Trustworthy Refactoring via Decomposition and Schemes

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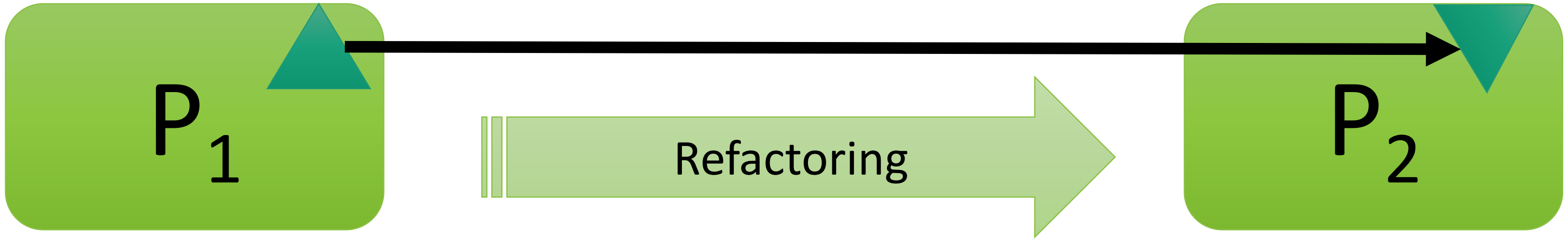
Refactoring correctness

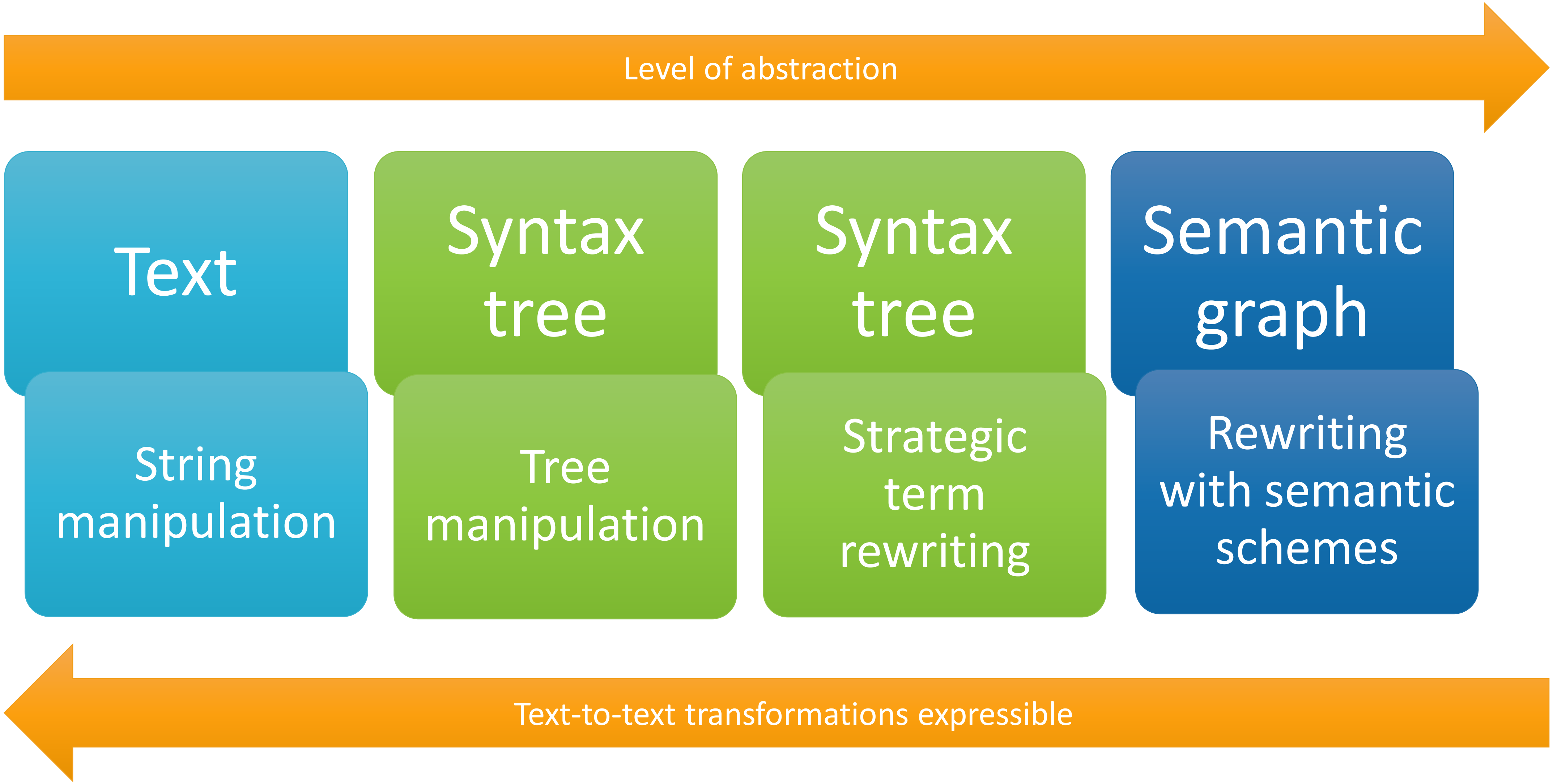
- For any input program, the refactoring transformation results in a program **semantically equivalent** to the input, w.r.t. a definition of language semantics and equivalence.



