Reusable Components of Semantic Specifications

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Modularity – A Good Thing!

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Our paper

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- **modular framework**: component-based semantics

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- **modular framework**: component-based semantics
- **preliminary case study**: CAML LIGHT

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  - *Programming Language Components and Specifications*
- **testing component reusability**
  - *major case studies*: C#, JAVA, …
- developing a **language <u>specifier</u>'s workbench**

Component-based semantics

Component-based semantics

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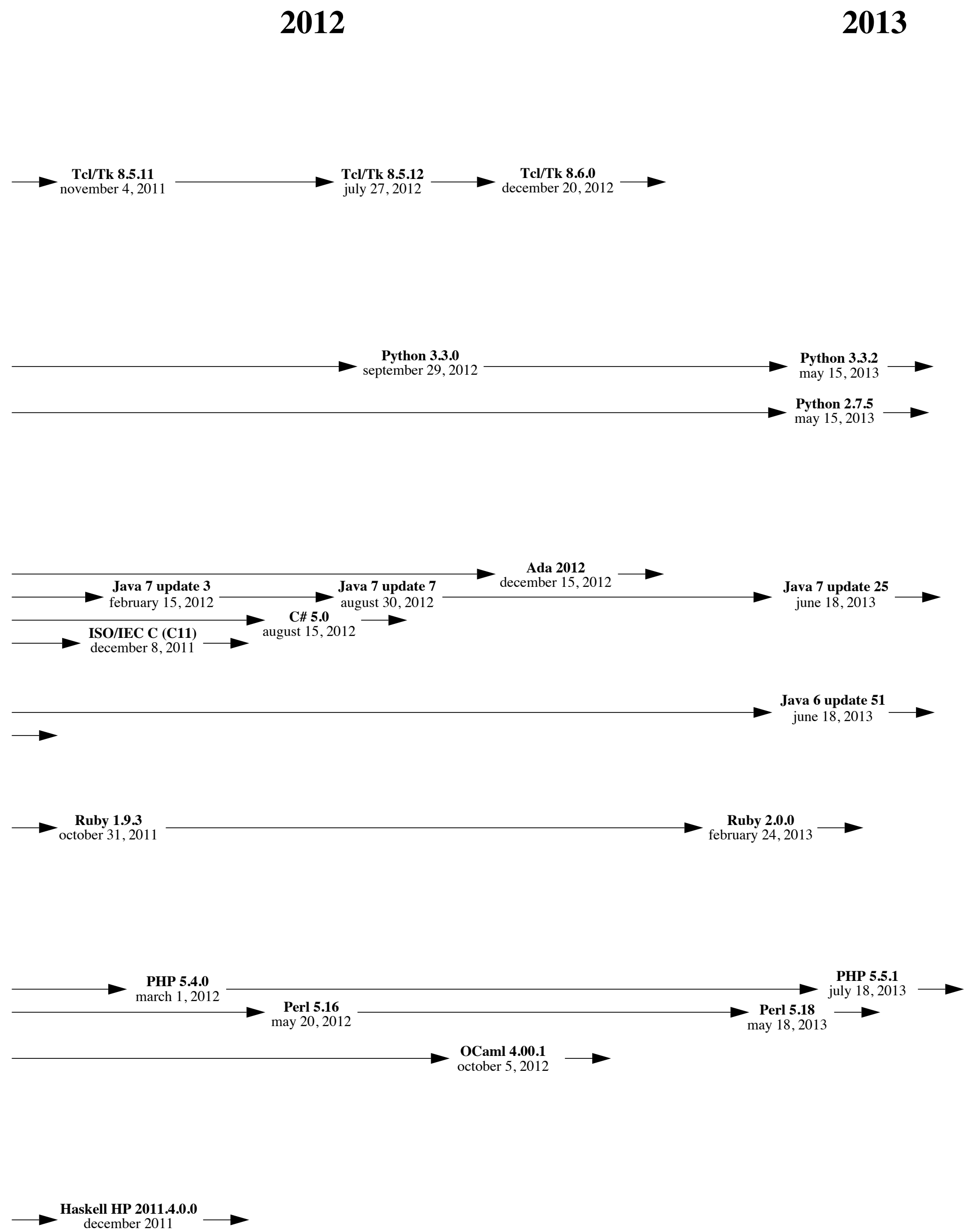
Evolving languages

