Combinatory Logic Synthesizer

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Outline

Composition Synthesis

- Typed function composition (modus ponens)

$$\frac{\Gamma \vdash F : \tau' \to \tau \quad \Gamma \vdash G : \tau'}{\Gamma \vdash (F\ G) : \tau}(\to\mathrm{E})$$

  as logical model of applicative composition of *named component interfaces* $(X : \rho) \in \Gamma$ from a *repository* Γ, satisfying *goal* τ

- *Inhabitation problem* as foundation for *automatic synthesis:* $\exists e.\ \Gamma \vdash e : \tau$? Notation $\Gamma \vdash ? : \tau$
  - Does there exist a program composition e from repository Γ with $\Gamma \vdash e : \tau$? Inhabitation algorithm is used to *construct* (synthesize) e from Γ and τ

- CLS is inherently *component-oriented*

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Foundations in Combinatory Logic

$$\begin{array}{llll} \text{Types} & \tau & ::= & \alpha \mid \tau \to \tau' \\ \text{Terms} & e, e' & ::= & X \mid (e\ e') \end{array}$$

Rules

$$\frac{}{\Gamma, (X : \tau) \vdash X : S(\tau)}(\text{var})$$

$$\frac{\Gamma \vdash e : \tau' \to \tau \quad \Gamma \vdash e' : \tau'}{\Gamma \vdash (e\ e') : \tau}(\to \text{E})$$

Under Curry-Howard isomorphism, Hilbert-style presentation of minimal propositional logic (schematism + modus ponens)

Relativized Inhabitation

- We consider the *relativized inhabitation* problem:
  - **Given** Γ **and** τ, *does there exist* e *such that* $\Gamma \vdash e : \tau$*?*
- Relativized inhabitation is much harder
  - *Undecidable*: **Linial-Post theorems, 1948 ff.**
- *The CLS view:* Already in simple types, relativized inhabitation defines a Turing-complete logic programming language for component composition

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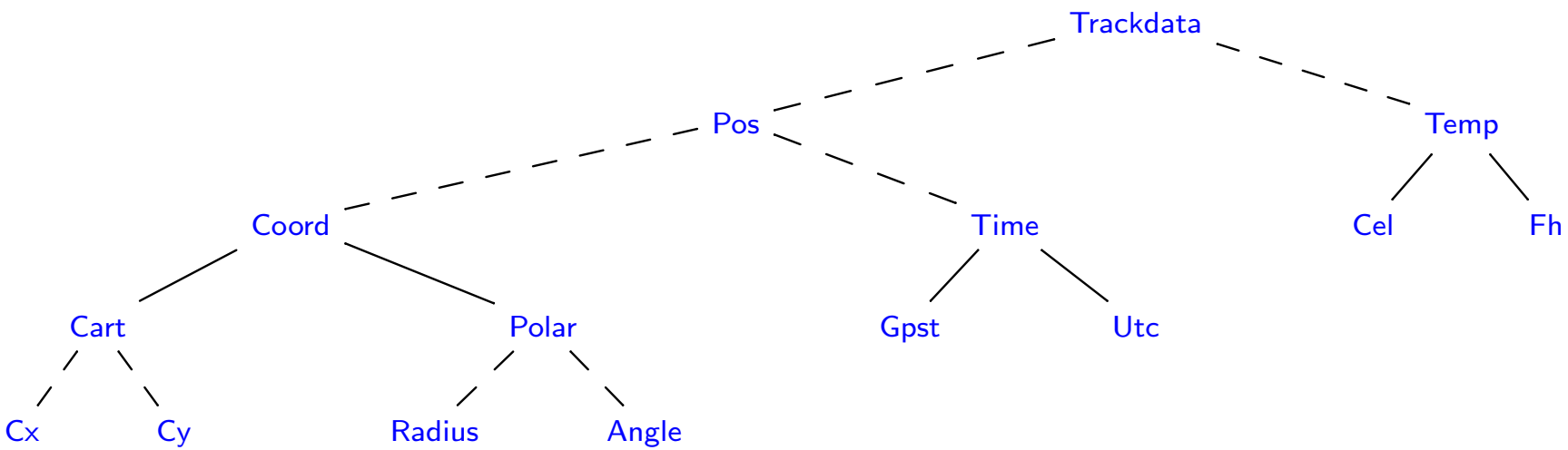
Example Repository

