Funcons

reusable components of language specifications

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Contents

Note: Slides 31–34 and 40–47 were not presented

Specification vs implementation

Suppose you were developing a new software language…

- would ***you*** specify a ***formal semantics*** of it?

Yes: a few languages from the 80s and 90s

- ADA, SCHEME, STANDARD ML, CONCURRENT ML

No: all other major programming languages

- HASKELL, OCAML, SCALA, JAVA, C#, … (and most DSLs)

Funcons

Make formal semantics *easier* than BNF !

Encourage language developers to use formal semantics for:

- ***documentation***
  - language features, design decisions
- ***implementation***
  - rapid prototyping, exploration of design alternatives

Conjecture

Using a ***component-based*** semantic meta-language can significantly reduce the effort of language specification

Meta-language engineering

Meta-language requirements

- clear, concise, expressive ***notation***
- solid ***foundations***
- ***tool support*** for browsing, checking, validating
- ease of ***co-evolution*** of languages and specifications
- ***reusable components***

Funcons

Funcons

- correspond to ***fundamental programming concepts***
- language-***independent***
- have ***fixed*** behaviour
- specified ***independently***
- ***new*** funcons can be added

Kinds of funcons

Computations

- **Normal:** flowing, giving, binding, storing, linking, generating, interacting, …
- **Abnormal:** failing, throwing, returning, controlling, …
- (Concurrent: not yet specified)

Kinds of funcons

Values *(some types are built-in)*

- **Primitive:** atoms, bools, ints, floats, chars, strings
- **Composite:** algebraic datatypes, tuples, lists, vectors, sets, multisets, maps, pointers, references, variants, …
- **Abstractions:** closures, thunks, functions, patterns, …
- none : no-value