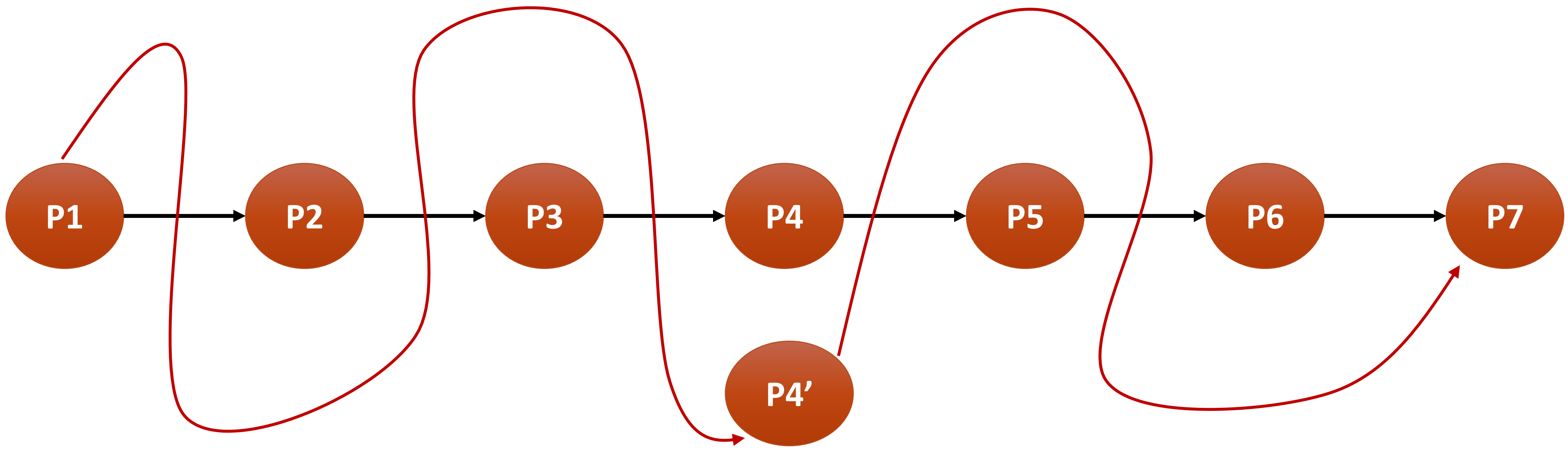
$P_1 \equiv P_2$

- In practice, only part of the program is modified
- **Extensive changes: completeness + consistency**