$$
\Gamma = \{
\begin{array}{lcl}
\texttt{O} & : & \texttt{TrObj} \\
\texttt{Tr} & : & \texttt{TrObj} \to \texttt{D}((\texttt{R},\texttt{R}),\texttt{R},\texttt{R}) \\
\texttt{pos} & : & \texttt{D}((\texttt{R},\texttt{R}),\texttt{R},\texttt{R}) \to ((\texttt{R},\texttt{R}),\texttt{R}) \\
\texttt{cdn} & : & ((\texttt{R},\texttt{R}),\texttt{R}) \to (\texttt{R},\texttt{R}) \\
\texttt{fst} & : & (\texttt{R},\texttt{R}) \to \texttt{R} \\
\texttt{snd} & : & (\texttt{R},\texttt{R}) \to \texttt{R} \\
\texttt{tmp} & : & \texttt{D}((\texttt{R},\texttt{R}),\texttt{R},\texttt{R}) \to \texttt{R} \\
\texttt{cc2pl} & : & ((\texttt{R},\texttt{R}),\texttt{R}) \to ((\texttt{R},\texttt{R}),\texttt{R}) \\
\texttt{cl2fh} & : & \texttt{R} \to \texttt{R}
\end{array}
\}
$$

JR: *Towards Combinatory Logic Synthesis*, BEAT'13

Semantic Type Structure



Semantic Repository

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\mathscr{C} = \{ & \\
& \texttt{O} : \texttt{TrObj} \\
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Complexity for Finite and Bounded CL

Theorem (RU TLCA 2011)

For finite combinatory logic FCL*:*

1. *Relativized inhabitation in* $\mathrm{FCL}(\to)$ *is in* PTIME
2. *Relativized inhabitation in* $\mathrm{FCL}(\to, \cap)$ *is* EXPTIME*-complete*

Theorem (DMRU CSL 2012)

For bounded combinatory logic BCL_k*:*

1. *Relativized inhabitation in* $\mathrm{BCL}_k(\to)$ *is* EXPTIME*-complete for all* k
2. *Relativized inhabitation in* $\mathrm{BCL}_k(\to, \cap)$ *is* $(k+2)$*-*EXPTIME*-complete*

Staged Composition Synthesis (DMR ESOP 2014)

Goal: Introduce metalanguage L2 *into composition synthesis*

- L1 may be limited, e.g.:
  - L1 might be very low-level
  - L1 might not have a notion of function application
- L2 should contain λ-calculus
  - Special-purpose composition operators
  - Meta-level computation over L1-code
  - Higher-order abstraction
- Challenges
  - How to expose language distinction in types?
  - How to ensure *implementation type correctness*?
  - How to ensure *staged* composition?

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Main Ideas in Staged Composition Synthesis

Use modal types $\Box\phi$ *("code of type* ϕ*") to expose language distinction to composition synthesis.*

- Introduction of modal intersection types
- Davies and Pfenning's calculus $\lambda_e^{\Box,\to}$ as L2 implementation language
- Challenges of staging solved by theory of $\lambda_e^{\Box,\to}$
- Challenge of implementation type correctness solved by conservative extension theorem
- Extension of inhabitation (semi-)algorithm for modal intersection types
- Extension of **(CL)S**-framework and experiments

