# Types of Morphisms in Bicategories

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In this chapter, we study special kinds of morphisms in bicategories:

1. *Monomorphisms and Epimorphisms in Bicategories (Sections 14.1 and 14.2).* There is a large number of different notions capturing the idea of a "monomorphism" or of an "epimorphism" in a bicategory.

   Arguably, the notion that best captures these concepts is that of a *pseudomonic morphism* (Definition 14.1.10.1.1) and of a *pseudoepic morphism* (Definition 14.2.10.1.1), although the other notions introduced in Sections 14.1 and 14.2 are also interesting on their own.

## Contents

# 14.1 Monomorphisms in Bicategories

## 14.1.1 Representably Faithful Morphisms

Let $C$ be a bicategory.

**Definition 14.1.1.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **representably faithful**[1] if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f_*\colon \mathsf{Hom}_C(X, A) \to \mathsf{Hom}_C(X, B)$$

given by postcomposition by $f$ is faithful.

**Remark 14.1.1.1.2.** In detail, $f$ is representably faithful if, for all diagrams in $C$ of the form

$$\begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha \Downarrow \Downarrow \beta"] & A \arrow[r, "f"] & B, \end{tikzcd}$$

if we have

$$\mathrm{id}_f \star \alpha = \mathrm{id}_f \star \beta,$$

then $\alpha = \beta$.

[1] *Further Terminology:* Also called simply a **faithful morphism**, based on Item 1 of Definition 14.1.1.1.3.

**Example 14.1.1.1.3.** Here are some examples of representably faithful morphisms.

1. *Representably Faithful Morphisms in* $\mathsf{Cats}_2$. The representably faithful morphisms in $\mathsf{Cats}_2$ are precisely the faithful functors; see Categories, Item 2 of Definition 11.6.1.1.2.

2. *Representably Faithful Morphisms in* **Rel**. Every morphism of **Rel** is representably faithful; see Relations, Item 1 of Definition 8.5.11.1.1.

## 14.1.2 Representably Full Morphisms

Let $C$ be a bicategory.

**Definition 14.1.2.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **representably full**[2] if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f_*\colon \mathsf{Hom}_C(X, A) \to \mathsf{Hom}_C(X, B)$$

given by postcomposition by $f$ is full.

**Remark 14.1.2.1.2.** In detail, $f$ is representably full if, for each $X \in \mathrm{Obj}(C)$ and each 2-morphism

$$\beta\colon f\circ\phi \Longrightarrow f\circ\psi, \qquad \begin{tikzcd} X \arrow[r, bend left, "f\circ\phi"] \arrow[r, bend right, "f\circ\psi"'] \arrow[r, phantom, "\beta\Downarrow"] & B \end{tikzcd}$$

of $C$, there exists a 2-morphism

$$\alpha\colon \phi \Longrightarrow \psi, \qquad \begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & A \end{tikzcd}$$

of $C$ such that we have an equality

$$\begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & A \arrow[r, "f"] & B \end{tikzcd} = \begin{tikzcd} X \arrow[r, bend left, "f\circ\phi"] \arrow[r, bend right, "f\circ\psi"'] \arrow[r, phantom, "\beta\Downarrow"] & B \end{tikzcd}$$

[2] *Further Terminology:* Also called simply a **full morphism**, based on Item 1 of

of pasting diagrams in $C$, i.e. such that we have

$$\beta = \mathrm{id}_f \star \alpha.$$

**Example 14.1.2.1.3.** Here are some examples of representably full morphisms.

1. *Representably Full Morphisms in* $\mathsf{Cats}_2$. The representably full morphisms in $\mathsf{Cats}_2$ are precisely the full functors; see Categories, **??** of Definition 11.6.2.1.2.

2. *Representably Full Morphisms in* $\mathbf{Rel}$. The representably full morphisms in $\mathbf{Rel}$ are characterised in Relations, Item 2 of Definition 8.5.11.1.1.

### 14.1.3 Representably Fully Faithful Morphisms

Let $C$ be a bicategory.

