Combining Aspect-Oriented and Strategic Programming

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Outline

- *Introduction*
- *Aspects in Stratego*
- *Case Studies*
- *Discussion*
- *Conclusion*

Aspect-Oriented Programming

- Goal of AOP is the *modularization* of *separate* and *cross-cutting concerns*.
  - *concern* – here: a non-functional property;
  - *cross-cutting* – spread across and repeatedly expressed in many program units;
  - *separate* – (most often) independent of each other.
- One concern maps to one *aspect*, examples
  - security, persistence, exception handling, traceability.
- Modularization – one concept = one module – not particular to any programming paradigm.

Stratego

- A term rewriting language where the application of the term rewriting *rules* are controlled by *user-definable strategies*.
- Language primitives:

Stratego

- A term rewriting language where the application of the term rewriting *rules* are co
  strategies.
- Language primitive
  - constructors

```
signature
 constructors
  Var    : Id -> Var
         : Var -> Exp
  Int    : String -> Exp
  Plus   : Exp * Exp -> Exp
  If     : Exp * Exp * Exp -> Exp
  While  : Exp * Exp -> Exp
  Assign : Var * Exp -> Exp
```

Stratego

- A term rewriting language where the application of the term rewriting *rules* are controlled by user-definable *strategies*.
- Language primitives:
  - constructors
  - rules

```
rules
  EvalBinOp:
  Plus(Int(i), Int(j)) -> Int(k)
  where <addS>(i,j) => k

  EvalIf:
  If(Int("0"), e1, e2) -> e2
```

Stratego

- A term rewriting language where the application of the term rewriting *rules* are controlled by user-definable *strategies*.
- Language primitives:
  - constructors
  - rules
  - strategies

```
strategies
  prop-const =
    PropConst
    <+ prop-const-assign
    <+ prop-const-if
    <+ prop-const-while
    <+ (
          all(prop-const)
          ; try(EvalBinOp)
       )
```

Stratego

- A term rewriting language where the application of the term rewriting *rules* are controlled by user-definable *strategies*.
- Language primitives:
  - constructors
  - rules
  - strategies
- Library provides many common strategies, such as `topdown`, `bottomup` and `innermost`.

Stratego/XT

- A distribution of Stratego, providing
  - a *component model* (XTC);
  - a *modular syntax definition formalism* (SDF) with *parser* (SGLR);
  - a *library* of generic strategies for program transformation, including
    - various term traversals;
    - data and control flow analysis;
    - command-line option parsing.

Example: Constant Propagation

- Problem: *We want to (a) replace variables with their constant values when known, and (b) simplify expressions involving constants.*
  - (strictly speaking, only (a) is constant propagation)

Example: Constant Propagation (2)

```
module prop-const
signature
 constructors
  Var    : Id -> Var
         : Var -> Exp
  Int    : String -> Exp
  Plus   : Exp * Exp -> Exp
  If     : Exp * Exp * Exp -> Exp
  While  : Exp * Exp -> Exp
  Assign : Var * Exp -> Exp
rules
  EvalBinOp : Plus(Int(i), Int(j)) -> Int(k) where <addS>(i,j) => k
  EvalIf    : If(Int("0"), e1, e2) -> e2
strategies
  prop-const = PropConst <+ prop-const-assign <+ prop-const-if
               <+ prop-const-while <+ (all(prop-const) ; try(EvalBinOp))

  prop-const-assign = Assign(?Var(x), prop-const => e)
    ; if <is-value> e then rules( PropConst : Var(x) -> e )
                      else rules( PropConst :- Var(x) ) end

  prop-const-if = If(prop-const, id, id)
    ; (EvalIf ; prop-const <+ (If(id,prop-const,id) /PropConst\ If(id,id,prop-const)))

  prop-const-while = ?While(e1, e2) ; (While(prop-const,id)
    ; EvalWhile <+ (/PropConst\* While(prop-const, prop-const)))
```

AspectStratego

- An extension to Stratego, providing *pointcuts* and *advice* which together offer a type of *code composition*.
- Properties
  - declarative;
  - a strict superset of Stratego – every valid Stratego program is a valid AspectStratego program;
  - allows modularization of some cross-cutting concerns.
    - but not timing constraints, synchronization, ...