Funcon library

```
# Values

## Types
[
  Type   universe
  Type   values          Alias vals
  Type   types
  Type   empty-type
  Funcon is-in-type      Alias is
  Type   datatype-values
  Type   no-value
  Funcon none
  Type   cast-to-type    Alias cast
  Type   is-defined      Alias is-def
  Type   ground-values   Alias ground-vals
  Funcon is-equal        Alias is-eq
]

## Primitive values

### The null value
[
  Datatype unit-type
  Funcon   null-value    Alias null
]

### Booleans
[
  Datatype booleans      Alias bools
  Funcon   true
  Funcon   false
  Funcon   not
  Funcon   implies
  Funcon   and
  Funcon   or
  Funcon   exclusive-or  Alias xor
]

### Bits and bit vectors
[
  Type     bits
  Datatype bit-vectors
  Type     bytes           Alias octets
  Funcon   bit-vector-not
  Funcon   bit-vector-and
  Funcon   bit-vector-or
  Funcon   bit-vector-xor
  Funcon   bit-vector-shift-left
  Funcon   bit-vector-logical-shift-right
  Funcon   bit-vector-arithmetic-shift-right
  Funcon   integer-to-bit-vector
  Funcon   bit-vector-to-integer
  Funcon   bit-vector-to-natural
  Funcon   unsigned-bit-vector-maximum
  Funcon   signed-bit-vector-maximum
  Funcon   signed-bit-vector-minimum
  Funcon   is-in-signed-bit-vector
  Funcon   is-in-unsigned-bit-vector
]

### Integers
[
  Type   integers                    Alias ints
  Type   integers-from               Alias from
  Type   integers-up-to              Alias up-to
  Type   bounded-integers            Alias bounded-ints
  Type   positive-integers           Alias pos-ints
  Type   negative-integers           Alias neg-ints
  Type   natural-numbers             Alias nats
  Funcon natural-successor           Alias nat-succ
  Funcon natural-predecessor         Alias nat-pred
  Funcon integer-add                 Alias int-add
  Funcon integer-subtract            Alias int-sub
  Funcon integer-multiply            Alias int-mul
  Funcon integer-divide              Alias int-div
  Funcon integer-modulo              Alias int-mod
  Funcon integer-power               Alias int-pow
  Funcon integer-absolute-value      Alias int-abs
  Funcon integer-negate              Alias int-neg
  Funcon integer-is-less             Alias is-less
  Funcon integer-is-less-or-equal    Alias is-less-or-equal
  Funcon integer-is-greater          Alias is-greater
  Funcon integer-is-greater-or-equal Alias is-greater-or-
equal
  Funcon binary-natural              Alias binary
  Funcon octal-natural               Alias octal
  Funcon decimal-natural             Alias decimal
  Funcon hexadecimal-natural         Alias hexadecimal
]

### Floats
[
  Datatype float-formats
  Funcon   binary32
  Funcon   binary64
  Funcon   binary128
  Funcon   decimal64
  Funcon   decimal128
  Type     floats
  Funcon   float
  Funcon   quiet-not-a-number      Alias qNaN
  Funcon   signaling-not-a-number  Alias sNaN
  Funcon   positive-infinity       Alias pos-inf
  Funcon   negative-infinity       Alias neg-inf
  Funcon   float-convert
  Funcon   float-equal
  Funcon   float-is-less
  Funcon   float-is-less-or-equal
  Funcon   float-is-greater
  Funcon   float-is-greater-or-equal
  Funcon   float-negate
  Funcon   float-absolute-value
  Funcon   float-add
  Funcon   float-subtract
  Funcon   float-multiply
  Funcon   float-multiply-add
  Funcon   float-divide
  Funcon   float-remainder
  Funcon   float-sqrt
  Funcon   float-integer-power
  Funcon   float-float-power
  Funcon   float-round-ties-to-even
  Funcon   float-round-ties-to-infinity
  Funcon   float-floor
  Funcon   float-ceiling
  Funcon   float-truncate
  Funcon   float-pi
  Funcon   float-e
  Funcon   float-log
  Funcon   float-log10
  Funcon   float-exp
  Funcon   float-sin
  Funcon   float-cos
  Funcon   float-tan
  Funcon   float-asin
  Funcon   float-acos
  Funcon   float-atan
  Funcon   float-sinh
  Funcon   float-cosh
  Funcon   float-tanh
  Funcon   float-asinh
  Funcon   float-acosh
  Funcon   float-atanh
  Funcon   float-atan2
]

### Characters
[
  Type     characters                            Alias chars
  Datatype unicode-characters
  Type     unicode-points
  Funcon   unicode-character                     Alias char
  Funcon   unicode-point                         Alias unicode
  Type     basic-multilingual-plane-characters   Alias bmp-chars
  Type     basic-multilingual-plane-points
  Type     iso-latin-1-characters                Alias latin-1-chars
  Type     iso-latin-1-points
  Type     ascii-characters                      Alias ascii-chars
  Type     ascii-points
  Funcon   utf-8
  Funcon   utf-16
  Funcon   utf-32
  Funcon   backspace
  Funcon   horizontal-tab
  Funcon   line-feed
  Funcon   form-feed
  Funcon   carriage-return
  Funcon   double-quote
  Funcon   single-quote
  Funcon   backslash
]

### Strings
[
  Type   strings
  Funcon string
  Funcon string-append
  Funcon to-string
]

## Composite values

### Sequences of values
[
  Funcon length
  Funcon index
  Funcon first
  Funcon second
  Funcon third
  Funcon is-in
  Funcon first-n
  Funcon drop-first-n
  Funcon reverse
  Funcon n-of
  Funcon intersperse
]

### Datatypes
[
  Funcon datatype-value
  Funcon datatype-value-atom
  Funcon datatype-value-elements
]

### Tuples
[
  Datatype tuples
  Funcon   tuple-elements
  Funcon   tuple-zip
]

### Lists
[
  Datatype lists
  Funcon   list
  Funcon   list-elements
  Funcon   list-nil       Alias nil
  Funcon   list-cons      Alias cons
  Funcon   list-head      Alias head
  Funcon   list-tail      Alias tail
  Funcon   list-length
  Funcon   list-append
]

### Vectors
[
  Datatype vectors
  Funcon   vector
  Funcon   vector-elements
]

### Sets
[
  Type   sets
  Funcon set
  Funcon set-elements
  Funcon is-in-set
  Funcon is-subset
  Funcon set-insert
  Funcon set-unite
  Funcon set-intersect
  Funcon set-difference
  Funcon set-size
  Funcon some-element
  Funcon element-not-in
]

### Maps
[
  Type   maps
  Funcon map
  Funcon map-elements
  Funcon map-lookup    Alias lookup
  Funcon map-domain    Alias dom
  Funcon map-override
  Funcon map-unite
  Funcon map-delete
]

### Multisets (bags)
[
  Type   multisets
  Funcon multiset
  Funcon multiset-elements
  Funcon multiset-occurrences
  Funcon multiset-insert
  Funcon multiset-delete
  Funcon is-submultiset
]

### Graphs
[
  Type   directed-graphs
  Funcon is-cyclic
  Funcon topological-sort
]

### References and pointers
[
  Datatype references
  Funcon   reference
  Type     pointers
  Funcon   dereference
]

### Records
[
  Datatype records
  Funcon   record
  Funcon   record-select
]

### Variants
[
  Datatype variants
  Funcon   variant
  Funcon   variant-id
  Funcon   variant-value
]

// Further types of composite values to be added

## Abstraction values

### Generic abstractions
[
  Type   abstractions
  Funcon abstraction
  Funcon closure
]

### Thunks
[
  Datatype thunks
  Funcon   thunk
  Funcon   force
]

### Functions
[
  Datatype functions
  Funcon   function
  Funcon   apply
  Funcon   supply
  Funcon   compose
  Funcon   uncurry
  Funcon   curry
  Funcon   partial-apply
]

### Patterns
[
  Datatype patterns
  Funcon   pattern
  Funcon   match
  Funcon   case
  Funcon   pattern-any
  Funcon   pattern-bind
  Funcon   pattern-type
  Funcon   pattern-prefer
  Funcon   pattern-unite
  Funcon   structural-match
  Funcon   structural-pattern-prefer
  Funcon   structural-pattern-unite
]

# Computations

## Types of computation
[
  Funcon   computation-types
]

## Normal computation

### Flowing
[
  Funcon interleave
  Funcon atomic
  Funcon left-to-right   Alias l-to-r
  Funcon sequential      Alias seq
  Funcon effect
  Funcon choice
  Funcon if-then-else
  Funcon while
  Funcon do-while
]

### Giving
[
  Entity given-value
  Funcon give
  Funcon given
  Funcon no-given
  Funcon left-to-right-map
  Funcon interleave-map
  Funcon left-to-right-filter
  Funcon interleave-filter
  Funcon fold-left
  Funcon fold-right
]

### Binding
[
  Type     environments       Alias envs
  Datatype identifiers        Alias ids
  Funcon   identifier-tagged  Alias id-tagged
  Funcon   fresh-identifier
  Entity   environment        Alias env
  Funcon   bind-value         Alias bind
  Funcon   unbind
  Funcon   bound-value        Alias bound
  Funcon   bound-link
  Funcon   closed
  Funcon   scope
  Funcon   accumulate
  Funcon   bind-recursively
  Funcon   recursive
]

### Generating
[
  Type   atoms
  Entity used-atom-set
  Funcon fresh-atom
  Funcon use-atom-not-in
]

### Storing
[
  Datatype variables                     Alias vars
  Funcon   variable                      Alias var
  Type     stores
  Entity   store
  Funcon   clear-store
  Funcon   fresh-variable                Alias fresh-var
  Funcon   allocate-variable             Alias alloc-var
  Funcon   de-allocate-variable          Alias de-alloc-var
  Funcon   initialise-variable           Alias init
  Funcon   allocate-initialised-variable
  Funcon   assign-variable-value         Alias assign
  Funcon   assigned-variable-value       Alias assigned
  Funcon   current-value
  Funcon   un-assign
  Funcon   structural-allocate
  Funcon   structural-assign
  Funcon   structural-assigned
]

### Linking
[
  Datatype links
  Funcon   link
  Funcon   fresh-link
  Funcon   fresh-initialised-link   Alias fresh-init-link
  Funcon   set-link
  Funcon   follow-if-link
]

### Interacting

#### Input
[
  Entity standard-in
  Funcon read
]

#### Output
[
  Entity standard-out
  Funcon print
]

## Abnormal computation

### Sticking
[
  Funcon stuck
]

### Failing
[
  Datatype signals
  Funcon   signal
  Entity   failure
  Funcon   fail
  Funcon   else
  Funcon   check-true
  Funcon   definitely   Alias def
]

### Throwing
[
  Entity thrown
  Funcon throw
  Funcon handle-thrown
  Funcon handle-recursively
  Funcon finally
]

### Continuing
[
  Entity control-signal
  Entity resume-signal
  Funcon control
  Funcon prompt
  Funcon hole
  Funcon plug
]

// Concurrent computation to be added
```