Representation - transformation



(De)composition

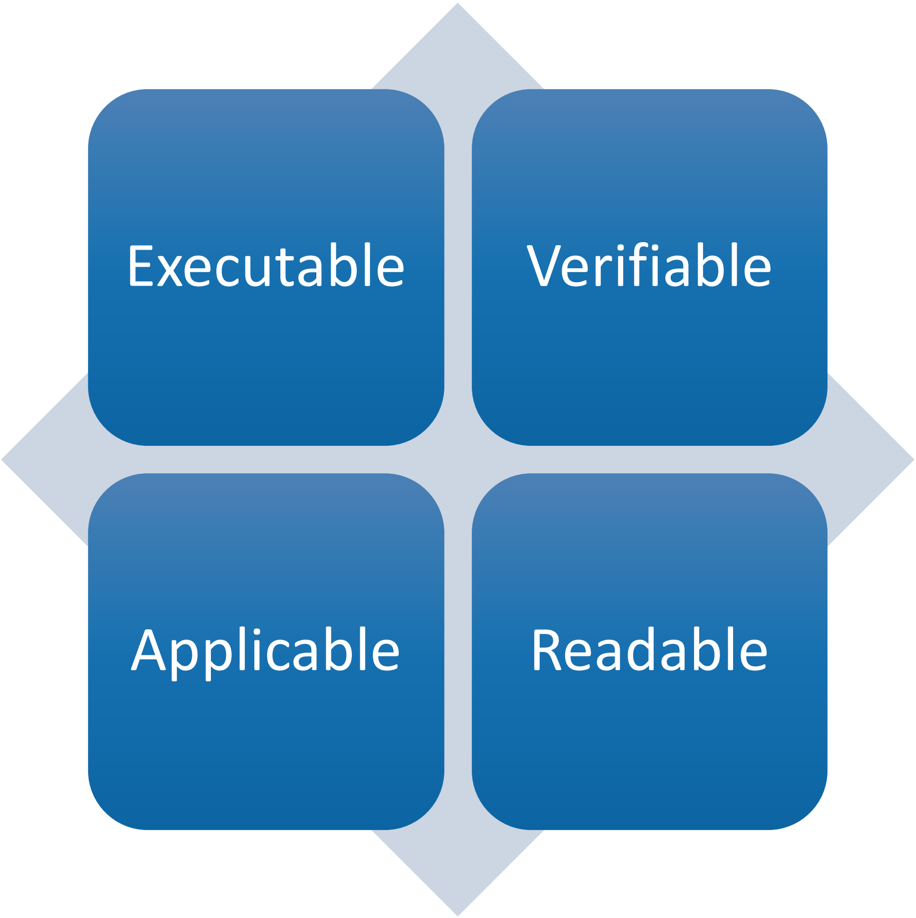


- PRO: likely results in simple, reusable micro-refactorings
- CON: it may be hard to find the proper decomposition

Semantic schemes

- Completeness and consistency
  - Ensures compensation for each change, at every affected location
- Sequential program of term rewrite rules
- With modifiers based on data and control dependency
  - Data-flow
    - Forward
    - Backward
  - Introduce or modify binding
    - Variable
    - Function

A refactoring specification formalism



Term rewriting

+

Semantic predicates

+

Semantic schemes

+

Selector functions

+

Refactoring functions

Case study: „generalise function definition"

```
f(X) -> begin X * 2 end.
g(X) -> f(X+1).
```

⇒

```
f(X, Y) -> begin X * Y() end.
f(X) -> f(X, fun () -> 2 end).
g(X) -> f(X+1).
```

At first glance: only 2 steps

- Create the generalised function
- Make the less general function invoke the generalised one

Compositional approach: 6 steps

- Wrap the selected element into an unnamed function application
- Create a function abstraction from the body of the function
- Create a variable abstraction from the selected element
- Lift the variable to the function scope
- Lift the variable to function parameter
- Rename the generalised function to the original name

```
f(X) -> begin X * 2 end.
g(X) -> f(X + 1).
```

```
f(X) -> begin X * fun () -> 2 end () end.
g(X) -> f(X+1).
```

STEP 1: wrap expression into unnamed function

```
LOCAL REFACTORING wrap ()
                   E
   ______________________________
   fun (Vars..) -> E end (Vars..)
WHEN
   Vars.. = free_vars(E) AND non_bind(E)
```

```
f(X) -> begin X * fun () -> 2 end () end.
g(X) -> f(X+1).
```

```
t(X) -> begin X * fun () -> 2 end () end.
f(X) -> t(X).
g(X) -> f(X+1).
```

STEP 2: extract expression into function (t - temporary)

INTRODUCE FUNCTION extract_to_function(NewName)

DEFINITION

```
NewName(Vars..) -> E .
```

REFERENCE

$$\frac{\texttt{E}}{\texttt{NewName(Vars..)}}$$

WHEN Vars.. = free_vars(E)

```
t(X) -> begin X * fun () -> 2 end () end.
f(X) -> t(X).
g(X) -> f(X+1).
```

```
t(X) -> begin Y = fun () -> 2 end, X* Y() end.
f(X) -> t(X).
g(X) -> f(X+1).
```

STEP 3: extract expression into variable (Y)

INTRODUCE VARIABLE extract_to_variable(NewName)