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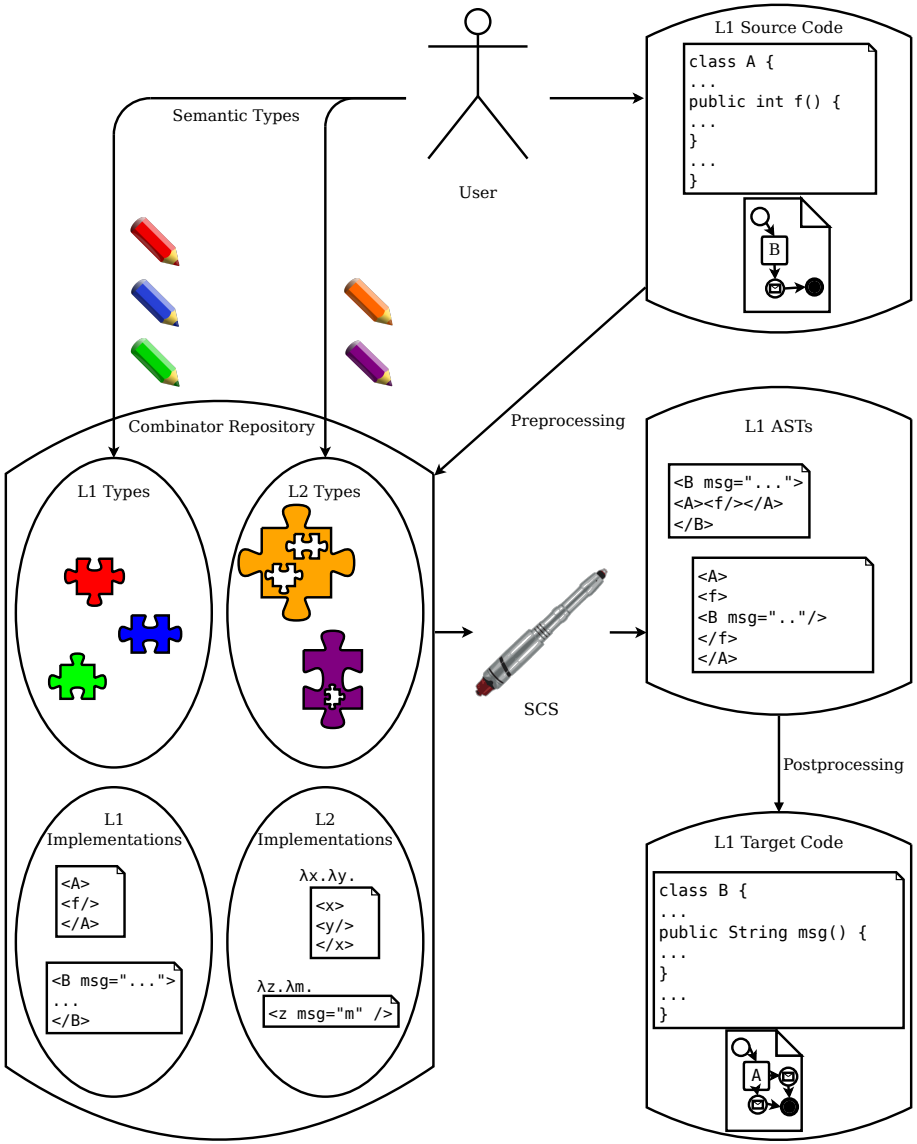
Tool Pipeline



Combinatory Logic Synthesizer Features

- Theorem prover (proofs-as-programs correspondence)
- Combinatory Logic Synthesis for $\mathrm{BCL}_0(\cap, \leq)$
- Version 1.0
  - Proof-of-concept
  - Enumerates inhabitants (even cyclic ones)
  - Variable kinding
  - Atomic subtyping extension for taxonomies
- Version 2.0
  - Algebraic optimizations
  - Co-variant type constructors