Pointcuts

- *Pointcut* $\stackrel{\text{def}}{=}$ an expression on logical *combinators* and *joinpoint (context) predicates* which identifies a *joinpoint*.
- *Joinpoint* $\stackrel{\text{def}}{=}$ a *point in the program execution* where control-flow passes twice: into and out of the subcomputation at that point.
- Pointcuts are used to *identify locations* in the program, based on *static* (structural) and *dynamic* (runtime) properties.

Pointcuts (2)

```
pointcut
  log-rule-or-strat(n, y) =

    (rules(P* => n) + strategies(p* => n)) ; args(y)
```

Pointcuts (2)

```
pointcut
  log-rule-or-strat(n, y) =

    (rules(P* => n) + strategies(p* => n)) ; args(y)
```

joinpoint predicates

combinators

joinpoint context predicate

Pointcuts (3)

- *Joinpoint predicates*
  - Static (structure) predicates
  - `calls(name-expr => n)` – a strategy or rule invocation
  - `strategies(...)` – a strategy definition
  - `rules(...)` – a rule definition
  - `matches(pattern => t)` – a pattern match
  - `builds(...)` – a term construction
  - `fails` – explicit invocation of `fail`

Pointcuts (4)

- *Joinpoint context predicates*
  - (potentially) dynamic (runtime) predicates
    - modifiers to *joinpoint predicates*
  - `withincode(name-expr => n)` – joinpoint within a rule or strategy
  - `matchflow(flow-regex => t)` – joinpoint with a given execution history
  - `args(`n_0`, `n_1`,..., `n_n`)` – joinpoint with `n` arguments
  - `rhs / lhs(pattern => t)` – joinpoint with given left-hand side

Pointcuts (5)

- *Combinators*
  - ; (and)
  - + (or)
  - `not()`

```
pointcut
  log-rule-or-strat(n, y) =
    (rules(P* => n) + strategies(p* => n)) ; args(y)
```

Pointcuts (6)

```
pointcut
  log-rule-or-strat(n, y) =

    (rules(P* => n) + strategies(p* => n)) ; args(y)
```

Advice

- *Advice* $\stackrel{\text{def}}{=}$ a *body of code* `c` (a strategy expression) associated with a pointcut `p`.
- Advice is used to insert code into the joinpoint identified by the pointcut `p`.
- Three main kinds of advice:
  - *before* – `c` is inserted before the joinpoint of `p`
  - *after* – `c` is inserted after the joinpoint of `p`
  - *around* – `c` is inserted around the joinpoint of `p`
    - use `proceed` to identify the "hole" for `p`

Advice (2)

- Three kinds of *after* advice
  - *after succeed* – run iff the joinpoint code succeeded
  - *after fail* – run iff the joinpoint code failed
  - *after* – run after joinpoint code, regardless of success
    - *after succeed* and *after fail* may change success to failure or vice versa. After may not.

Advice (3)

```
strategies

  invoked(|s) = ![ “Invoked '”, s, “'” ]
  failed(|s) = ![ “Failed '”, s, “'” ]
  finished(|s) = ![ “Finished '”, s, “'” ]

  prop-const = PropConst <+ prop-const-assign
  PropConst = id

aspects
  pointcut rule-or-strat(n, y) =
    (rules(P* => n) + strategies(p* => n)) ; args(y)

  aspect p-logger =
  before        : rule-or-strat(s, t) = log(|Debug, <invoked(|s)>)
  after fail    : rule-or-strat(s, t) = log(|Debug, <failed(|s)>)
  after         : rule-or-strat(s, t) = log(|Debug, <finished(|s)>)
```