Granularity

Funcons are *individual* programming constructs

- *not deltas*
- *not language features*
- *not language extensions*

Funcons can be *freely* combined

- *independent, unordered, no constraints*

CBS: component-based semantics

Component-based semantics

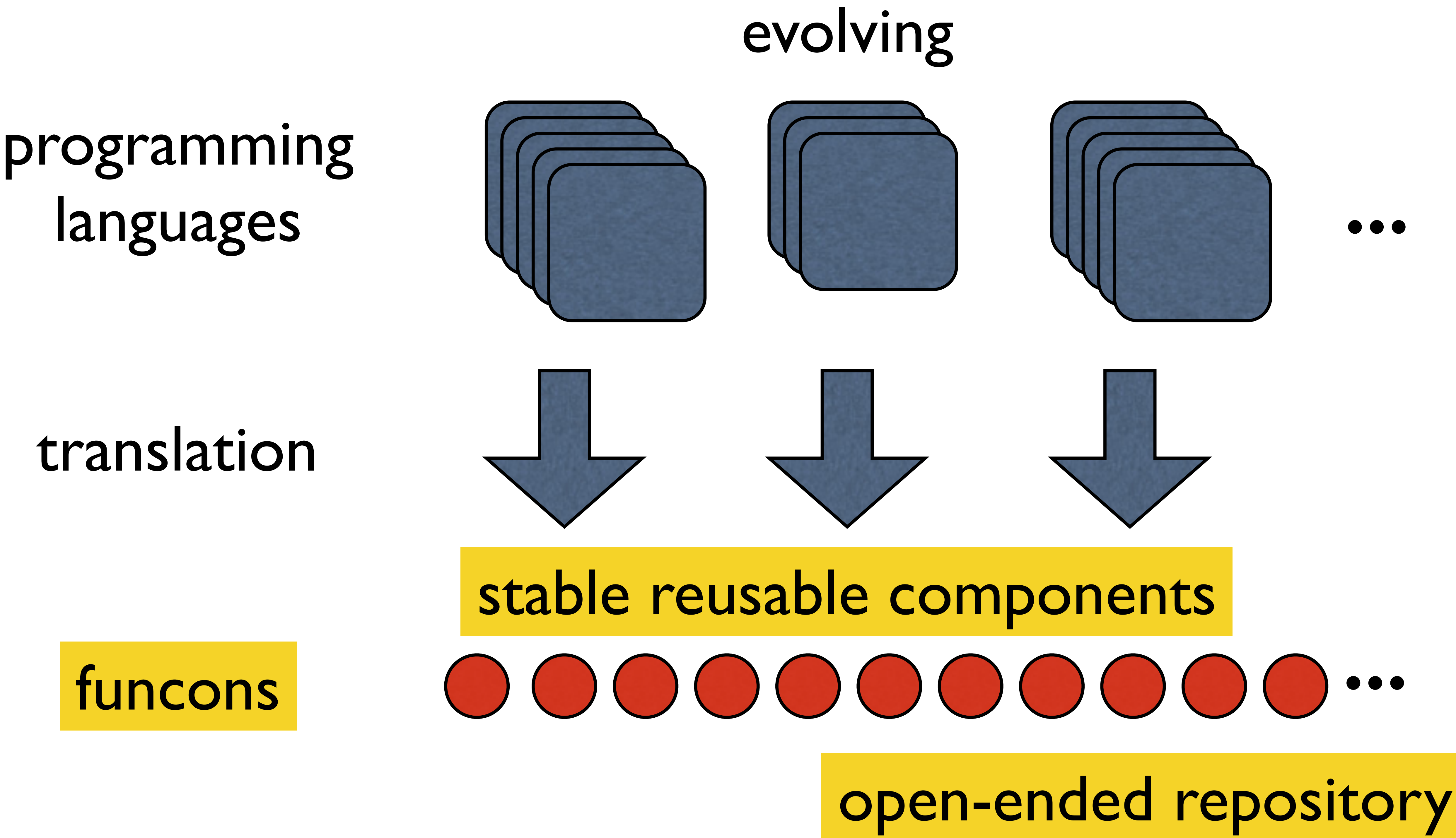
Language semantics by reduction

- *translation:* language constructs → funcon terms, ***hence:***
- *derivation:* funcon semantics → language semantics

Reusable components of language specifications

- *funcon specifications*

Component-based semantics



Conjecture

Using a ***component-based*** semantic meta-language can significantly reduce the effort of language specification

Language specification in CBS

Syntax

```
E : exp ::= ... | 'let' id '=' exp 'in' exp | ...
```

Semantics

```
eval[[ _ : exp ]] : =>values
```

Rule

```
eval[[ 'let' I '=' E1 'in' E2 ]] =
  scope ( bind ( I, eval[[E1]] ), eval[[E2]] )
```

Language specification in CBS

Syntax

```
  S : stm ::= ... | 'while' '(' exp ')' stm | ...
```

Semantics

```
  exec[[ _ : stm ]] : =>no-value
```

Rule

```
  exec[[ 'while' '(' E ')' S ]] =
                 while-true (
                              eval[[E]],
                    exec[[S]] )
```

Language specification in CBS
co-evolution

Syntax

```
  S : stm ::= ... | 'while' '(' exp ')' stm | ...
```

Semantics

```
  exec[[ _ : stm ]] : =>no-value
```

Rule

```
  exec[[ 'while' '(' E ')' S ]] =
                    while-true (
                       not is-eq ( eval[[E]], 0 ),
                       exec[[S]] )
```

Language specification in CBS

co-evolution

```
Syntax
  S : stm ::= ... | 'while' '(' exp ')' stm | 'break' | ...

Semantics
  exec[[ _ : stm ]] : =>no-value

Rule
  exec[[ 'while' '(' E ')' S ]] =
    handle-break while-true (
                   not is-eq ( 0, eval[[E]] ),
                   exec[[S]] )

Rule
  exec[[ 'break' ]] = break
```

Version control?

Funcons never change!

- *no versioning*
- *optimal reusability*

Languages evolve

- *ordinary version control*
- *no support for language reuse/extension/composition*

Tool support

CBS tool support

implemented in SPOOFAX (v2.4)

CBS-Editor

- for developing language and funcon specifications
- CBS parser (in SDF3)
- CBS name resolution, arity-checking (in NABL2)
- HTML generation (in STRATEGO, CSS)
- language-editor generation (in STRATEGO)