Heuristic Optimizations

Strategies

- Algorithm engineering
- Type-theoretic / algebraic optimizations

Experimental Runtime Performance for Γ_n^m in $\mathbb{Z}_n$

(n, m)	Initial (CL)S	Lookahead-(CL)S	Redesigned (CL)S
$(2, 3)$	210 ms	111 ms	93 ms
$(3, 2)$	12504 ms	124 ms	98 ms
$(3, 3)$	–	354 ms	110 ms
$(4, 4)$	–	$7.5 * 10^6$ ms	121 ms
$(7, 7)$	–	–	1063 ms
$(10, 10)$	–	–	54250 ms
$(43, 3)$	–	–	8813 ms

Current & Future Work

- Application to connector synthesis (ArchiType)
- Application to OO-synthesis (mixins, traits, DI)
- Combinatory process synthesis
- Algorithm engineering
- Constrained types $Q(\vec{\alpha}) \Rightarrow \phi$
- Automatic software configuration (OpenNebula Cloud)
- Stratified logics
- Component-oriented synthesis in theorem-proving?
- ...

Application – Spring DI DAO Synthesis

$$\texttt{EmployeeController} : (\Box\texttt{Scope} \cap \alpha) \rightarrow \Box(\texttt{EmployeeDAO} \cap \alpha) \rightarrow \Box(\texttt{EmployeeController} \cap \alpha \cap \texttt{setterTarget})$$

```
EmployeeController :λScope. letbox scope = Scope in
                    λDAO. letbox dao = DAO in
                      box "<bean xsi:type='cls:Constructor'>"
                          "<name>EmployeeController</name>"
                          "<typeName>EmployeeController</typeName>"
                          "<scope>"scope"</scope>"
                          "<argument>"
                          "<typeName>EmployeeDAO</typeName>"
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Interface to request Spring Dependency Injection candidates (embedded DSL):

```
public interface InhabitationRequest {
    public Class [] libraryClasses();
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Instead of using goal type:

$$\square(\texttt{EmployeeController} \cap \texttt{Session} \cap \texttt{setterTarget})$$