Weaving

- *Weaving* $\stackrel{\text{def}}{=}$ the act of *composing advice code* into the *joinpoints* picked out by their *pointcuts*.
- Conceptually, the procedure is:

```
foreach aspect as
  foreach advice ad
    traverse program {
      if pointcut of ad matches
        insert code of ad
    }
```

Weaving (2)

```
pointcut
  (rules(P* => n) + strategies(p* => n)) ; args(y)
```

+

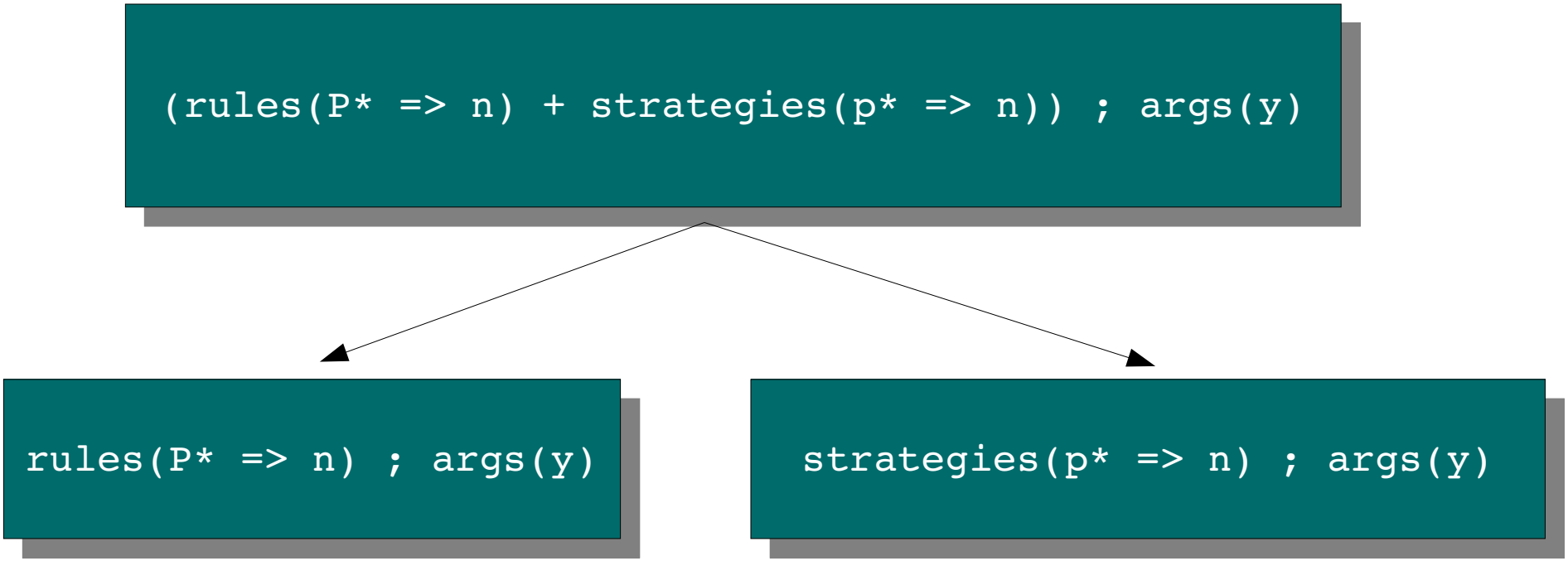
```
before :
  rule-or-strat(s, t) =
    log(|Debug, <invoked(|s)>)
```

on

```
prop-const = PropConst <+ prop-const-assign
```

Weaving (3)

- Decomposing pointcuts:



Weaving (4)

```
strategies(p* => n) ; args(y)
```

```
rule-or-strat(s, t) = log(|Debug, <invoked(|s)>)
```

```
prop-const = PropConst <+ prop-const-assign
```

⇓

```
prop-const =
  log(|Debug, <invoked(|"prop-const")>)
  ; PropConst <+ prop-const-assign
```

Weaving (5)

- All weaving is done on the template:

```
before ;
if pointcut-code then
  if after-succeed then try(after) else after ; fail end
  else
  if after-fail then try(after) else after ; fail end
end
```

- Idea: *after succeed* and *after fail* can change success/failure, *after* cannot.