CBS tool support

main features

Generated Language-Editors

- program parsing and translation to funcons

Integrated external HASKELL tools

- generation of funcon interpreters

Internal DYNSEM tools

- generation of funcon interpreters

Demo

Demo of current CBS tool

Browsing/editing CBS specifications

- languages and funcons

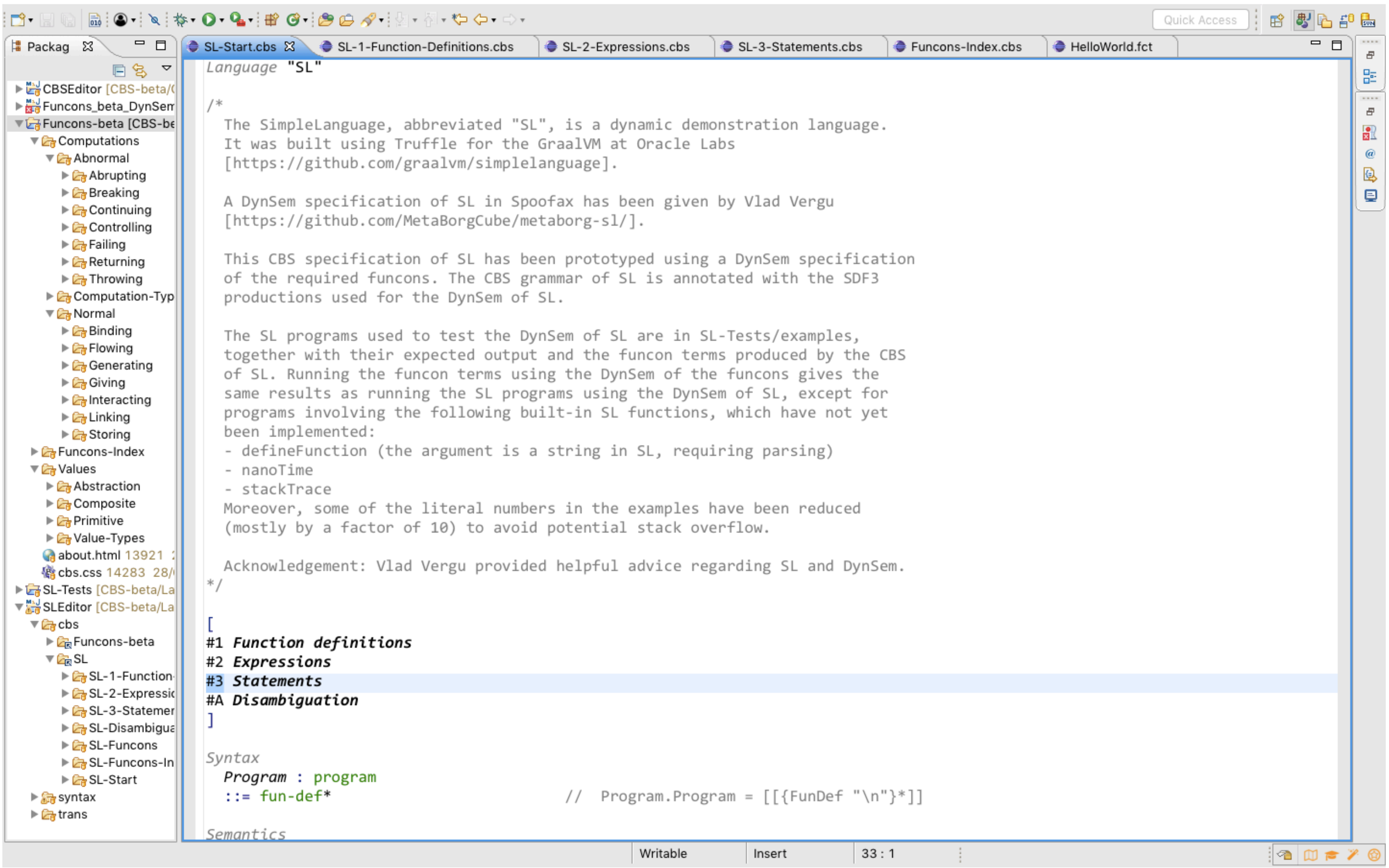
Translating programs to funcons

- using generated STRATEGO code

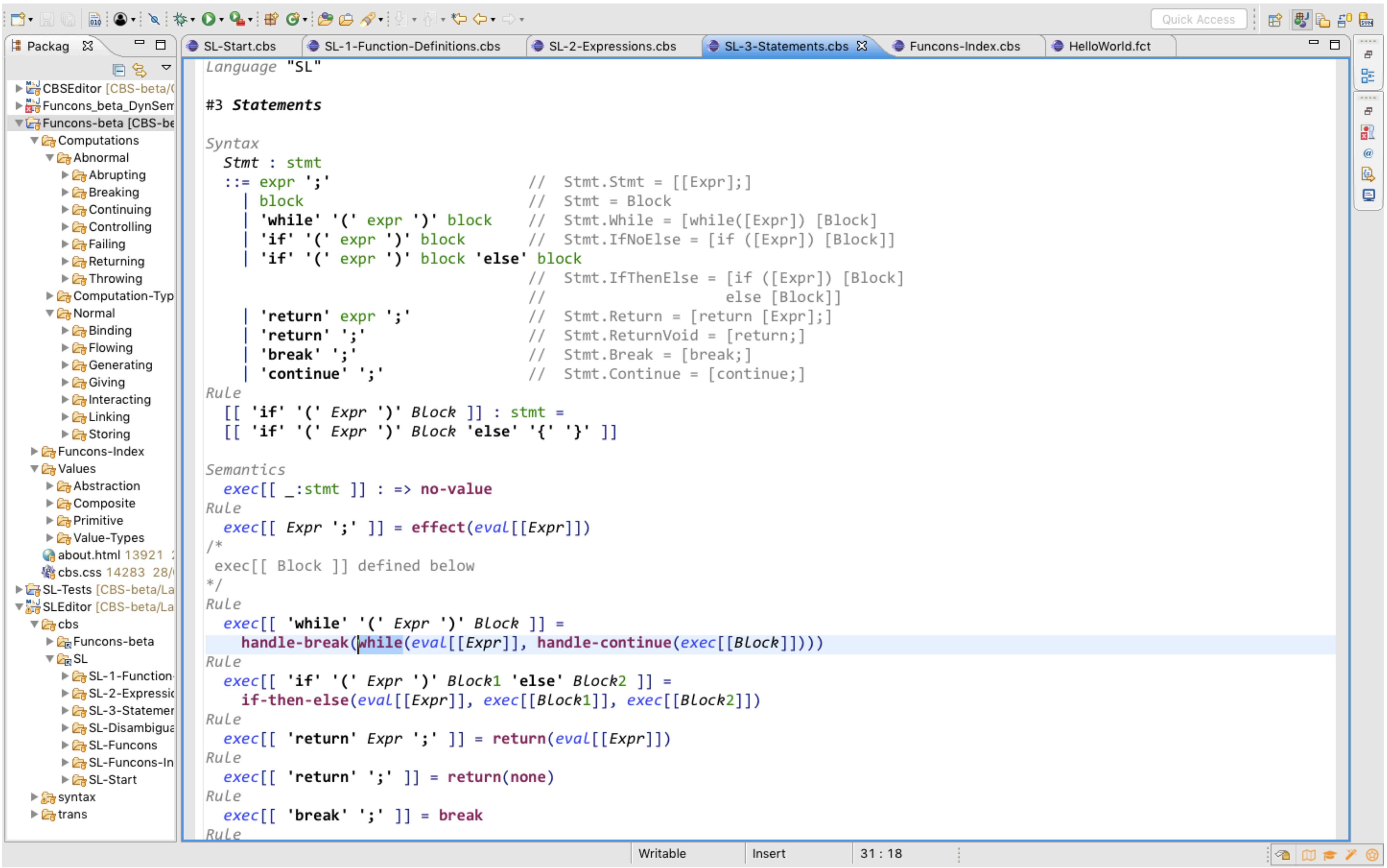
'Running' programs by interpreting funcons