Component-based semantics



[Éric Lévénez]

Evolving languages

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Fundamental programming constructs (funcons)

Evolving languages

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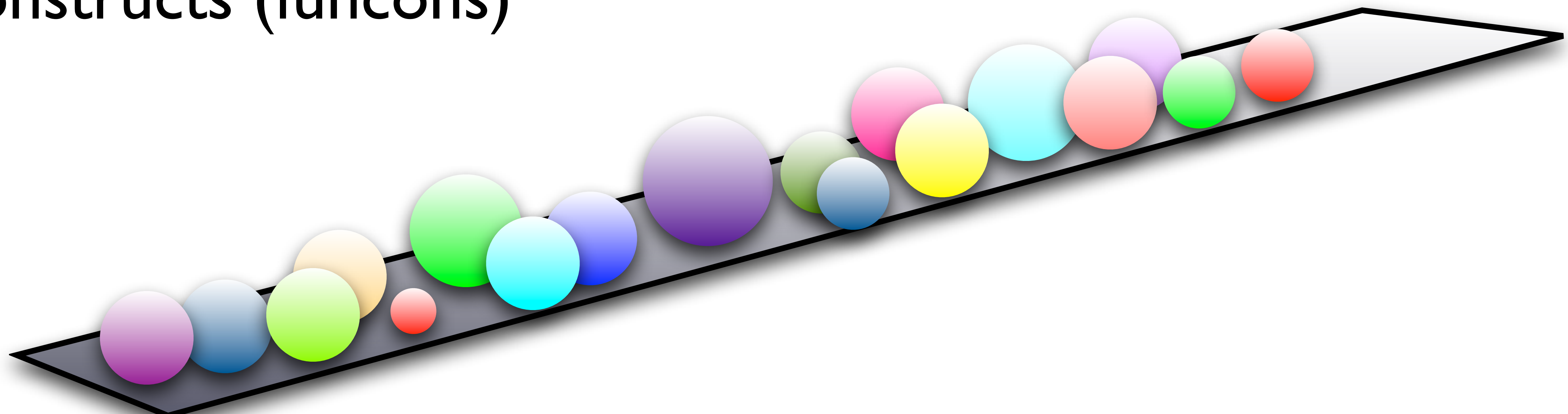

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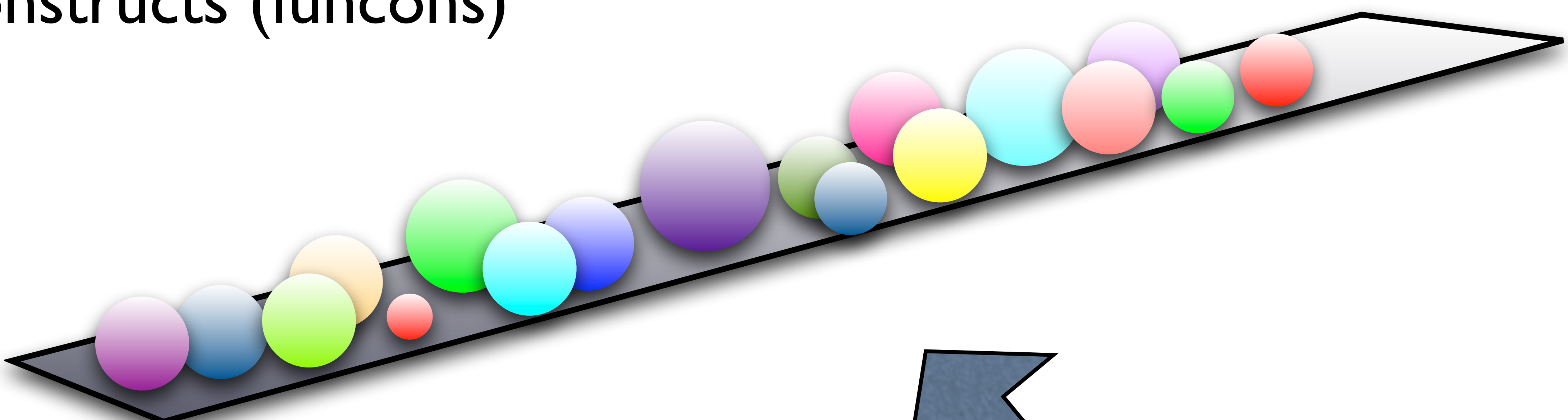