DEFINITION IN SCOPE

NewName = E

REFERENCE

$$\frac{E}{NewName}$$

```
t(X) -> begin Y = fun () -> 2 end, X* Y() end.
f(X) -> t(X).
g(X) -> f(X+1).
```

```
t(X) -> Y = fun () -> 2 end, begin X* Y() end.
f(X) -> t(X).
g(X) -> f(X+1).
```

STEP 4: lift variable to outer scope

INTRODUCE VARIABLE outer_variable()

DEFINITION IN OUTER SCOPE

Name = E

REFERENCE

$$\frac{\text{Name = E}}{\text{Name}}$$

```
t(X) -> Y = fun () -> 2 end, begin X* Y() end.
f(X) -> t(X).
g(X) -> f(X+1).
```

```
t(X, Y) -> begin X * Y() end.
f(X) -> t(X, fun () -> 2 end).
g(X) -> f(X+1).
```

STEP 5: variable to function parameter

FUNCTION REFACTORING variable_to_parameter()

DEFINITION

$$\frac{\texttt{(Args..) -> X = E, Body..}}{\texttt{(Args.., X) -> Body..}}$$

REFERENCE

$$\frac{\texttt{(Args2..)}}{\texttt{(Args2.., E)}}$$

```
t(X, Y) -> begin X * Y() end.
f(X) -> t(X, fun () -> 2 end).
g(X) -> f(X+1).
```

```
f(X, Y) -> begin X * Y() end.
f(X) -> f(X, fun () -> 2 end).
g(X) -> f(X+1).
```

STEP 6: rename function (to f)

FUNCTION SIGNATURE REFACTORING `rename_function(NewName)`

$$\frac{\texttt{Name(Args..)}}{\texttt{NewName(Args..)}}$$

```
t(X, Y) -> begin X * Y() end.
f(X) -> t(X, fun () -> 2 end).
g(X) -> f(X+1).
```

```
f(X, Y) -> begin X * Y() end.
```

```
REFACTORING generalise_function(ParamName)
DO
  THIS.wrap()
  THIS = THIS.function_part()
  Old = function(THIS)
  Name = name(Old)
  New = Old.body().extract_to_function(t)
  Var = THIS.extract_to_variable(ParamName)
  Var.to_function_parameter()
  New.rename_function(Name)
```

FUNCTION S ... ame)