**Definition 14.1.3.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **representably fully faithful**[3] if the following equivalent conditions are satisfied:

1. The 1-morphism $f$ is representably faithful (Definition 14.1.1.1.1) and representably full (Definition 14.1.2.1.1).

2. For each $X \in \mathrm{Obj}(C)$, the functor

$$f_*\colon \mathsf{Hom}_C(X, A) \to \mathsf{Hom}_C(X, B)$$

given by postcomposition by $f$ is fully faithful.

**Remark 14.1.3.1.2.** In detail, $f$ is representably fully faithful if the conditions in Definition 14.1.1.1.2 and Definition 14.1.2.1.2 hold:

1. For all diagrams in $C$ of the form

$$\begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow\Downarrow\beta"] & A \arrow[r, "f"] & B, \end{tikzcd}$$

if we have

$$\mathrm{id}_f \star \alpha = \mathrm{id}_f \star \beta,$$

then $\alpha = \beta$.

Definition 14.1.2.1.3.

[3] *Further Terminology:* Also called simply a **fully faithful morphism**, based on Item 1 of

2. For each $X \in \mathrm{Obj}(C)$ and each 2-morphism

$$\beta\colon f \circ \phi \Longrightarrow f \circ \psi, \qquad \begin{tikzcd} X \arrow[r, bend left, "f\circ\phi"] \arrow[r, bend right, "f\circ\psi"'] \arrow[r, phantom, "\beta\Downarrow"] & B \end{tikzcd}$$

of $C$, there exists a 2-morphism

$$\alpha\colon \phi \Longrightarrow \psi, \qquad \begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & A \end{tikzcd}$$

of $C$ such that we have an equality

$$\begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & A \arrow[r, "f"] & B \end{tikzcd} = \begin{tikzcd} X \arrow[r, bend left, "f\circ\phi"] \arrow[r, bend right, "f\circ\psi"'] \arrow[r, phantom, "\beta\Downarrow"] & B \end{tikzcd}$$

of pasting diagrams in $C$, i.e. such that we have

$$\beta = \mathrm{id}_f \star \alpha.$$

**Example 14.1.3.1.3.** Here are some examples of representably fully faithful morphisms.

1. *Representably Fully Faithful Morphisms in* $\mathsf{Cats}_2$. The representably fully faithful morphisms in $\mathsf{Cats}_2$ are precisely the fully faithful functors; see Categories, Item 6 of Definition 11.6.3.1.2.

2. *Representably Fully Faithful Morphisms in* $\mathbf{Rel}$. The representably fully faithful morphisms of $\mathbf{Rel}$ coincide (Relations, Item 3 of Definition 8.5.11.1.1) with the representably full morphisms in $\mathbf{Rel}$, which are characterised in Relations, Item 2 of Definition 8.5.11.1.1.

## 14.1.4 Morphisms Representably Faithful on Cores

Let $C$ be a bicategory.

**Definition 14.1.4.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **representably faithful on cores** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f_*\colon \mathsf{Core}(\mathsf{Hom}_C(X, A)) \to \mathsf{Core}(\mathsf{Hom}_C(X, B))$$

given by postcomposition by $f$ is faithful.

**Remark 14.1.4.1.2.** In detail, $f$ is representably faithful on cores if, for all diagrams in $C$ of the form

$$\begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow\Downarrow\beta"] & A \arrow[r, "f"] & B, \end{tikzcd}$$

if $\alpha$ and $\beta$ are 2-isomorphisms and we have

$$\mathrm{id}_f \star \alpha = \mathrm{id}_f \star \beta,$$

then $\alpha = \beta$.

## 14.1.5 Morphisms Representably Full on Cores

Let $C$ be a bicategory.

**Definition 14.1.5.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **representably full on cores** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f_*\colon \mathsf{Core}(\mathsf{Hom}_C(X, A)) \to \mathsf{Core}(\mathsf{Hom}_C(X, B))$$

given by postcomposition by $f$ is full.

