data.length; i++ ) {
  // do a computation with data[i]
}
```

Java < 5

- (New) Java solution: no ordering implied
  - Intent is expressed more clearly

```
foreach ( DataStructure ds in data ) {
  // do something with ds
}
```

Java 5

The default is parallel

- In Fortress, a loop is by **default parallel**
  - i.e. the compiler can distribute it to several cores

```
for I <- 1:m, j <- 1:n do
  a[i,j] := b[i] c[j]
end
```

Fortress

- If you need **sequential** execution, you have to **explicitly specify that**.

```
for i <- seq(1:m) do
  for j <- seq(1:n) do
    print a[i,j]
  end
end
```

Fortress

- Fortress does more for concurrency:
  - it knows about **machine resources** (processors, memory)
  - **Allocates** to those resources explicitly or automatically

„Shared Memory is BAD“ (Joe Armstrong)

- Some (many?) claim that the **root of all evil is shared memory** (more specifically: shared, mutable state):
- If you **cannot modify** shared state, no need for locking
  - Fulfilled by pure functional languages
- If you **don‘t even have shared state**, it's even better.
  - This leads to message-passing concurrency
  - Aka Actor Modell
- **Erlang:** most prominent example language (these days)
  - Funtional Language
  - Conceived of 20 years ago at Ericsson
  - Optimized for distributed, fault tolerant (telco-)systems
  - Actors/Message Passing based (called Process there ☹)

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BAD!

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Actors / Message Passing in Erlang

- The **only way to exchange information** between actors is via message passing.
- *Spawn* **creates a new process** – it executes the lambda expression passed as an argument

```
Pid = spawn(fun() -> doSomething() end)
```

Erlang

- **Sending** a message (any Erlang data structure) happens via the ! notation

```
Pid ! Message
```

Erlang

Actors / Message Passing in Erlang II

- An Actor's **received messages** are put into a „mailbox"
- A Unix Select-like command ***receive*** takes out one at a time.
- **Pattern Matching** is used to distinguish between the different messages
  - **lower case:** constants
  - **upper case:** free variables that will be bound)

```
loop
  receive
    {add, Id, Name, FirstName} -> ActionsToAddInformation;
    {remove,Id} -> ActionsToRemoveItAgain;
    ...
    after Time -> TimeOutActions
end
```

Erlang

Erlang-Style Message Passing in Scala

- Necessary **ingredients for Actors** include
  - Closures
  - Efficient Pattern Matching
- **Scala** has those features, too.
  - It also provides a way to define new „keywords“ (*receive*) and operators (*!*)

```
receive {
    case Add(name, firstName) => …
    case Remove(name, firstName) =>…
    case _ => loop(value)
}
```

Erlang

- This piece of Scala code doesn‘t just look almost like the Erlang version, it also **performs similarly**.

Best of Both Worlds in Singularity

- **MP disadvantage:** message data copying overhead
- Singularity (Sing#) solution: Best of Both Worlds
  - Use **message passing semtantics** and APIs
  - But **internally** use **shared** memory (memory exchange)
  - Enforce this via **static analysis** in compiler
- Example (pseudocode)

```
struct MyMessage {
  // fields…
}

MyMessage m = new MyMessage(…)

receiver ! m

// use static analysis here to ensure that
// no write access to m
```

Singularity

Agents and Channels in Axum

- Axum is a **Microsoft Devlabs** project. No guarantees ☺
- Core abstractions are **agents** (i.e. actors) and **channels** (message flow pipelines)

```
agent MainAgent:
    channel Microsoft.Axum.Application {

  function int Fibonacci(int n) {
    if( n<=1 ) return n;
    return Fibonacci(n-1) + Fibonacci(n-2);
  }

  int numCount = 10;

  void ProcessResult(int n) {
    Console.WriteLine(n);
    if( --numCount == 0 )
      PrimaryChannel::ExitCode <-- 0;
  }

  public MainAgent() {
    var numbers =
      new OrderedInteractionPoint<int>();

    numbers ==> Fibonacci ==> ProcessResult;

    for( int i=0; i<numCount; i++ )
      numbers <-- 42-i;
  }
}
```

Axum

Fancy Dataflow Networks

- 1:1 – Forwarding