Name(A

NewName(

Verification technique

Local refactoring

- Simple rewriting: conditional pattern equivalence

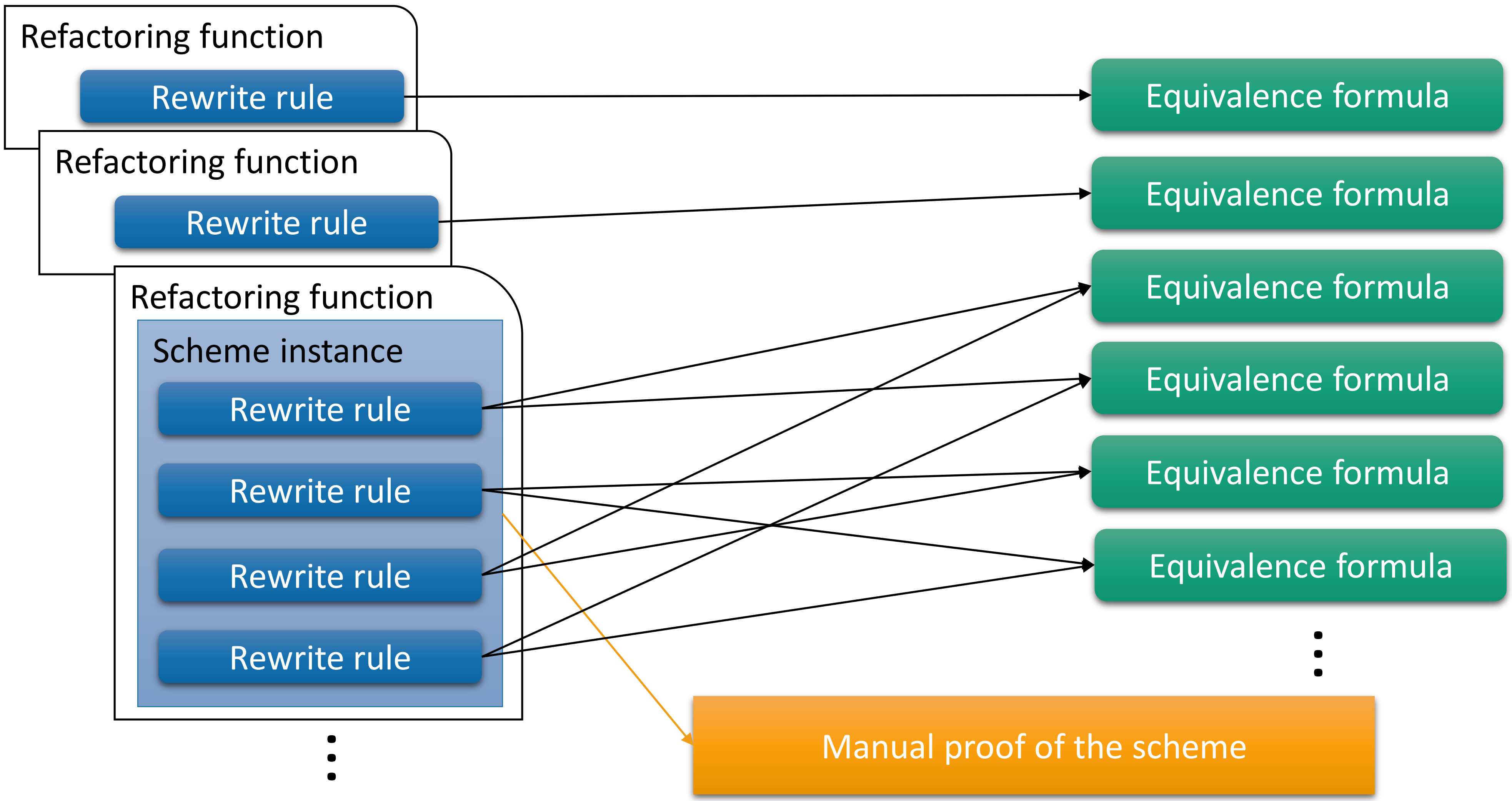
Extensive refactoring

- Scheme verification: inductive proof on the semantic relation
- Scheme instance verification: conditional pattern equivalences

Composite refactoring

- Correct if the components are correct

Verification technique



Equivalence checking (in Matching Logic)

📖 Stefan Ciobaca et al. (2016): A Language-Independent Proof System for Full Program Equivalence.

a formula with a pair of configuration patterns

set of pairs of configuration patterns that are known to be equivalent

$$\varphi \Downarrow^{\infty} Eq$$

All concrete pairs of program configurations that match to $\boldsymbol{\varphi}$ *both diverge or reach an instance of* Eq.

Proof System

AXIOM $\dfrac{\varphi \in Eq}{\vdash \varphi \Downarrow^{\infty} Eq}$

CONSEQ $\dfrac{\vDash \varphi \to \exists \tilde{x}.\varphi' \quad \varphi' \Downarrow^{\infty} Eq}{\vdash \varphi \Downarrow^{\infty} Eq}$

STEP $\dfrac{\vDash \varphi_1 \Rightarrow^{*} \varphi_1' \quad \vDash \varphi_2 \Rightarrow^{*} \varphi_2' \quad \vdash \langle \varphi_1', \varphi_2' \rangle \Downarrow^{\infty} Eq}{\vdash \langle \varphi_1, \varphi_2 \rangle \Downarrow^{\infty} Eq}$

CASE ANALYSIS

CIRCULARITY

Verification of „wrap”

```
LOCAL REFACTORING wrap ()
                         E
   ─────────────────────────────────
   fun (Vars..) -> E end (Vars..)
WHEN
  Vars.. = free_vars(E) AND non_bind(E)
```

Verification of „wrap”

$$\left\langle \begin{array}{c} \langle\langle E\rangle_{\mathrm{code}}\langle\varepsilon_0\rangle_{\mathrm{env}}\cdots\rangle_{\mathrm{cfg}} \\ \langle\langle \texttt{fun (}\mathit{Vars}\texttt{) -> } E \texttt{ end (}\mathit{Vars}\texttt{)}\rangle_{\mathrm{code}}\langle\varepsilon_0\rangle_{\mathrm{env}}\cdots\rangle_{\mathrm{cfg}} \end{array} \right\rangle \Downarrow^{\infty} \left\langle \begin{array}{c} \langle\langle \mathit{Code}\rangle_{\mathrm{code}}\langle\varepsilon\rangle_{\mathrm{env}}\rangle_{\mathrm{cfg}} \\ \langle\langle \mathit{Code}\rangle_{\mathrm{code}}\langle\varepsilon\rangle_{\mathrm{env}}\rangle_{\mathrm{cfg}} \end{array} \right\rangle, \ldots$$