**Remark 14.1.5.1.2.** In detail, $f$ is representably full on cores if, for each $X \in \mathrm{Obj}(C)$ and each 2-isomorphism

$$\beta\colon f \circ \phi \overset{\sim}{\Longrightarrow} f \circ \psi, \qquad \begin{tikzcd} X \arrow[r, bend left, "f\circ\phi"] \arrow[r, bend right, "f\circ\psi"'] \arrow[r, phantom, "\beta\Downarrow"] & B \end{tikzcd}$$

Definition 14.1.3.1.3.

of $C$, there exists a 2-isomorphism

$$\alpha\colon \phi \overset{\sim}{\Longrightarrow} \psi, \qquad \begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & A \end{tikzcd}$$

of $C$ such that we have an equality

$$\begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & A \arrow[r, "f"] & B \end{tikzcd} \quad = \quad \begin{tikzcd} X \arrow[r, bend left, "f\circ\phi"] \arrow[r, bend right, "f\circ\psi"'] \arrow[r, phantom, "\beta\Downarrow"] & B \end{tikzcd}$$

of pasting diagrams in $C$, i.e. such that we have

$$\beta = \mathrm{id}_f \star \alpha.$$

## 14.1.6 Morphisms Representably Fully Faithful on Cores

Let $C$ be a bicategory.

**Definition 14.1.6.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **representably fully faithful on cores** if the following equivalent conditions are satisfied:

1. The 1-morphism $f$ is representably faithful on cores (Definition 14.1.5.1.1) and representably full on cores (Definition 14.1.4.1.1).
2. For each $X \in \mathrm{Obj}(C)$, the functor

   $$f_*\colon \mathsf{Core}(\mathsf{Hom}_C(X, A)) \to \mathsf{Core}(\mathsf{Hom}_C(X, B))$$

   given by postcomposition by $f$ is fully faithful.

**Remark 14.1.6.1.2.** In detail, $f$ is representably fully faithful on cores if the conditions in Definition 14.1.4.1.2 and Definition 14.1.5.1.2 hold:

1. For all diagrams in $C$ of the form

   $$\begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow\Downarrow\beta"] & A \arrow[r, "f"] & B, \end{tikzcd}$$

if $\alpha$ and $\beta$ are 2-isomorphisms and we have

$$\mathrm{id}_f \star \alpha = \mathrm{id}_f \star \beta,$$

then $\alpha = \beta$.

2. For each $X \in \mathrm{Obj}(C)$ and each 2-isomorphism

$$\beta \colon f \circ \phi \overset{\sim}{\Longrightarrow} f \circ \psi, \qquad \begin{tikzcd} X \arrow[r, bend left, "f\circ\phi"] \arrow[r, bend right, "f\circ\psi"'] \arrow[r, phantom, "\beta\Downarrow"] & B \end{tikzcd}$$

of $C$, there exists a 2-isomorphism

$$\alpha \colon \phi \overset{\sim}{\Longrightarrow} \psi, \qquad \begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & A \end{tikzcd}$$

of $C$ such that we have an equality

$$\begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & A \arrow[r, "f"] & B \end{tikzcd} = \begin{tikzcd} X \arrow[r, bend left, "f\circ\phi"] \arrow[r, bend right, "f\circ\psi"'] \arrow[r, phantom, "\beta\Downarrow"] & B \end{tikzcd}$$

of pasting diagrams in $C$, i.e. such that we have

$$\beta = \mathrm{id}_f \star \alpha.$$

### 14.1.7 Representably Essentially Injective Morphisms

Let $C$ be a bicategory.

**Definition 14.1.7.1.1.** A 1-morphism $f : A \to B$ of $C$ is **representably essentially injective** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f_* \colon \mathsf{Hom}_C(X, A) \to \mathsf{Hom}_C(X, B)$$

given by postcomposition by $f$ is essentially injective.

**Remark 14.1.7.1.2.** In detail, $f$ is representably essentially injective if, for each pair of morphisms $\phi, \psi \colon X \rightrightarrows A$ of $C$, the following condition is satisfied:

($\star$) If $f \circ \phi \cong f \circ \psi$, then $\phi \cong \psi$.

## 14.1.8 Representably Conservative Morphisms

Let $C$ be a bicategory.

**Definition 14.1.8.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **representably conservative** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f_*\colon \mathsf{Hom}_C(X, A) \to \mathsf{Hom}_C(X, B)$$

given by postcomposition by $f$ is conservative.