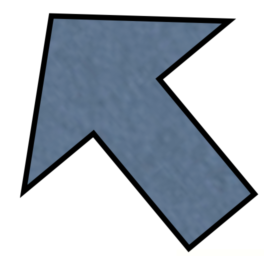

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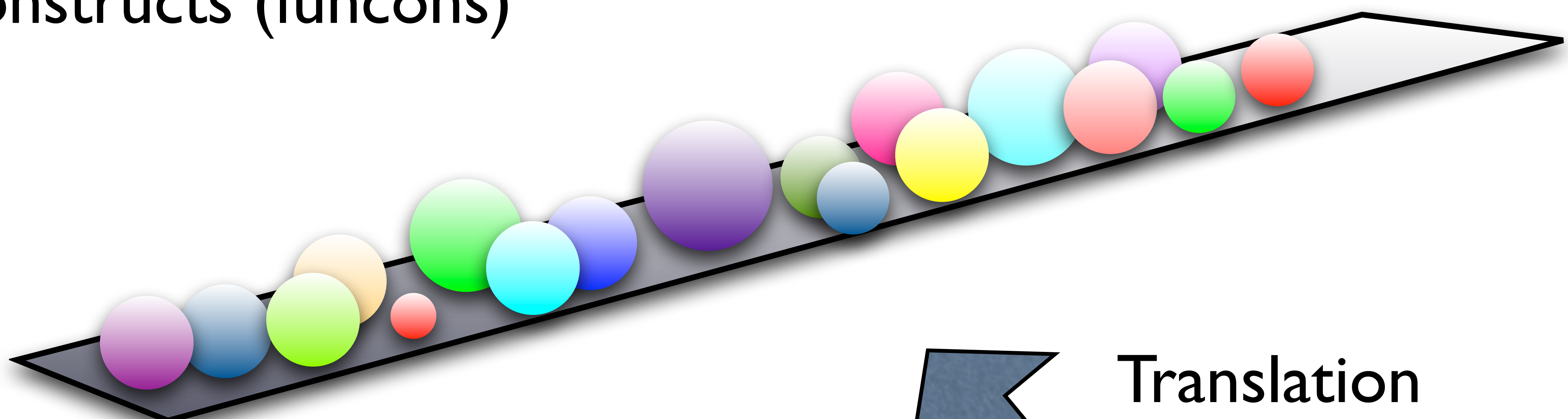

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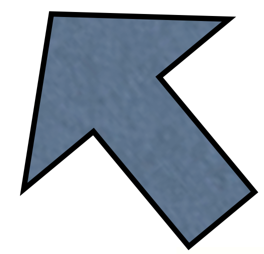

Translation (reduction)

Evolving languages

Reusable components

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Fundamental constructs (funcons)

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- correspond to programming constructs

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  - ***directly*** (**if-true**), or

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  - ***fixed*** notation, and

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specified/proved once and for all!

Component reuse

Component reuse

Language construct:

- *exp* ::= *exp* **?** *exp* **:** *exp*

Component reuse

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Translation to funcons:

- *expr*⟦ E_1 **?** E_2 **:** E_3 ⟧ =
  if-true(*expr*⟦ E_1 ⟧, *expr*⟦ E_2 ⟧, *expr*⟦ E_3 ⟧)

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For languages with non-Boolean tests:

- *expr*⟦ E_1 **?** E_2 **:** E_3 ⟧ =
  if-true(**not**(**equal**(*expr*⟦ E_1 ⟧, 0)),
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Component reuse

Language construct:

- stm ::= **`if(`** exp **`)`** stm **`else`** stm

Translation to funcons:

- $comm[\![$ **`if(`** E_1 **`)`** S_2 **`else`** S_3 $]\!]$ =
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For languages with non-Boolean tests:

destructive change

- *comm*⟦ **`if`** **`(`**E_1**`)`** S_2 **`else`** S_3 ⟧ =
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Component specification

Component specification

Notation

if-true(boolean, comp(T), comp(T)) : comp(T)

Component specification

Notation

$$\textbf{if-true}(\text{boolean}, \text{comp}(T), \text{comp}(T)) : \text{comp}(T)$$

Static semantics

$$\frac{E : \textbf{boolean}, \quad X_1 : T, \quad X_2 : T}{\textbf{if-true}(E, X_1, X_2) : T}$$

