

# A Type Theory for Strictly Associative $\infty$ -Categories

Alex Rice   Eric Finster   Jamie Vicary

SYCO 10



- 1 Weak Globular Infinity Categories
- 2 Type Theories for Infinity Categories
- 3 Strict Associators

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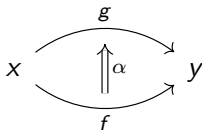
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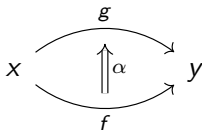
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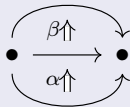
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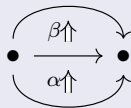
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Composition along a 0-boundary:



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## Coherence

- For a 1-cell  $f : x \rightarrow y$ , there are unitors  $\lambda_f : \text{id}_x \circ f \rightarrow f$  and  $\rho_f : f \circ \text{id}_y$ .
- $\lambda_{\text{id}_x}$  and  $\rho_{\text{id}_x}$  are both arrows  $\text{id}_x \circ \text{id}_x \rightarrow \text{id}_x$ .
- These should be equivalent.

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- All weak monoidal categories and all weak 2-categories are equivalent to a strict version of themselves.
- However this is no longer possible at dimensions 3 and higher.

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<sup>2</sup>Finster, R., and Vicary, *A Type Theory for Strictly Associative Infinity Categories*

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- Types: Source and Target for a term.
- Substitutions: A mapping from variables of one context to terms of another.

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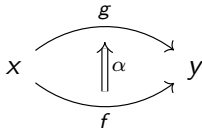
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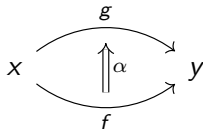
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## Disc contexts

For each natural number we can define the *disc context*  $D_n$ .

$D_0$



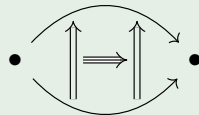
$D_1$



$D_2$



$D_3$



$$D_2 := x : \star, y : \star, f : x \rightarrow_{\star} y, g : x \rightarrow_{\star} y, \alpha : f \rightarrow_{x \rightarrow_{\star} y} g$$

Composition can be done with the `coh` constructor.

## `coh` constructor

Given:

- A context  $\Gamma$  - the shape of the composition,
- A type  $A$  in  $\Gamma$  - the boundary of the composition,
- A substitution  $\sigma : \Gamma \rightarrow \Delta$  - the terms to be composed,

we get a term in  $\Delta$ :

$$\text{coh } (\Gamma : A)[\sigma]$$

The contexts for which the `coh` constructor is well typed are called *pasting contexts*

# Example composition

Suppose we have:

$$\bullet \xrightarrow{f} \bullet \xrightarrow{g} \bullet \xrightarrow{h} \bullet$$

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$$(f \cdot g) \cdot h := \text{coh } (\Gamma : x \rightarrow z)[a \mapsto f \cdot g, \\ b \mapsto h]$$



- CaTT as we have presented it has no non-trivial equality and no computation.
- The idea is to implement a reduction relation that unifies the operations we want to strictify.
- By doing this we obtain a type theory for which the models are semistrict categories.

$\text{CaTT}_{\text{sa}}$  has a definitional equality based on an operation we call insertion.

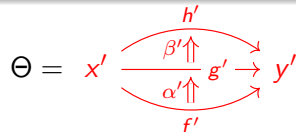
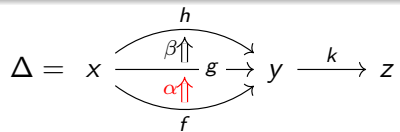
1-associator

$$x \xrightarrow{f} y \xrightarrow{g} z \qquad x' \xrightarrow{f'} y' \xrightarrow{g'} z'$$


is sent to:

$$x \xrightarrow{f} x' \xrightarrow{f'} y' \xrightarrow{g'} z'$$

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$$\Delta = x \begin{array}{c} \xrightarrow{h} \\ \beta \uparrow \uparrow \\ \xrightarrow{g} \\ \alpha \uparrow \uparrow \\ \xrightarrow{f} \end{array} y \xrightarrow{k} z$$

$$\Theta = x' \begin{array}{c} \xrightarrow{h'} \\ \beta' \uparrow \uparrow \\ \xrightarrow{g'} \\ \alpha' \uparrow \uparrow \\ \xrightarrow{f'} \end{array} y' \xrightarrow{k} z$$

$$\Delta \ll_{\alpha} \Theta = x' \begin{array}{c} \xrightarrow{h} \\ \beta \uparrow \uparrow \\ \xrightarrow{h'} \\ \beta' \uparrow \uparrow \\ \xrightarrow{g'} \\ \alpha' \uparrow \uparrow \\ \xrightarrow{f'} \end{array} y' \xrightarrow{k} z$$