**Remark 14.1.8.1.2.** In detail, $f$ is representably conservative if, for each pair of morphisms $\phi, \psi\colon X \rightrightarrows A$ and each 2-morphism

$$\alpha\colon \phi \Longrightarrow \psi, \qquad \begin{tikzcd} X \arrow[r, bend left, "\phi"{name=U}] \arrow[r, bend right, "\psi"'{name=D}] & A \arrow[from=U, to=D, phantom, "\alpha\Downarrow"] \end{tikzcd}$$

of $C$, if the 2-morphism

$$\mathrm{id}_f \star \alpha\colon f \circ \phi \Longrightarrow f \circ \psi, \qquad \begin{tikzcd} X \arrow[rr, bend left, "f\circ\phi"{name=U}] \arrow[rr, bend right, "f\circ\psi"'{name=D}] & & B \arrow[from=U, to=D, phantom, "\mathrm{id}_f\star\alpha\Downarrow"] \end{tikzcd}$$

is a 2-isomorphism, then so is $\alpha$.

## 14.1.9 Strict Monomorphisms

Let $C$ be a bicategory.

**Definition 14.1.9.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is a **strict monomorphism** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f_*\colon \mathsf{Hom}_C(X, A) \to \mathsf{Hom}_C(X, B)$$

given by postcomposition by $f$ is injective on objects, i.e. its action on objects

$$f_*\colon \ \mathrm{Obj}(\mathsf{Hom}_C(X, A)) \to \mathrm{Obj}(\mathsf{Hom}_C(X, B))$$

is injective.

**Remark 14.1.9.1.2.** In detail, $f$ is a strict monomorphism in $C$ if, for each diagram in $C$ of the form

$$X \underset{\psi}{\overset{\phi}{\rightrightarrows}} A \xrightarrow{f} B,$$

if $f \circ \phi = f \circ \psi$, then $\phi = \psi$.

**Example 14.1.9.1.3.** Here are some examples of strict monomorphisms.

1. *Strict Monomorphisms in* $\mathsf{Cats}_2$. The strict monomorphisms in $\mathsf{Cats}_2$ are precisely the functors which are injective on objects and injective on morphisms; see Categories, Item 1 of Definition 11.7.2.1.2.

2. *Strict Monomorphisms in* $\mathbf{Rel}$. The strict monomorphisms in $\mathbf{Rel}$ are characterised in Relations, Definition 8.5.10.1.1.

## 14.1.10 Pseudomonic Morphisms

Let $C$ be a bicategory.

**Definition 14.1.10.1.1.** A 1-morphism $f : A \to B$ of $C$ is **pseudomonic** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f_* : \mathsf{Hom}_C(X, A) \to \mathsf{Hom}_C(X, B)$$

given by postcomposition by $f$ is pseudomonic.

**Remark 14.1.10.1.2.** In detail, a 1-morphism $f : A \to B$ of $C$ is pseudomonic if it satisfies the following conditions:

1. For all diagrams in $C$ of the form

$$\begin{tikzcd} X \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow\Downarrow\beta"] & A \arrow[r, "f"] & B, \end{tikzcd}$$

   if we have

$$\mathrm{id}_f \star \alpha = \mathrm{id}_f \star \beta,$$

   then $\alpha = \beta$.

2. For each $X \in \mathrm{Obj}(\mathcal{C})$ and each 2-isomorphism

$$\beta\colon f \circ \phi \overset{\sim}{\Longrightarrow} f \circ \psi, \qquad \begin{tikzcd} X \arrow[r, bend left, "f \circ \phi"{name=U}] \arrow[r, bend right, "f \circ \psi"'{name=D}] & B \arrow[from=U, to=D, phantom, "\beta \Downarrow"] \end{tikzcd}$$

of $\mathcal{C}$, there exists a 2-isomorphism

$$\alpha\colon \phi \overset{\sim}{\Longrightarrow} \psi, \qquad \begin{tikzcd} X \arrow[r, bend left, "\phi"{name=U}] \arrow[r, bend right, "\psi"'{name=D}] & A \arrow[from=U, to=D, phantom, "\alpha \Downarrow"] \end{tikzcd}$$