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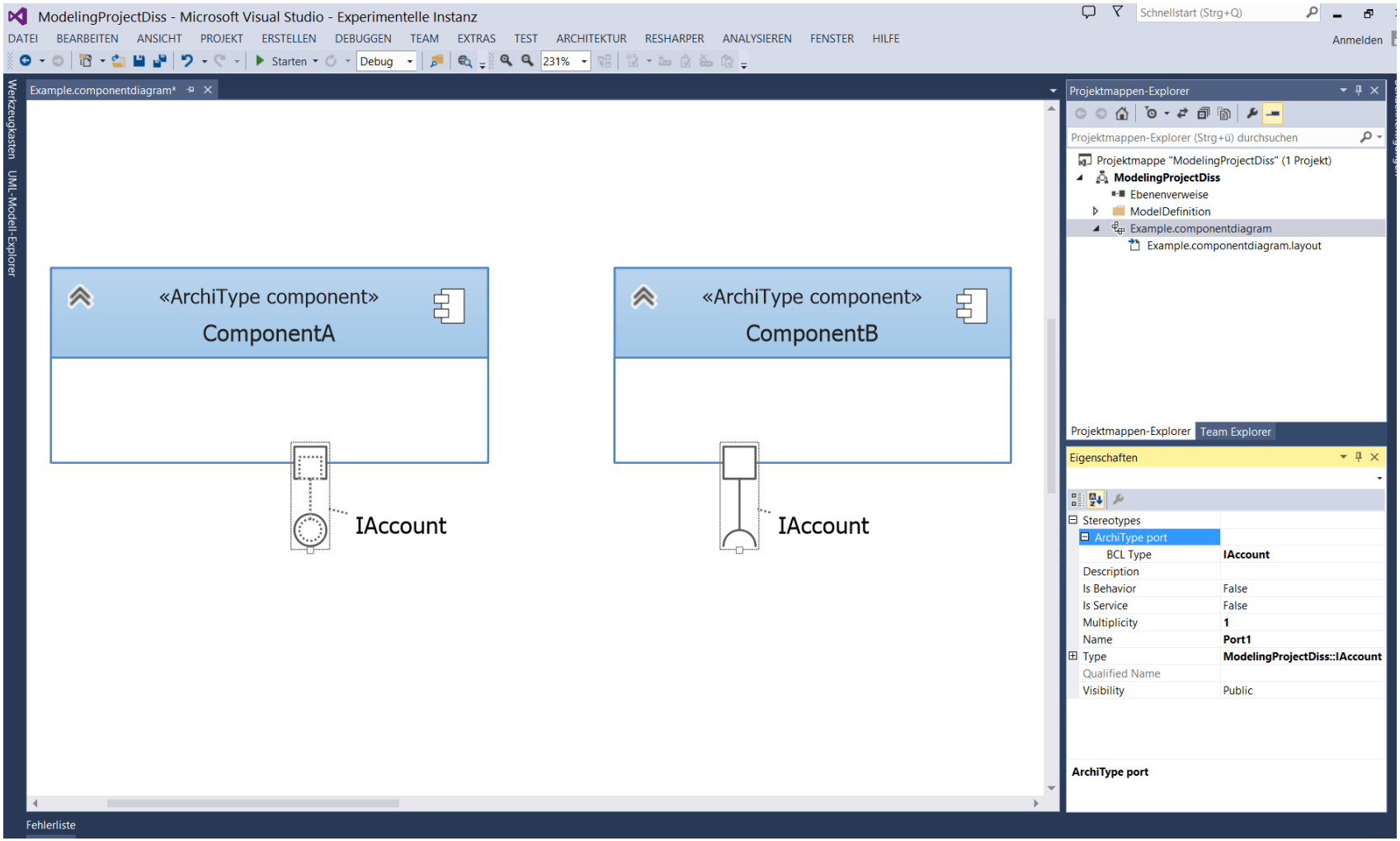