- using generated HASKELL or specified DYNSEM

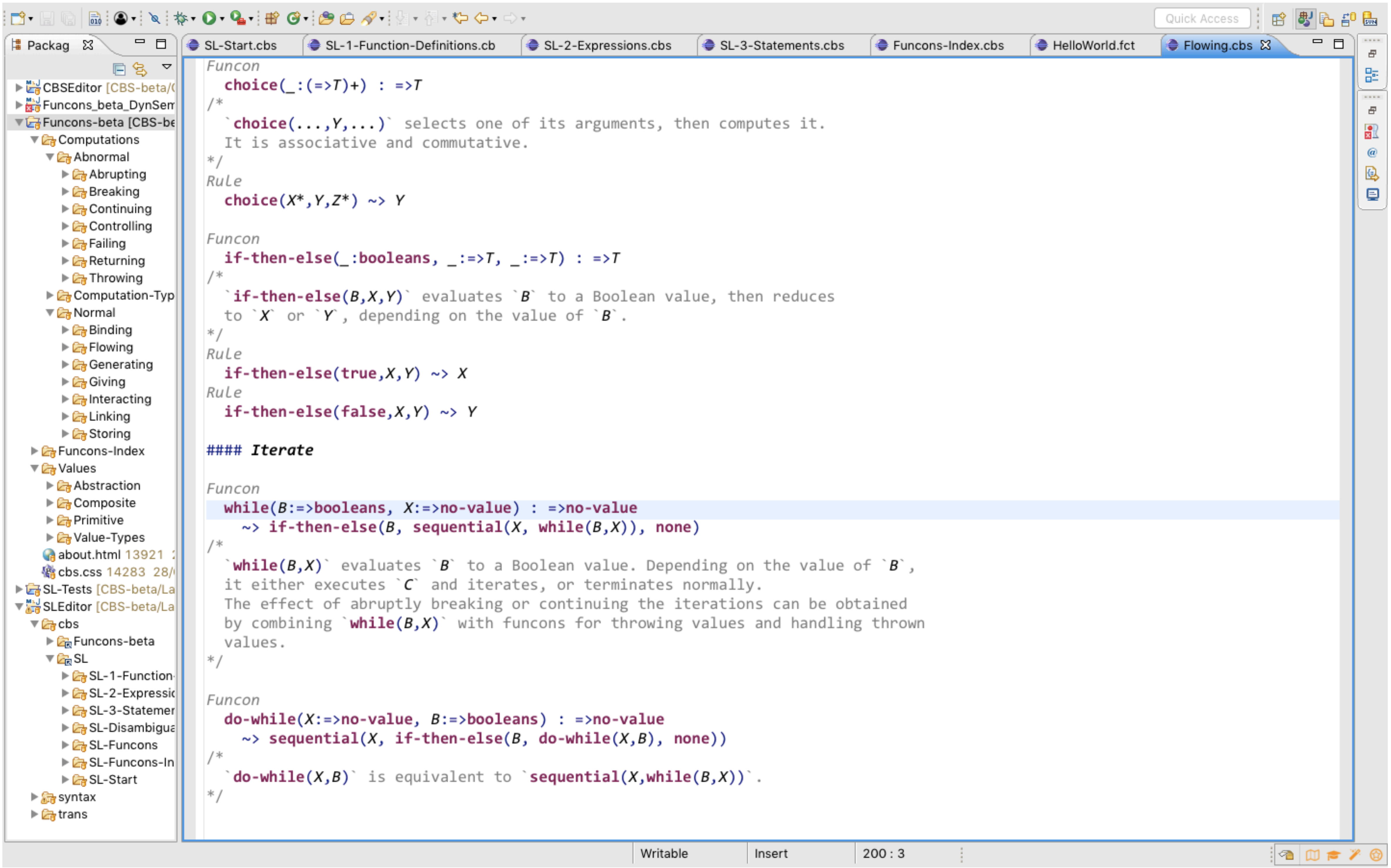
Demo: language specification



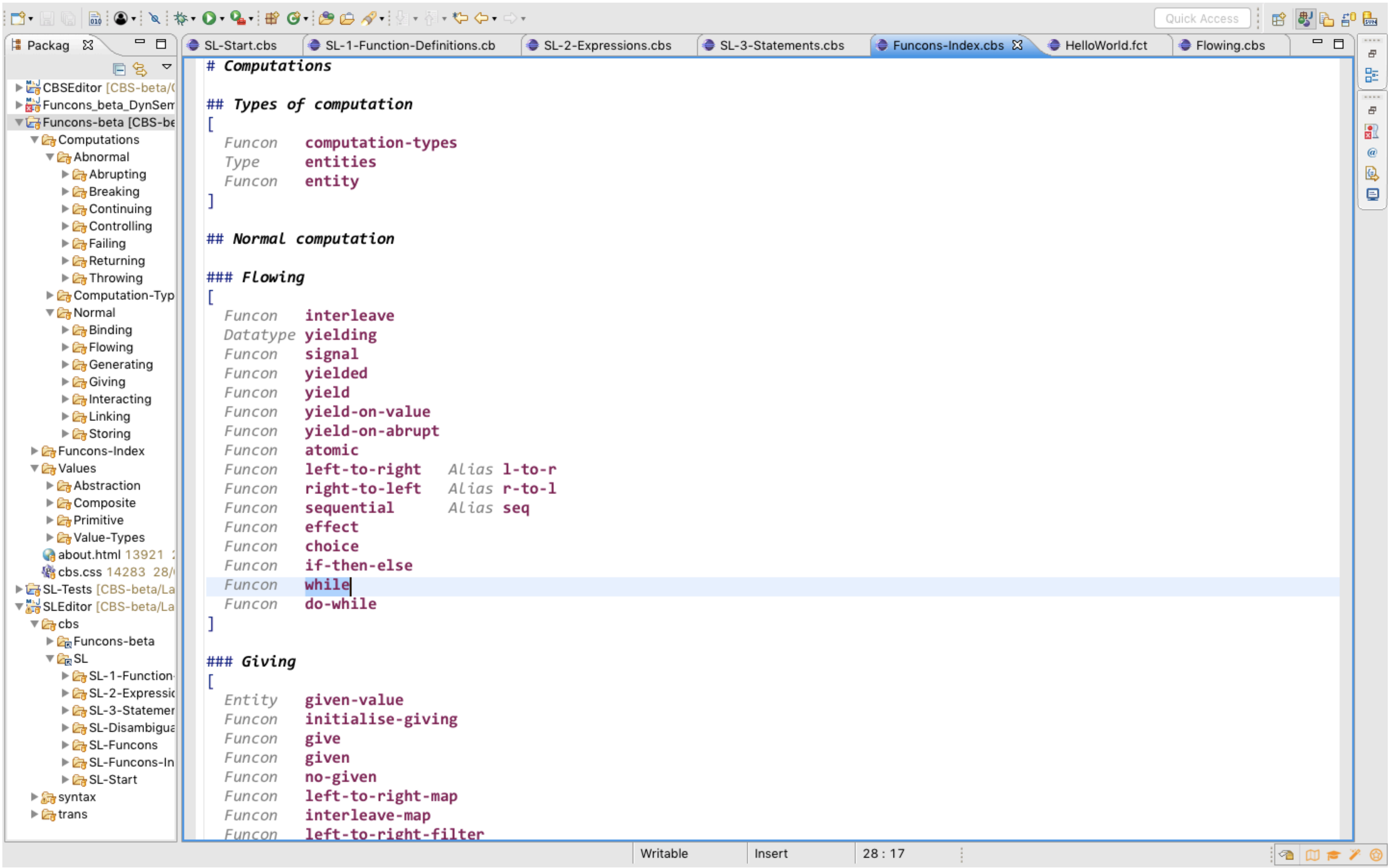
Demo: funcon reference



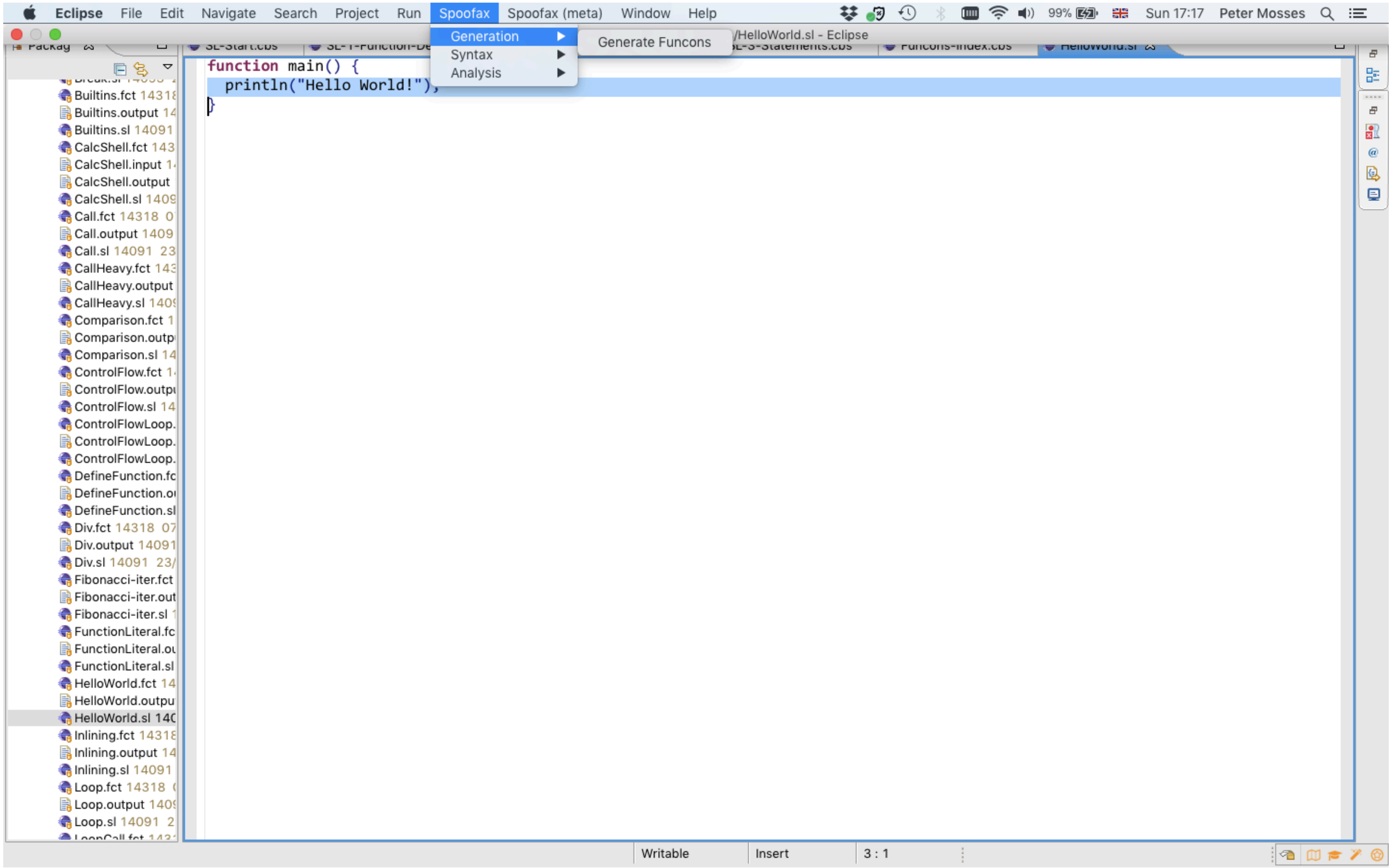
Demo: funcon specification



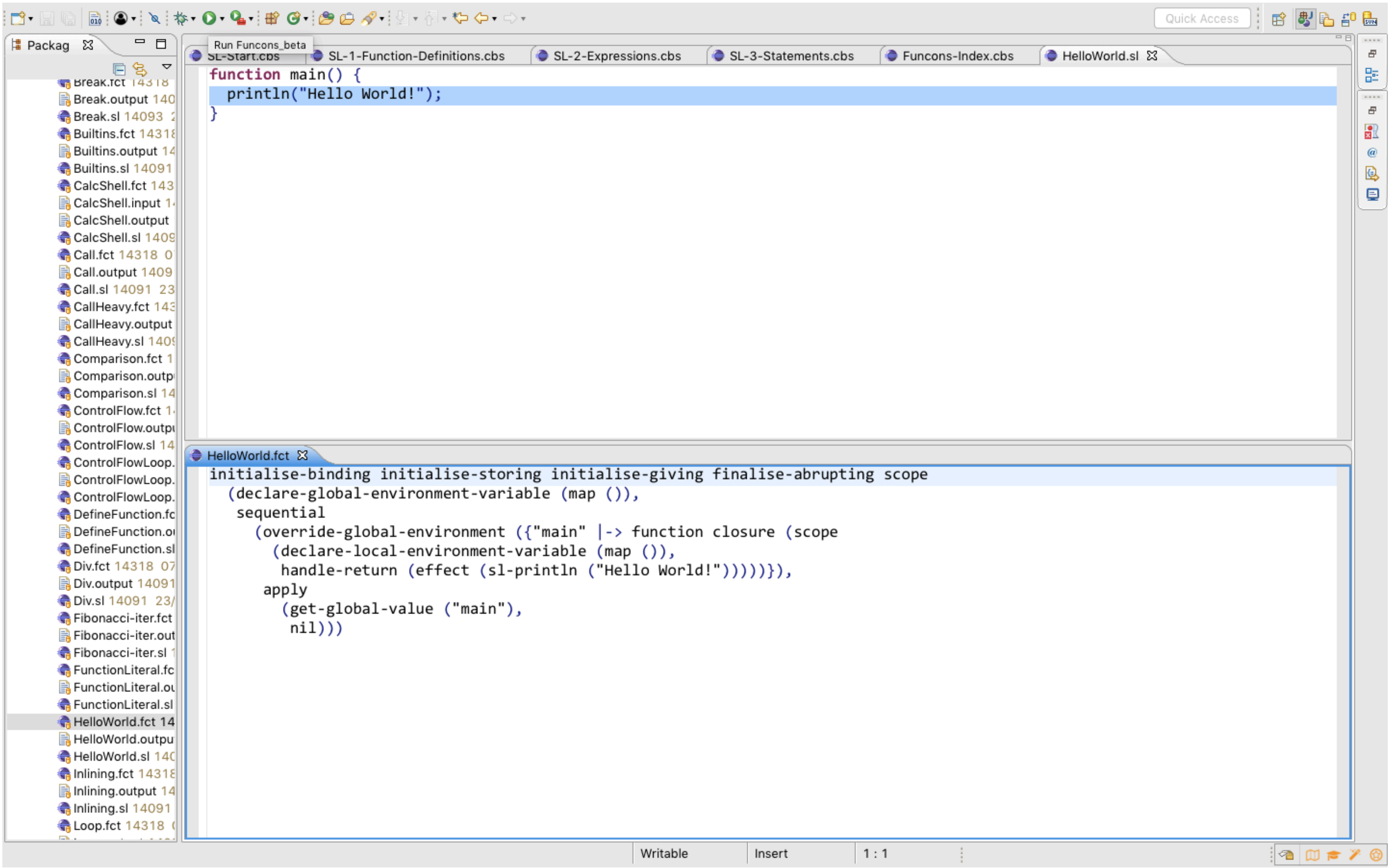
Demo: funcon index



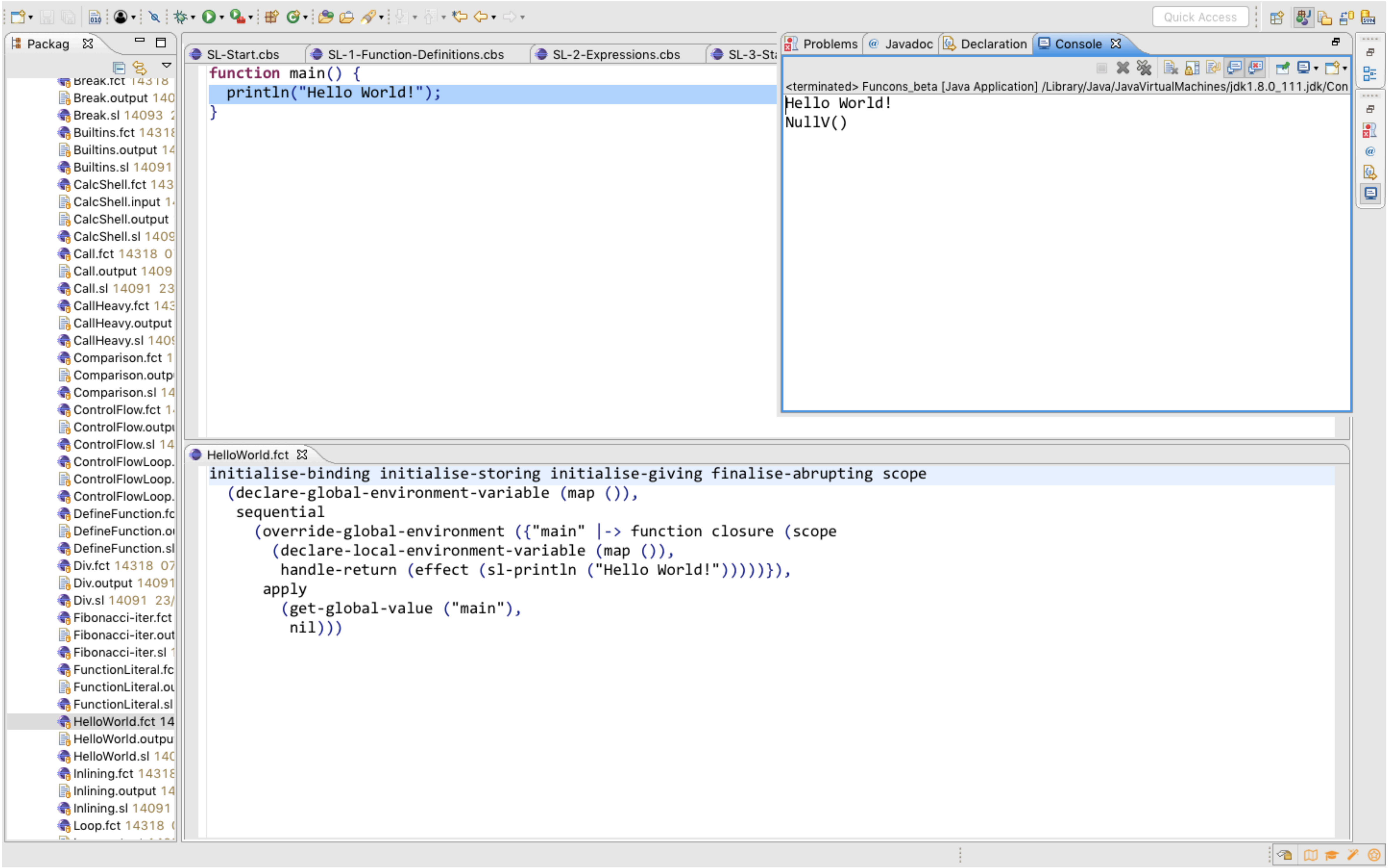
Demo: translation to funcons



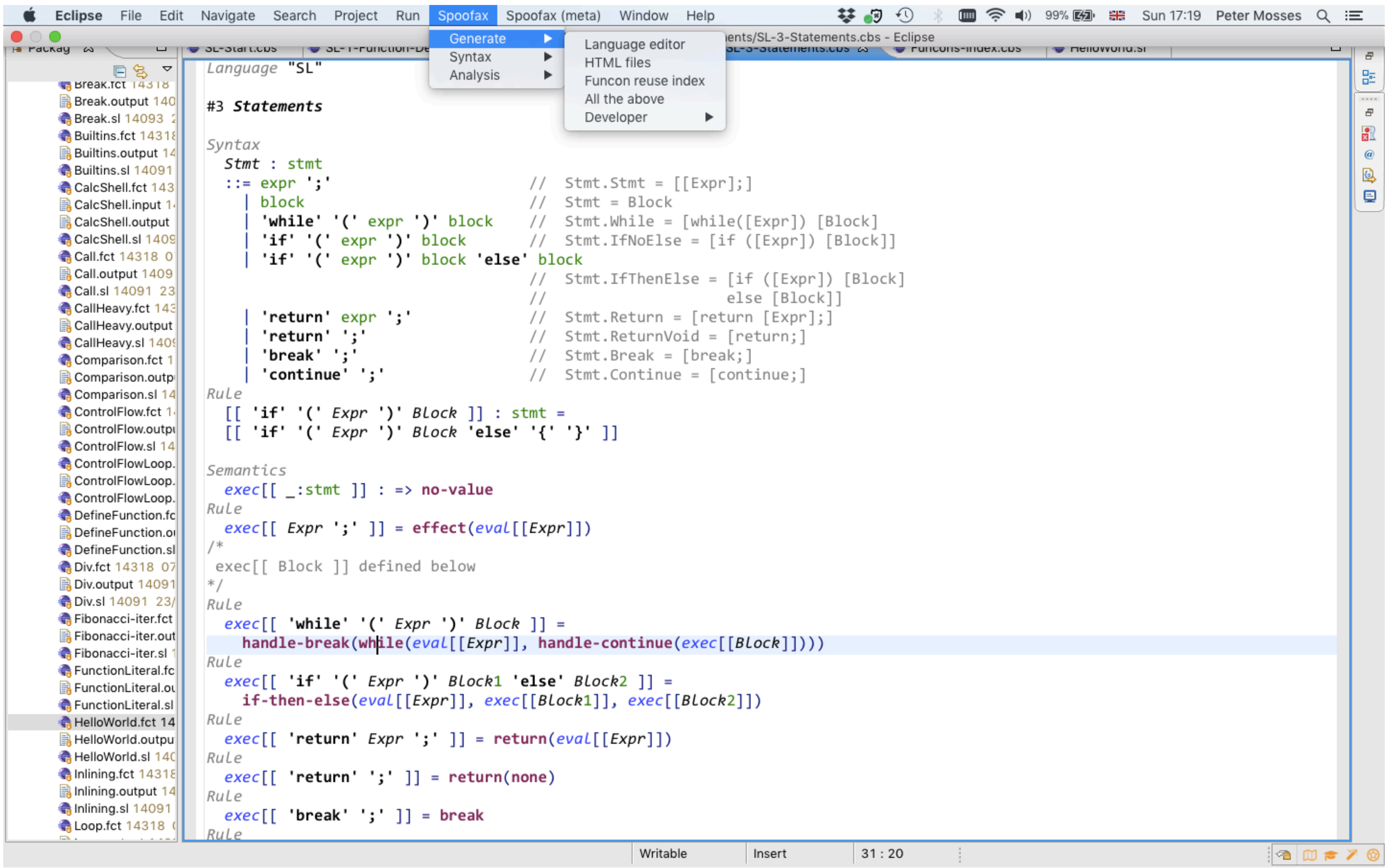
Demo: running funcons



Demo: resulting behaviour

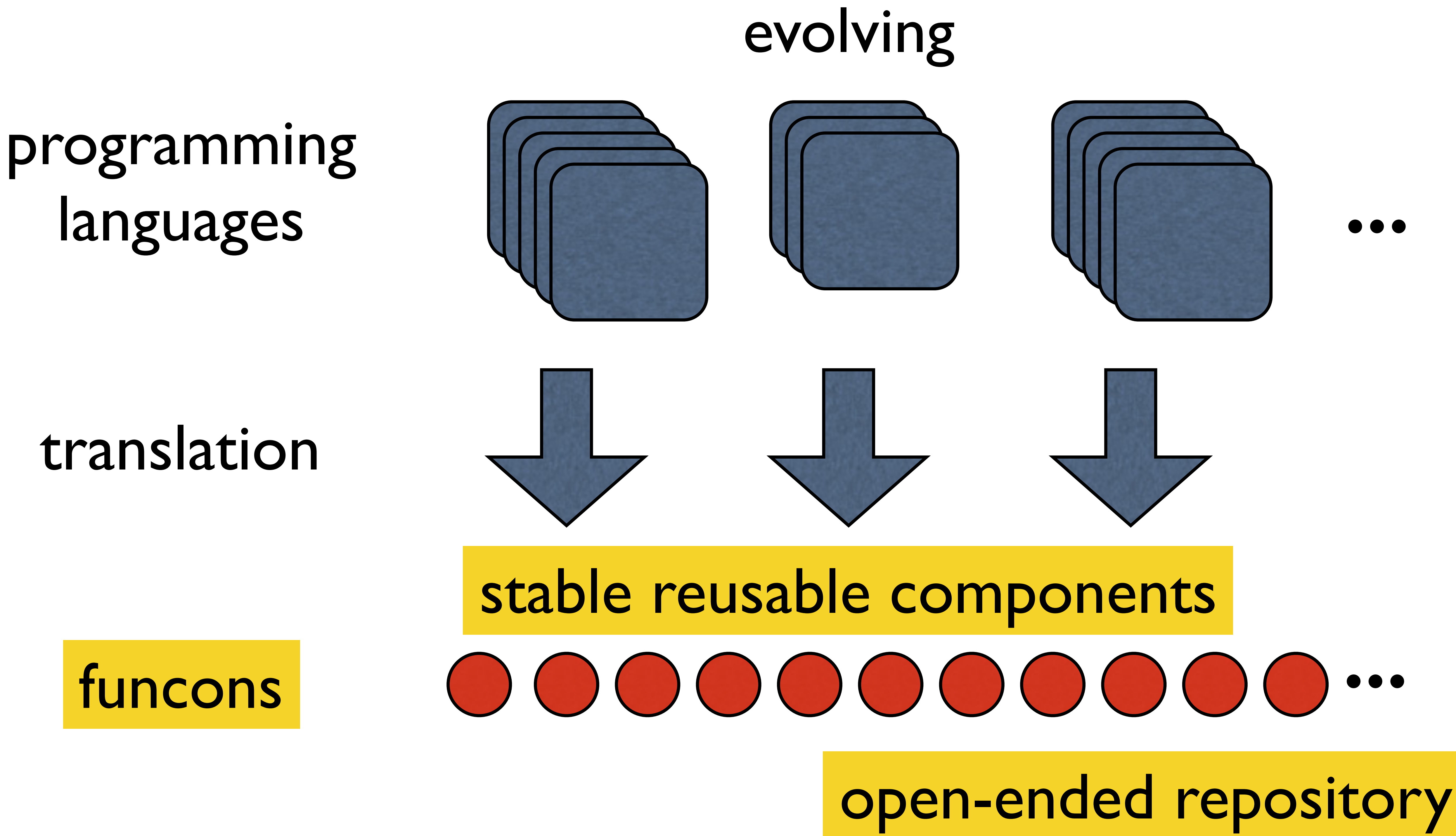


Demo: (re)generating



Conclusion

Language specification in CBS



Conjecture

Using a ***component-based*** semantic meta-language can significantly reduce the effort of language specification