```
PrimaryChannel::Click ==> HandleClick;
```

Axum

- Many:1- Multiplexing and Combine

```
var ip1 = new OrderedInteractionPoint<int>();
var ip2 = new OrderedInteractionPoint<int>();
ip1 <-- 10;
ip2 <-- 20;
var ips = new OrderedInteractionPoint<int>[]{ ip1, ip2 };

void PrintOneNumber(int n) {
  Console.WriteLine(n);
}

ips >>- PrintOneNumber;  // multiplexing

void PrintManyNumbers(int[] nums) {
  foreach(var i in nums) Console.WriteLine(i);
}

ips &>- PrintManyNumbers; // combine
```

Axum

Fancy Dataflow Networks II

- 1:Many – Broadcast and Alternate

```
agent AdderAgent : channel Adder {
  public AdderAgent() {
    var ipJoin = new OrderedInteractionPoint<int[]>();
    { PrimaryChannel::Num1 ==> ShowNumber,
      PrimaryChannel::Num2 ==> ShowNumber }
    &>- ipJoin -<: { GetSum, GetSum } >>-
    PrimaryChannel::Sum;
  }

  private int ShowNumber(int n) {
    Console.WriteLine("Got number {0}", n);
    return n;
  }

  private function int GetSum(int[] nums) {
    return nums[0] + nums[1];
  }
}
```

Axum

CONTENTS

Languages vs. Platforms

- **Virtual Machines:** Let's have a **small set of** stable, fast, scalable **platforms** and a **larger variety of languages** for different tasks running on those platforms.
  - **CLR** has always had a clear distinction
  - **JVM** is getting there: JRuby, Jython, Groovy, Scala
    - *invokedynamic*, tail recursion
- The same concept applies to **enterprise platforms:** JEE as an **„operating system"** for enterprise apps has
  - Scalability
  - Deploymnet
  - Manageability, Operations
- ... and use **different languages/frameworks** on top of this „Enterprise OS"
  - This is an advantage of Groovy/Grails vs. Ruby/Rails

CONTENTS

When defining a language, always think about tooling!

- Tooling includes
  - **editing** (coloring, code completion, refactoring, etc.)
  - (static) **analysis**
- Powerful tooling is **simpler** to build for **statically typed** languages
- However, **IDEs for dynamic languages** are feasible, too:
  - Netbeans Ruby support
  - Smalltalk Browsers
- **Metaprogramming** is simpler to do in **dynamic languages**
  - there‘s no tooling to be adapted with the language
  - How can the IDE know about changes to programs at RT?
  - Compile-Time meta programming does not include tooling

When defining a language, always think about tooling! II

- Design language to **make tooling simple:**
- Do you see the difference?

`SELECT a,b,c FROM someTable …`	**SQL**
`from someCollection select a,b,c …`	**Linq**

When defining a language, always think about tooling! III

- Internal DSLs – implemented mostly in dynamic languages – **do not provide any tool support** for the DSL
  - Main disadvantage of dynamic, internal DSLs
  - Usability for business user limited!?
- In **external DSLs** you build a **custom editor** which then typically provides the well-known IDE productivity features (to one extend or another). Examples include
  - **GMF** for graphical notations
  - **Xtext** for textual notations
- **Static Analysis** becomes a central issue for **concurrency**
  - If concurrency is supported on **language level**, more compiler/analysis support becomes available.
  - MS Singularity Project is a good example

CONTENTS

Summary

- The time when only one language rules are over.
- Languages are a **topic of discussion** again
- It's about **language concepts**, not little details!
- New Buzzword: **Polyglott Programming** (new concept?) Build a system using several languages,
  - A robust, static, compiled languages for the **foundation**
  - The **more volatile parts** are done with a more productive, often dynamically typed language
  - DSLs are used for **end-user** configuration/customization
- Languages I could have talked about:
  - F# (functional), Ada 2005 (concurrency)

CONTENTS

THANKS!

THE END.