Example: Algorithm Skeletons

- Problem: *We have a generic strategy for forward propagating transformations, and we want to instantiate it.*
- Library implementor
  - *Generalize constant propagator* into *forward propagator*
  - Provide *instantiation aspect*.
- Library user
  - Implements *concrete instantiation aspect*.
- Weaver produces *constant propagator.*

Example: Algorithm Skeletons (2)

```
module forward-prop
strategies

 forward-prop =
   fail <+ prop-assign <+ prop-if <+ prop-while <+ all(forward-prop)

 prop-assign =
   Assign(?Var(x), forward-prop => e) ; id

 prop-if =
   If(forward-prop, id, id)
   ; (If(id,forward-prop,id) /\ If(id,id,forward-prop))

 prop-while =
   ?While(e1, e2)
   ; (/\* While(forward-prop, forward-prop)))
```

- Skeleton follows *subject language*; common to all *forward propagating transformations*.

Example: Algorithm Skeletons (3)

```
aspects
 pointcut prop-rule(r) =
   (calls(dr-fork-and-intersect) ; args(_, _, r))
   + (calls(dr-fix-and-intersect) ; args(_, r))
 pointcut prop-rule    = fails ; withincode(forward-prop)
 pointcut forward-prop = calls(all) ; withincode(forward-prop)
 pointcut prop-assign  = calls(id) ; withincode(prop-assign)
 pointcut prop-if    = calls(dr-fork-and-intersect) ; withincode(prop-if)
 pointcut prop-while = calls(dr-fix-and-intersect) ; withincode(prop-while)
```

- These pointcuts identify the *variation points* of the skeleton. By filling in the *variation points* using *advice*, the skeleton is *instantiated*.

Example: Type Checking of Terms

- Problem: *We want to check the validity of a term with respect to a signature by inserting format checking code.*
  - In Stratego, terms are *"free form"*, only numerical arity must be respected.
  - The Stratego/XT suite contains *format checker generators*, but they are intended to be run only after a transformation is complete.
  - We can use aspects to insert *typechecking code* for us, and have detailed control of its insertion.

Example: Type Checking of Terms

```
module typecheck-example
aspects

  pointcut typecheck-rules(n, t) = rules(n) ; rhs(t)

  aspect typechecker =
    around : typecheck-rules(n, t) =
      proceed
      ; (
          typecheck(|t)
          <+ (log(|incorrect-term(n)) ; fail)
        )
```

Discussion

- General *meta-programming*, *extensible interpreters* and *reflection* are strictly more powerful than aspects, but also more complicated.
  - We are questing for a linguistic *"sweet spot"* where we can still do useful code composition.
- Even with its apparent limitations, AspectStratego provides a mechanism for *extension* and *adaptation* in addition to *modularization*.

Discussion (2)

- Experience from implementation and use tells us:
  - Our aspects are most likely *too limited*
    - We wanted to use aspects for *origin tracking*, but we have not (yet) come up with a good aspect-based solution.
    - *Introspection* offered in the current version is insufficient – more *reflective capabilities* of Stratego needed.
      - E.g. querying a strategy for its arity, module, etc.
  - A Stratego *interpreter* or *staged programming facilities* would be useful as a mechanism for implementing the aspect language compiler.

Conclusion

- Presented a *declarative extension* to Stratego and its *concrete application* to *logging*, *typechecking* of terms and *algorithm adaptation*.
- Compared our language extension to other language techniques for *modularization*, *extension* and *adaptation*.