Coherences for the Container Model of Type Theory

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Why do we need a container model of type theory?

For categorical semantics of (Q)IITs using containers!

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Example 1: (Simplified) intrinsic syntax of type theory

```
data Con : Set
data Ty : Con → Set

data Con where
  ◇ : Con
  _,_ : (Γ : Con) (A : Ty Γ) → Con
  eq : (Γ : Con) (A : Ty Γ) (B : Ty (Γ , A)) →
     ((Γ , A) , B) ≡ (Γ , Σ Γ A B)

data Ty where
  ι : (Γ : Con) → Ty Γ
  Σ : (Γ : Con) (A : Ty Γ) → Ty (Γ , A) → Ty Γ
```

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Constructors are expressed via argument and target functors [Altenkirch et al., 2018].

E.g. For `_,_ : (Γ : Con) (A : Ty Γ) → Con` we have:

$$L : \mathbf{A_1} \rightarrow \mathbf{Set}$$
$$L(C, T, e) :\equiv \sum(\Gamma : C)(T\,\Gamma)$$

$$R : \int L \rightarrow \mathbf{Set}$$
$$= (C : \mathrm{Set})(T : C \rightarrow \mathrm{Set})(e : C)(L(C, T, e)) \rightarrow \mathbf{Set}$$
$$R(C, T, e, \Gamma, A) :\equiv C$$

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Conjecture:
Restricting ourselves to **container functors** ensures we can only construct **strictly positive** (Q)IITs.

Prerequisite:
A general way to **express type contexts as containers**, i.e. a container model of type theory.

The container model (outlined in [Altenkirch and Kaposi, 2021])

- Contexts are set-containers $S_\Gamma : \mathrm{Set} \triangleleft P_\Gamma : S_\Gamma \to \mathrm{Set}$ with extension functor

$$[\![S_\Gamma \triangleleft P_\Gamma]\!] : \mathbf{Set} \to \mathbf{Set}$$

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- Types in context $\Gamma = S_\Gamma \lhd P_\Gamma$ are generalised containers $S_A : \text{Set} \lhd P_A : S_A \to |\int [\![\Gamma]\!]|$, with extension functor

$$[\![S_A \lhd P_A]\!] : (\textstyle\int [\![\Gamma]\!]) \to \mathbf{Set}.$$

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- Terms of type A in context Γ are dependent natural transformations from $[\![\Gamma]\!]$ to $[\![A]\!]$:

$$\int_{X:\mathrm{Set}} (\gamma : [\![\Gamma]\!]\, X) \to [\![A]\!](X, \gamma)$$

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- Context extension is given by $\Gamma.A = S_A \triangleleft P_A^X$

Presheaf model vs Container model

Presheaf model

- Contexts: $\mathbf{C}^{\mathrm{op}} \to \mathbf{Set}$
- Substitutions: natural transformations
- Types: $(\int \Gamma)^{\mathrm{op}} \to \mathbf{Set}$
- Terms: $\int_{X:\mathrm{Set}} (\gamma : \Gamma\, X) \to A(X, \gamma)$
- Context extension: $\Gamma.A\, X = \sum(\rho : \Gamma\, X)(A\,(X, \rho))$

Container model

- Contexts: $\mathbf{Set} \to \mathbf{Set}$
- Substitutions: container morphisms
- Types: $(\int [\![\Gamma]\!]) \to \mathbf{Set}$
- Terms: $\int_{X:\mathrm{Set}} (\gamma : [\![\Gamma]\!]\, X) \to [\![A]\!](X, \gamma)$
- Context extension: $[\![\Gamma.A]\!]\, X = \sum(\rho : [\![\Gamma]\!]\, X)([\![A]\!]\,(X, \rho))$

Coherence issues in the absence of UIP

1. $Ty : \mathbf{Con}^{\mathrm{op}} \to \cancel{\mathbf{Set}}\ \mathbf{Gpd}$

   The **collection of types is a groupoid**, not an h-set. Additional coherence laws need to be checked.

$$
\begin{tikzcd}
 & & A[\sigma][\delta][\gamma] \arrow[dll] \arrow[drr] & & \\
A[\sigma][\delta \circ \gamma] \arrow[dr] & & & & A[\sigma \circ \delta][\gamma] \arrow[dl] \\
 & A[\sigma \circ (\delta \circ \gamma)] \arrow[rr] & & A[(\sigma \circ \delta) \circ \gamma] &
\end{tikzcd}
$$

$$
\begin{tikzcd}
 & A[id_\Gamma][\gamma] \arrow[dl] \arrow[dr] & \\
A[id_\Gamma \circ \gamma] \arrow[rr] & & A[\gamma]
\end{tikzcd}
\qquad
\begin{tikzcd}
 & A[\gamma][id_\Gamma] \arrow[dl] \arrow[dr] & \\
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\end{tikzcd}
$$

2. **Functor laws do not hold strictly**, but only up to isomorphism, due to definition of type substitution $A[\gamma]$:

$$
\begin{tikzcd}
S_{A[\gamma]} \arrow[r, "snd"] \arrow[d, "fst"'] \arrow[dr, phantom, "\lrcorner", very near start] & S_A \arrow[d, "P_A^s"] \\
S_\Delta \arrow[r, "\gamma_s"'] & S_\Gamma
\end{tikzcd}
\quad \lhd \quad
\begin{tikzcd}
P_\Gamma\,(\gamma_s(fst\ s)) \arrow[r, "P_A^f(snd\ s)"] \arrow[d, "\gamma_p(fst\ s)"'] & P_A^X(snd\ s) \arrow[d, "inr"] \\
P_\Delta(fst\ s) \arrow[r, "inl"'] \arrow[ur, phantom, "\ulcorner", very near end] & P^X_{A[\gamma]}\ s
\end{tikzcd}
$$

How do we solve the issues?

View model as set-CwF

$\downarrow$

Strictification

View model as 'higher' CwF
[Kraus, 2021, Uemura, 2022]

$\downarrow$

Prove extra coherence laws

$\downarrow$

Interpretation of syntax is unclear!

How do we solve the issues?

View model as set-CwF

View model as ‘higher’ CwF
[Kraus, 2021, **?**]

Strictification $\longleftarrow$ we do both $\longrightarrow$ Prove extra coherence laws

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Strictified container model

- We use an inductive-recursive universe U : Set, $El : U \to$ Set.

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Strictified container model

- We use an inductive-recursive universe U : Set, $El \colon U \to$ Set.
- Contexts are codes for set-containers

$$S_\Gamma^U \colon U \triangleleft P_\Gamma^U \colon El\, S_\Gamma^U \to U$$

- Types in context Γ are codes for generalised containers, together with a substitution—we delay substitution

$$(\Gamma \xrightarrow{\delta} \Delta, S_B^U \colon U \triangleleft P_B^U \colon El\, S_B^U \to |\textstyle\int[\![\Delta]\!]|^U)$$

$B[\delta]$

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- Type substitution can now be defined as

$$(B[\delta])[\gamma] :\equiv B[\delta \circ \gamma]$$

Strictified container model

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$B[\delta]$

- Type substitution can now be defined as

$$(B[\delta])[\gamma] :\equiv B[\delta \circ \gamma]$$

Now, the collection of types is an h-set, and functor laws hold strictly.

Contributions & ongoing work

- Worked out details of 'higher' container model outlined in [Altenkirch and Kaposi, 2021], including extra coherence laws
- Finalizing details of strictified container model
- Constructing Π-types, Σ-types, universe in both versions
- Started a formalisation of the 'higher' container model in Cubical Agda

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Thank you!

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