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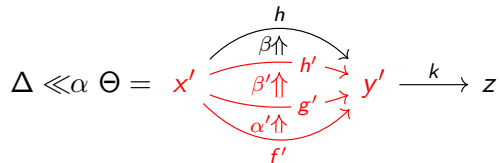
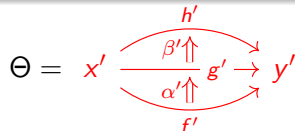
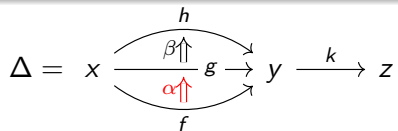
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$$\kappa : \Delta \rightarrow \Delta \ll_{\alpha} \Theta$$

Given  $\sigma : \Delta \rightarrow \Gamma$  and  $\tau : \Theta \rightarrow \Gamma$  we get:

$$\sigma \ll_{\alpha} \tau : \Delta \ll_{\alpha} \Theta \rightarrow \Gamma$$

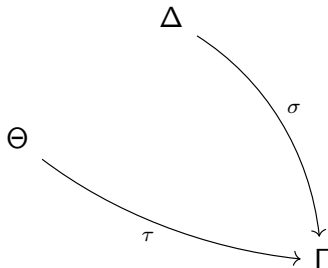
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Insertion also satisfies a *universal property*. Suppose we have  $\text{coh } (\Delta : A)[\sigma]$  where  $\sigma(\alpha) = \text{coh } (\Theta : B)[\tau]$ .



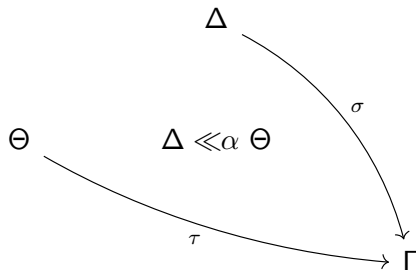
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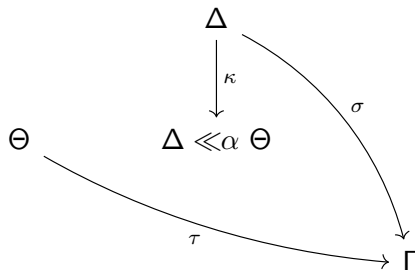
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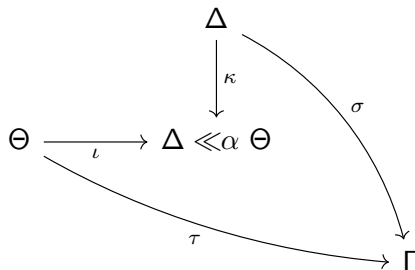
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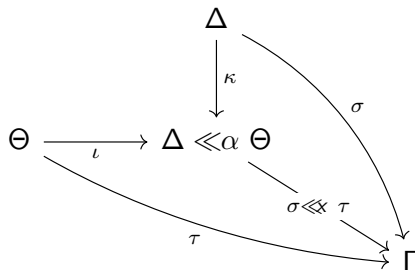
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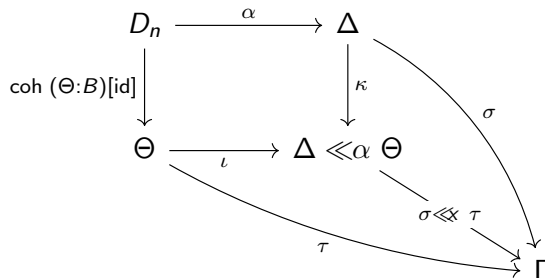
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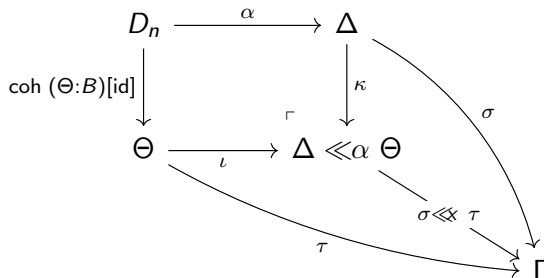
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Insertion generates a reduction relation for  $\text{Catt}_{\text{sa}}$ :

$$\text{coh } (\Delta : A)[\sigma] \rightsquigarrow \text{coh } (\Delta \ll_{\alpha} \Theta : A[\![\kappa]\!])[\sigma \ll_{\alpha} \tau]$$

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This reduction has been proven to have the following properties:

- Subject reduction
- Termination
- Confluence

-  Finster, Eric and Samuel Mimram. *A Type-Theoretical Definition of Weak  $\omega$ -Categories*. 2017. DOI: [10.1109/lics.2017.8005124](https://doi.org/10.1109/lics.2017.8005124). eprint: [1706.02866](https://arxiv.org/abs/1706.02866).
-  Finster, Eric, Alex R., and Jamie Vicary. *A Type Theory for Strictly Associative Infinity Categories*. 2021. arXiv: [2109.01513](https://arxiv.org/abs/2109.01513).
-  Finster, Eric, David Reutter, et al. *A Type Theory for Strictly Unital  $\infty$ -Categories*. Proceedings of the Thirty-Seventh Annual ACM/IEEE Symposium on Logic in Computer Science (LICS 2022). 2020. DOI: [10.1145/3531130.3533363](https://doi.org/10.1145/3531130.3533363). arXiv: [2007.08307](https://arxiv.org/abs/2007.08307).