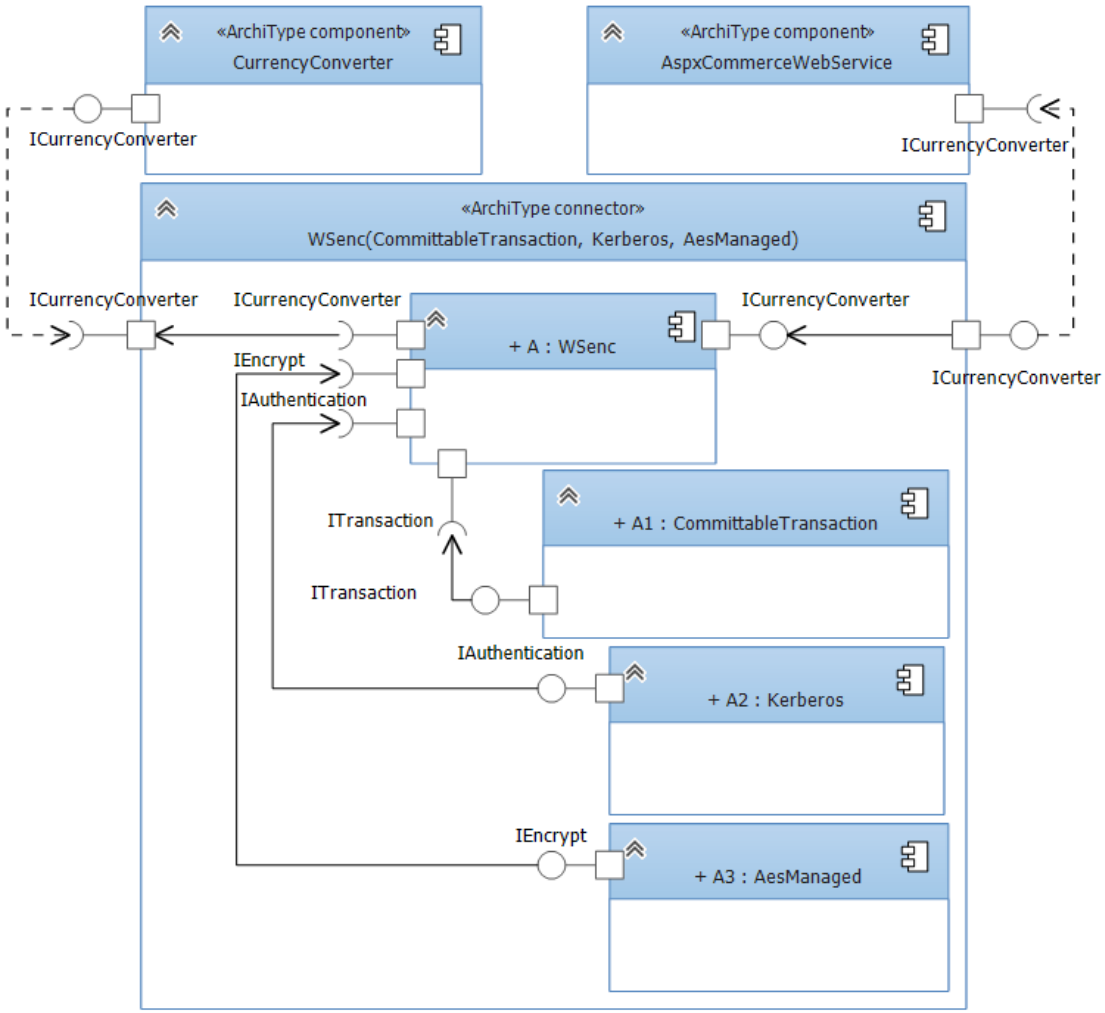
$$\square(\texttt{EmployeeController} \cap \texttt{Session} \cap \texttt{setterTarget})$$