Component specification

Notation

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$$\textbf{if-true}(\textbf{true}, X_1, X_2) \rightarrow X_1$$

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Component specification

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Component specification

modular extension

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This talk

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- ***fundamental constructs (funcons)***
  - notation
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Component-based semantics:

- ***translation to funcons***
  - illustrative examples
  - introduction to CAML LIGHT case study

Funcon notation – examples

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Sorts of funcons

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Sorts of funcons

- **comm** – *commands, with effects*

Funcon notation – examples

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- **decl** – *declarations, computing environments*

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Funcon notation – examples

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Funcon notation – examples

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  - *Scala*: $\Rightarrow T$

Funcon notation – examples

Sorts of funcons

- **comm** = **comp(skip)**
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Funcon notation – examples

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  - – *SCALA*: ⇒*T*

Funcon notation – examples

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Funcon notation – examples

Sorts of funcons

- **comm** = **comp(skip)**
- **decl** = **comp(env)**
- **expr** = **comp(value)**
- **...** T <: comp(T)
- **comp(*T*)** – *funcons computing values of type T*
  - SCALA: $\Rightarrow T$

Funcon notation – examples

Funcon notation – examples

Types of values

- **boolean**, **int**, **atom**, …
- **list**(*S*), **map**(*S*, *T*), …
- **array**, **record**, **tuple**, …
- **abs**(*S*, *T*)
  - **func** = **abs**(value, env), **patt** = **abs**(value, env), …

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Abstract types (language-dependent)

- **value**, **env**, **var**, **store**, …

Funcon notation – examples

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Control flow funcons – comm = comp(skip)

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Control flow funcons – comm = comp(skip)

- **seq**(skip, comp(*T*)) : comp(*T*)

Funcon notation – examples

Control flow funcons – comm = comp(skip)

- **seq**(skip, comp(T)) : comp(T)
- **skip** : skip

Funcon notation – examples

Control flow funcons – comm = comp(skip)

- **seq**(skip, comp(*T*)) : comp(*T*)
- **skip** : skip
- **if-true**(boolean, comp(*T*), comp(*T*)) : comp(*T*)

Funcon notation – examples

Control flow funcons – comm = comp(skip)

- **seq**(skip, comp(*T*)) : comp(*T*)
- **skip** : skip
- **if-true**(boolean, comp(*T*), comp(*T*)) : comp(*T*)
- **while-true**(comp(boolean), comm) : comm

Funcon notation – examples

Control flow funcons – comm = comp(skip)

- **seq**(skip, comp(T)) : comp(T)
- **skip** : skip
- **if-true**(boolean, comp(T), comp(T)) : comp(T)
- **while-true**(comp(boolean), comm) : comm

value sorts

Funcon notation – examples

Funcon notation – examples

Binding and scoping funcons – decl = comp(env)

- **scope**(env, comp(*T*)) : comp(*T*)
- **bind-value**(id, value) : env
- **bound-value**(id) : expr

Funcon notation – examples

Binding and scoping funcons – decl = comp(env)

- **scope**(env, comp(*T*)) : comp(*T*)
- **bind-value**(id, value) : env
- **bound-value**(id) : expr

Function abstraction and application

- **abs**(patt, expr) : func
- **apply**(func, value) : expr
- **close**(func) : comp(func)