Proving the conjecture

Case studies

- Various small example languages (IMP, SIMPLE, SL, MJ, …)
- CAML LIGHT
  - *Reusable components of semantic specifications* in *Trans. AOSD XII*, Springer, 2015
- C# (v1.2)
  - ongoing…

Funcons beta-release

(imminent…🙄)

2018(Q1): **Funcons-beta** to be made available **for review**

- *some details may change !*
- preliminary tool support, minimal documentation

2018(Q3/Q4): **Funcons** to be **released for reuse**

- *details will **not** be allowed to change !!*
- usable tool support, user-level documentation

PLANCOMPS

www.plancomps.org

“Programming Language Components and Specifications”

Funded project 2011–16: EPSRC Engineering and Physical Sciences Research Council

- at Swansea, Royal Holloway (RHUL), City, Newcastle

Current participants:

- A. Johnstone, E.A. Scott, L.T. van Binsbergen (RHUL)
  N. Sculthorpe (NTU), C. Bach Poulsen, PDM (Delft)

New participants are welcome !

Current and future work

- ***modular static semantics*** for funcons
  - *modular* type soundness proofs?
- improved ***tool support***
- funcons for ***threads and concurrency***
- completing a ***major case study: C#***

Appendix

Funcon specification in CBS

Normal computation: **flowing**

```
Funcon
  while-true ( _: =>booleans, _: =>no-value ) : =>no-value

Rule
  while-true ( X, Y )
    ~> if-then-else ( X, seq ( Y, while ( X, Y ) ), none)
```

Funcon specification in CBS

Normal computation: **flowing**

```
Funcon
  if-then-else ( _: bools, _: =>T, _: =>T) : =>T

Rule
  if-then-else ( true, X, Y ) ~> X

Rule
  if-then-else ( false, X, Y ) ~> Y
```

Funcon specification in CBS

Normal computation: **flowing**

```
Funcon
  seq ( _: no-value, _: =>T ) : =>T

Rule
  seq ( none, Y ) ~> Y
```

Funcon specification in CBS

Normal computation: **binding**

```
Funcon
  scope( _: envs, _: =>T ) : =>T

Rule
  env(map-override(Rho1,Rho0)) |- X ---> X'
  -----------------------------------------------------
  env(Rho0) |- scope ( Rho1:envs, X ) ---> scope ( Rho1, X')

Rule
  scope ( _:envs, V:T ) ~> V
```

References

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