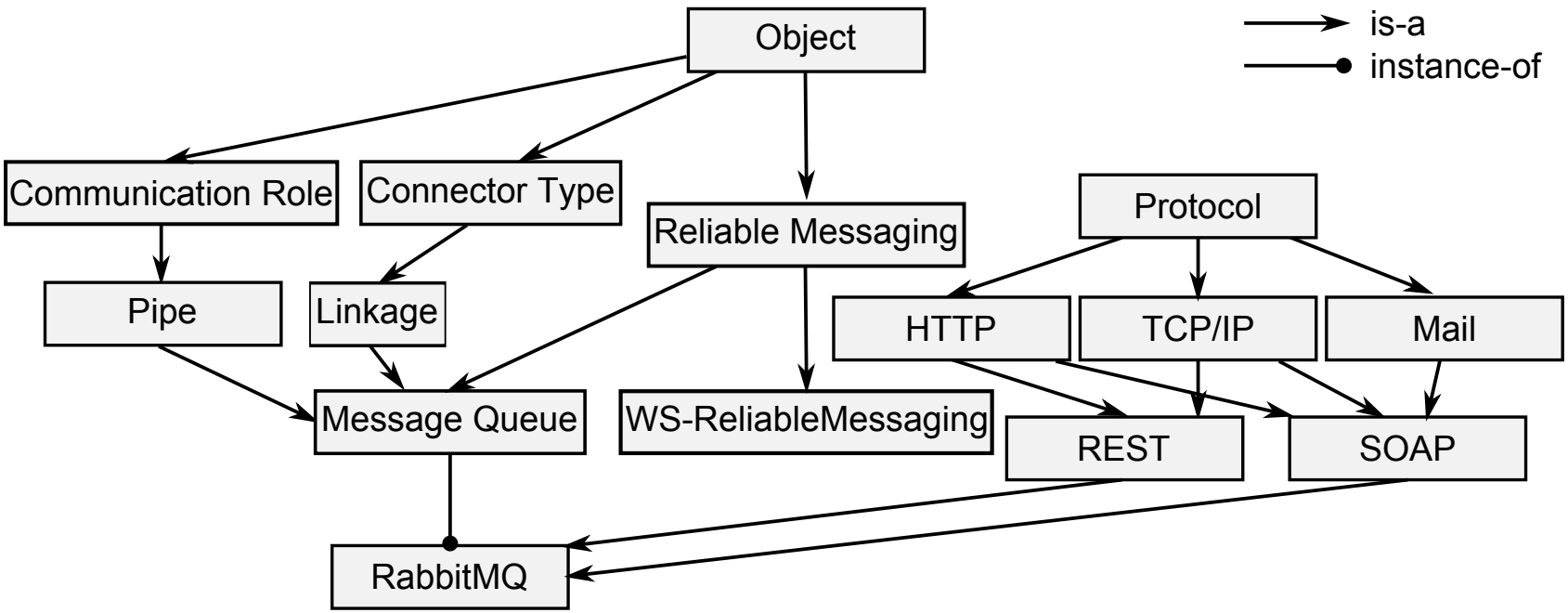
ArchiType


ModelingProjectDiss - Microsoft Visual Studio - Experimentelle Instanz
Example.componentdiagram*
«ArchiType component»
ComponentA
IAccount
«ArchiType component»
ComponentB
IAccount
Projektmappen-Explorer
Projektmappe "ModelingProjectDiss" (1 Projekt)
ModelingProjectDiss
Ebenenverweise
ModelDefinition
Example.componentdiagram
Example.componentdiagram.layout
Eigenschaften
Stereotypes
ArchiType port
BCL Type
IAccount
Description
Is Behavior
False
Is Service
False
Multiplicity
1
Name
Port1
Type
ModelingProjectDiss::IAccount
Qualified Name
Visibility
Public
ArchiType port
Fehlerliste

ArchiType


«ArchiType component»
CurrencyConverter
ICurrencyConverter
«ArchiType component»
AspxCommerceWebService
ICurrencyConverter
«ArchiType connector»
WSenc(CommittableTransaction, Kerberos, AesManaged)
ICurrencyConverter
ICurrencyConverter
ICurrencyConverter
ICurrencyConverter
+ A : WSenc
IEncrypt
IAuthentication
ITransaction
+ A1 : CommittableTransaction
ITransaction
IAuthentication
+ A2 : Kerberos
IEncrypt
+ A3 : AesManaged

ArchiType Taxonomy



ArchiType Experiments

	e-Commerce	ERP	Broker	SC
Subsystems	37	137	11	3
Classes	1293	691	11	3
LLOC	225 763	38 250	839	37
Generated/LLOC	2171	1731	993	257
Time/s	21.98	18.11	7	8.1
Refactoring/LLOC	5	20	No	No

Conclusion

- A new approach to component-oriented synthesis
- Types as logic programs that compute compositions
- Easily applicable to native API's
- Very large set of application scenarios
- Robust foundations in proof theory
- Applied in several experiments and domains

References

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- *Bounded Combinatory Logic*. With J. Rehof, M. Martens and P. Urzyczyn. CSL 2012.
- *Using Inhabitation in Bounded Combinatory Logic with Intersection Types for Composition Synthesis*. With J. Rehof, O.Garbe, M. Martens and P. Urzyczyn. EPTCS 2012.
- *The Complexity of Inhabitation with Explicit Intersection*. J. Rehof and P. Urzyczyn. R.L. Constable and A. Silva (Eds.): Logic and Program Semantics. Essays Dedicated to Dexter Kozen 2012.
- *Finite Combinatory Logic with Intersection Types*. J. Rehof and P. Urzyczyn. TLCA 2011.
- *Automatic Synthesis of Component & Connector-Software Architectures with Bounded Combinatory Logic*. B. Düdder. Dissertation. TU Dortmund 2014.
- **See also**: *Dagstuhl Seminar "Design and Synthesis from Components"*, Schloss Dagstuhl, June 1–6 2014.