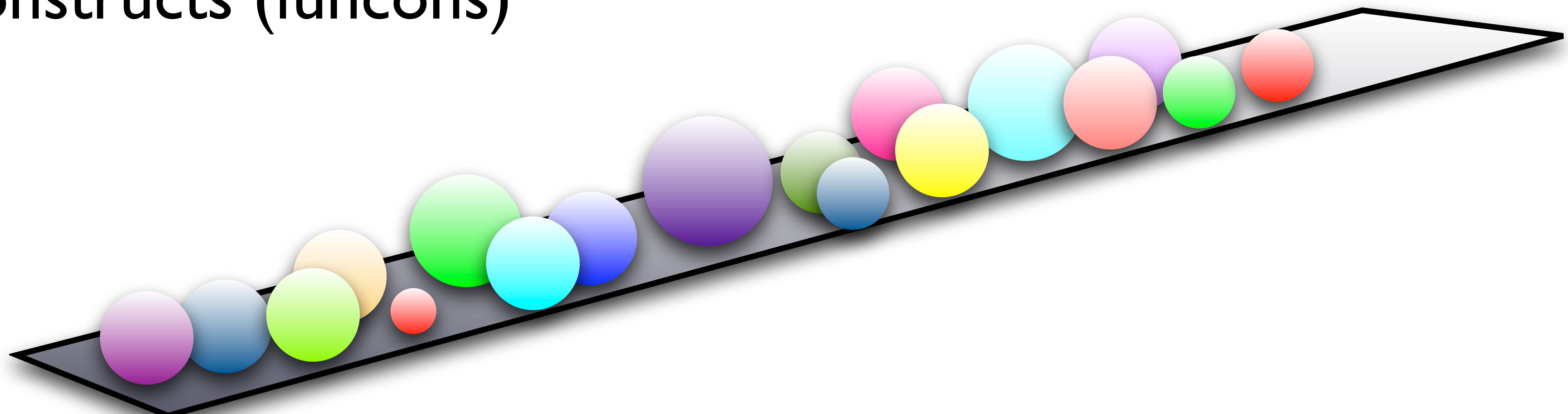
Funcon notation – examples

Storing funcons

- **allocate**(value) : comp(var)
- **assigned-value**(var) : expr
- **assign**(var, value) : comm

Funcon notation

Fundamental programming constructs (funcons)



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- ***fundamental constructs (funcons)***
  - ✓ notation
  - ➡ semantics

Component-based semantics:

- ***translation to funcons***
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Funcon semantics – format

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Notation *(algebraic signature):*

$$\textbf{\textit{Funcon}}(Sort_1, \ldots) : \; Sort$$

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Notation *(algebraic signature):*

$$\textbf{\textit{Funcon}}(\mathit{Sort}_1, \ldots) : \ \mathit{Sort}$$

Static semantics *(context-sensitive)*

$$\frac{\Gamma_1 \vdash \mathit{Var}_1 : \mathit{Type}_1, \quad \ldots}{\Gamma \vdash \textbf{\textit{Funcon}}(\mathit{Var}_1, \ldots) : \mathit{Type}}$$

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$$\frac{\Gamma_1 \vdash \mathit{Var}_1 : \mathit{Type}_1, \quad \ldots}{\Gamma \vdash \textbf{Funcon}(\mathit{Var}_1, \ldots) : \mathit{Type}}$$

Dynamic semantics *(transition system)*

$$\frac{\rho' \vdash (\mathit{Var}, \sigma) \rightarrow (\mathit{Var}', \sigma')}{\rho \vdash (\textbf{Funcon}(\mathit{Term}_1, \ldots), \sigma) \rightarrow (\mathit{Term}', \sigma')}$$

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Notation *(algebraic signature):*

$$\textbf{Funcon}(Sort_1, \ldots) : \ Sort$$

Static semantics *(context-sensitive)*

$$\frac{Var_1 : Type_1, \quad \ldots}{\textbf{Funcon}(Var_1, \ldots) : Type}$$

Dynamic semantics *(transition system)*

$$\frac{Var \quad \rightarrow \quad Var'}{\textbf{Funcon}(Term_1, \ldots) \quad \rightarrow \quad Term'}$$

Funcon semantics – features

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Aims:

- stable
- concise
- modular

Funcon semantics – features

Aims:

- stable
- concise
- modular

Means:

- ***I-MSOS*** – implicit propagation of auxiliary entities
- ***lifting*** – implicit rules for computing expression values
- ***rule format*** – bisimulation congruence, preservation

Funcon semantics – examples

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if-true(boolean, comp(*T*), comp(*T*)) : comp(*T*)

Funcon semantics – examples

if-true(boolean, comp(T), comp(T)) : comp(T)

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Implicit!

Funcon semantics – examples

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$\mathbf{seq}(\mathrm{skip}, \mathrm{comp}(T)) : \mathrm{comp}(T)$

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$$\textbf{seq}(\textbf{skip}, X) \to X$$

Funcon semantics – examples

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Funcon semantics – examples

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Implicit!