$$\land\ \mathit{Vars} = \texttt{free\_vars}(E) \land \texttt{non\_bind}(E)$$

$$1.\quad \vdash \left\langle \begin{array}{ll} \langle\langle \mathit{Code}\rangle_{\mathsf{code}} & \langle\varepsilon\rangle_{\mathsf{env}}\cdots\rangle_{\mathsf{cfg}} \\ \langle\langle \mathit{Code}\rangle_{\mathsf{code}} & \langle\varepsilon\rangle_{\mathsf{env}}\cdots\rangle_{\mathsf{cfg}} \end{array} \right\rangle_{\mathsf{eq}} \quad \Downarrow^{\infty}\ \mathrm{Eq} \quad \textsc{Axiom}$$

$$2.\quad \vdash \left\langle \begin{array}{ll} \langle\langle E\rangle_{\mathsf{code}} & \langle\varepsilon_0\rangle_{\mathsf{env}}\cdots\rangle_{\mathsf{cfg}} \\ \langle\langle E\rangle_{\mathsf{code}} & \langle\varepsilon_0\rangle_{\mathsf{env}}\cdots\rangle_{\mathsf{cfg}} \end{array} \right\rangle_{\mathsf{eq}} \land \Psi \quad \Downarrow^{\infty}\ \mathrm{Eq} \quad \textsc{Conseq}(1)$$

$$3.\quad \vdash \left\langle \begin{array}{ll} \langle\langle E\rangle_{\mathsf{code}} & \langle\varepsilon_0\rangle_{\mathsf{env}}\cdots\rangle_{\mathsf{cfg}} \\ \langle\langle \texttt{fun}(\mathit{Vars})\texttt{->}\,E\ \texttt{end}(\mathit{Vars})\rangle_{\mathsf{code}} & \langle\varepsilon_0\rangle_{\mathsf{env}}\cdots\rangle_{\mathsf{cfg}} \end{array} \right\rangle_{\mathsf{eq}} \land \Psi \quad \Downarrow^{\infty}\ \mathrm{Eq} \quad \textsc{Step}(2)$$

$$\Psi \equiv \mathit{Vars} = \texttt{free\_vars}(E) \land \texttt{non\_bind}(E)$$

Verification of „extract_to_variable” (introduce variable scheme)

Template

```
DEFINITION IN SCOPE
  <name> = <pattern1>
REFERENCE
  <pattern2>
  ----------
  <pattern3>
```

Definition

```
ON scope(THIS)
            E..
  ------------------------
  <name> = <pattern1>, E..
WHEN fresh(<name>)
 AND pure(<pattern1>)
 AND closed(<pattern1>)
THEN ON THIS
  <pattern2>
  ----------
  <pattern3>
```

Contract

```
begin <name> = <pattern1>, <pattern3> end ≡ <pattern2>
```

Verification of „extract_to_variable” (introduce variable scheme)

Template

```
DEFINITION IN SCOPE
  <name> = <pattern1>
REFERENCE
  <
  -
  <
```

Definition

```
ON scope(THIS)
            E..
  -------------------------
```

$$\vdash \left\langle \begin{array}{ll} \langle\langle E\rangle_{\mathsf{code}} & \langle\varepsilon\rangle_{\mathsf{env}} \cdots\rangle_{\mathsf{cfg}} \\ \langle\langle \mathtt{begin}\ Name = E\, ,\, Name\ \mathtt{end}\rangle_{\mathsf{code}} & \langle\varepsilon\rangle_{\mathsf{env}} \cdots\rangle_{\mathsf{cfg}} \end{array}\right\rangle_{\mathsf{eq}} \wedge\ \mathrm{fresh}(Name) \Downarrow^{\infty} \quad E$$

```
THEN ON THIS
  <pattern2>
  ----------
  <pattern3>
```

Contract

```
begin <name> = <pattern1>, <pattern3> end ≡ <pattern2>
```

Summary

- Refactoring can be seen as a special case of strategic term rewriting
- By decomposition, we can split up big steps into small micro-steps
- Finding a decomposition may be far from trivial, but it pays off
- To check correctness, we translate the refactoring specification into a set of equivalence formulas in matching logic
- Refactoring specifications are executable and verifiable
- With appropriate restrictions (and appropriate program representation) we arrive at refactoring oriented programming