Funcon semantics – examples

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bound-value(id) : expr

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$$\text{env } \Gamma \vdash \textbf{bound-value}(I) : \Gamma(I)$$

Funcon semantics – examples

bound-value(id) : expr

env $\Gamma \vdash$ **bound-value**(I) : $\Gamma(I)$

env $\rho \vdash$ **bound-value**(I) $\rightarrow$ $\rho(I)$

Funcon semantics – examples

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scope(env, comp(T)) : comp(T)

Funcon semantics – examples

$$\mathbf{scope}(\mathrm{env}, \mathrm{comp}(T)) : \mathrm{comp}(T)$$

$$\frac{\mathrm{env}\ \Gamma \vdash D : \Gamma_1, \qquad \mathrm{env}\ (\Gamma_1/\Gamma) \vdash X : T}{\mathrm{env}\ \Gamma \vdash \mathbf{scope}(D, X) : T}$$

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Implicit!

This talk

Reusable components:

- ***fundamental constructs (funcons)***
  - ✓ notation
  - ✓ semantics

Component-based semantics:

- ***translation to funcons***
  - ➡ illustrative examples
  - \- introduction to CAML LIGHT case study

Language specifications

Language specifications

Syntax

- context-free
- concrete ↔ abstract

Language specifications

Syntax

- context-free
- concrete ↔ abstract

Semantics

- *translation*⟦ *abstract syntax sort* ⟧ : **funcon sort**
- specified inductively by equations
- induces both static and dynamic semantics
  - *relationship adjustable by adding 'static funcons'*

Component-based semantics – examples

Component-based semantics – examples

Translation function

Component-based semantics – examples

Translation function

- $\mathit{comm}[\![\ \mathit{stm}\ ]\!] : \mathbf{comm}$

Component-based semantics – examples

Translation function

- $comm[\![\ stm\ ]\!] : \mathbf{comm}$

Translation equations

Component-based semantics – examples

Translation function

- *comm*⟦ *stm* ⟧ : **comm**

Translation equations

- *stm* ::= **{ }**

Component-based semantics – examples

Translation function

- *comm*⟦ *stm* ⟧ : **comm**

Translation equations

- *stm* ::= **{ }**
  - *comm*⟦ **{ }** ⟧ = **skip**

Component-based semantics – examples

Translation function

- *comm*⟦ *stm* ⟧ : **comm**

Translation equations

- *stm* ::= **{ }**
  - *comm*⟦ **{ }** ⟧ = **skip**
- *stm* ::= *stm* stm^+

Component-based semantics – examples

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Translation equations

- $\textit{stm} ::= \texttt{\{ \}}$
  - $\textit{comm}[\![\ \texttt{\{ \}}\ ]\!] = \textbf{skip}$
- $\textit{stm} ::= \textit{stm}\ \textit{stm}^{+}$
  - $\textit{comm}[\![\ S_1\ S_2 \ldots\ ]\!] = \textbf{seq}(\textit{comm}[\![\ S_1\ ]\!], \textit{comm}[\![\ S_2 \ldots\ ]\!])$

Component-based semantics – examples

Component-based semantics – examples

Translation functions

- *comm*⟦ *stm* ⟧ : **comm**
- *expr*⟦ *exp* ⟧ : **expr**

Component-based semantics – examples

Translation functions

- *comm*⟦ *stm* ⟧ : **comm**
- *expr*⟦ *exp* ⟧ : **expr**

Translation equations

- *stm* ::= **`if`**`(`*exp*`)` *stm* **`else`** *stm*
  - *comm*⟦ **`if`**`(`*E*`)` S_1 **`else`** S_2 ⟧ =
    if-true(*expr*⟦ *E* ⟧, *comm*⟦ S_1 ⟧, *comm*⟦ S_2 ⟧)
- *stm* ::= **`if`**`(`*exp*`)` *stm*
  - *comm*⟦ **`if`**`(`*E*`)` *S* ⟧ = *comm*⟦ **`if`**`(`*E*`)` *S* **`else`** `{}` ⟧

Component-based semantics – examples

Translation functions

- *comm*⟦ *stm* ⟧ : **comm**
- *expr*⟦ *exp* ⟧ : **expr**

Translation equations

- *stm* ::= *id* **=** *exp* **;**
  - *comm*⟦ *I* **=** *E* **;** ⟧ =
    assign(**bound-value**(*I*), *expr*⟦ *E* ⟧)
- *exp* ::= *id*
  - *expr*⟦ *I* ⟧ = **assigned-value**(**bound-value**(*I*))

This talk

Reusable components:

- ***fundamental constructs (funcons)***
  - ✓ notation
  - ✓ semantics

Component-based semantics:

- ***translation to funcons***
  - ✓ illustrative examples
  - ➡ introduction to CAML LIGHT case study

Case study: CAML LIGHT

A pedagogical functional programming language

- a sub-language of CAML
  - *some constructs differ a bit from OCAML*
- similar to the Core of STANDARD ML
  - *except for order of evaluation!*
- higher-order, polymorphic, pattern-matching, …
- references, mutable arrays, mutable record fields, …
- abstract syntax defined in the reference manual

Case study: CAML LIGHT

Introduction

- section 3 of the paper

Full specification

- available online [www.plancomps.org/churchill2014]

(Incomplete) validation using test programs

- parser generated from abstract syntax grammar (in SDF2)
- translation to funcons implemented (in ASF+SDF)
- interpreter (in PROLOG) generated from I-MSOS rules

Needs polishing and further testing...

Conclusion

Conclusion

Funcons – A Good Thing!

- **reusable components** of semantic specifications
- each funcon **specified once and for all**
  - *I-MSOS, lifting, implicit rules*
- optimal(?) **abstraction level**
  - *simple translations*
  - *simple rules*

Conclusion

Funcons – A Good Thing!

- **reusable components** of semantic specifications
- each funcon **specified once and for all**
  - *I-MSOS, lifting, implicit rules*
- optimal(?) **abstraction level**
  - *simple translations*
  - *simple rules*

But further case studies are needed to prove it

- C#, JAVA, DSLs, **...**

Appendix

Funcon semantics – examples

assigned-value(var) : expr

$$\frac{E : \textbf{var}(T)}{\textbf{assigned-value}(E) : T}$$

$$(\textbf{assigned-value}(V), \text{store } \sigma) \rightarrow (\sigma(V), \text{store } \sigma)$$

$$\frac{E \rightarrow E'}{\textbf{assigned-value}(E) \rightarrow \textbf{assigned-value}(E')}$$

Implicit!

Funcon semantics – examples

assign(var, value) : expr

$$\frac{E_1 : \textbf{var}(T), \qquad E_2 : T}{\textbf{assign}(E_1, E_2) : \textbf{comm}}$$

$$(\textbf{assign}(V_1, V_2), \text{store } \sigma) \to (\textbf{comm}, \text{store } \sigma[V_1 \mapsto V_2])$$

$$\frac{E_1 \to E_1{}'}{\textbf{assign}(E_1, E_2) \to \textbf{assign}(E_1{}', E_2)}$$

Implicit!

$$\frac{E_2 \to E_2{}'}{\textbf{assign}(E_1, E_2) \to \textbf{assign}(E_1, E_2{}')}$$

Implicit!

Funcon notation – examples

Funcon notation – examples

Data flow funcons

Funcon notation – examples

Data flow funcons

- value <: expr – *computed values*

Funcon notation – examples

Data flow funcons

- value <: expr – *computed values*
- *lifted value operations*

Funcon notation – examples

Data flow funcons

- value <: expr – *computed values*
- *lifted value operations*
  - **not**(boolean) : boolean ➦
    not(expr) : expr

Funcon notation – examples

Data flow funcons

- value <: expr – *computed values*
- *lifted value operations*
  - **not**(boolean) : boolean ➦
    not(expr) : expr
  - **equal**(boolean, boolean) : boolean ➦
    equal(expr, expr) : expr

Funcon notation – examples

Data flow funcons

- value <: expr – *computed values*
- *lifted value operations*
  - **not**(boolean) : boolean ➦
    not(expr) : expr
  - **equal**(boolean, boolean) : boolean ➦
    equal(expr, expr) : expr
- *use of previously computed value*

Funcon notation – examples

Data flow funcons

- value <: expr – *computed values*
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  - **not**(boolean) : boolean ➦
    not(expr) : expr
  - **equal**(boolean, boolean) : boolean ➦
    equal(expr, expr) : expr
- *use of previously computed value*
  - **supply**(expr, comp(*X*)) : comp(*X*)

Funcon notation – examples

Data flow funcons

- value <: expr – *computed values*
- *lifted value operations*
  - **not**(boolean) : boolean ➦
    not(expr) : expr
  - **equal**(boolean, boolean) : boolean ➦
    equal(expr, expr) : expr
- *use of previously computed value*
  - **supply**(expr, comp(*X*)) : comp(*X*)
  - **given** : expr