of $\mathcal{C}$ such that we have an equality

$$\begin{tikzcd} X \arrow[r, bend left, "\phi"{name=U}] \arrow[r, bend right, "\psi"'{name=D}] & A \arrow[r, "f"] & B \arrow[from=U, to=D, phantom, "\alpha \Downarrow"] \end{tikzcd} = \begin{tikzcd} X \arrow[r, bend left, "f \circ \phi"{name=U}] \arrow[r, bend right, "f \circ \psi"'{name=D}] & B \arrow[from=U, to=D, phantom, "\beta \Downarrow"] \end{tikzcd}$$

of pasting diagrams in $\mathcal{C}$, i.e. such that we have

$$\beta = \mathrm{id}_f \star \alpha.$$

**Proposition 14.1.10.1.3.** Let $f\colon A \to B$ be a 1-morphism of $\mathcal{C}$.

1. *Characterisations.* The following conditions are equivalent:
   (a) The morphism $f$ is pseudomonic.
   (b) The morphism $f$ is representably full on cores and representably faithful.
   (c) We have an isocomma square of the form

$$A \overset{\text{eq.}}{\cong} A \overset{\leftrightarrow}{\times}_B A, \qquad \begin{tikzcd} A \arrow[r, "\mathrm{id}_A"] \arrow[d, "\mathrm{id}_A"'] & A \arrow[d, "F"] \\ A \arrow[r, "F"'] & B \arrow[from=2-1, to=1-2, phantom, "\Leftrightarrow"] \end{tikzcd}$$

   in $\mathcal{C}$ up to equivalence.

2. *Interaction With Cotensors.* If $C$ has cotensors with $\mathbb{1}$, then the following conditions are equivalent:

   (a) The morphism $f$ is pseudomonic.

   (b) We have an isocomma square of the form

$$A \overset{\text{eq.}}{\cong} A \overset{\leftrightarrow}{\times}_{\mathbb{1}\pitchfork F} B, \qquad \begin{tikzcd} A \arrow[r, hook] \arrow[d, "F"'] & \mathbb{1} \pitchfork A \arrow[d, "\mathbb{1}\pitchfork F"] \arrow[dl, phantom, "\Leftrightarrow"] \\ B \arrow[r, hook] & \mathbb{1} \pitchfork B \end{tikzcd}$$

   in $C$ up to equivalence.

*Proof.* *Item 1, Characterisations*: Omitted.
*Item 2, Interaction With Cotensors*: Omitted. □

## 14.2 Epimorphisms in Bicategories

### 14.2.1 Corepresentably Faithful Morphisms

Let $C$ be a bicategory.

**Definition 14.2.1.1.1.** A 1-morphism $f : A \to B$ of $C$ is **corepresentably faithful** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f^* : \mathsf{Hom}_C(B, X) \to \mathsf{Hom}_C(A, X)$$

given by precomposition by $f$ is faithful.

**Remark 14.2.1.1.2.** In detail, $f$ is corepresentably faithful if, for all diagrams in $C$ of the form

$$\begin{tikzcd} A \arrow[r, "f"] & B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow\Downarrow\beta"] & X, \end{tikzcd}$$

if we have

$$\alpha \star \mathrm{id}_f = \beta \star \mathrm{id}_f,$$

then $\alpha = \beta$.

**Example 14.2.1.1.3.** Here are some examples of corepresentably faithful morphisms.

1. *Corepresentably Faithful Morphisms in* $\mathsf{Cats}_2$. The corepresentably faithful morphisms in $\mathsf{Cats}_2$ are characterised in Categories, Item 5 of Definition 11.6.1.1.2.

2. *Corepresentably Faithful Morphisms in* **Rel**. Every morphism of **Rel** is corepresentably faithful; see Relations, Item 1 of Definition 8.5.13.1.1.

## 14.2.2 Corepresentably Full Morphisms

Let $C$ be a bicategory.

**Definition 14.2.2.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **corepresentably full** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f^*\colon \mathsf{Hom}_C(B,X) \to \mathsf{Hom}_C(A,X)$$

given by precomposition by $f$ is full.

**Remark 14.2.2.1.2.** In detail, $f$ is corepresentably full if, for each $X \in \mathrm{Obj}(C)$ and each 2-morphism

$$\beta\colon \phi\circ f \Longrightarrow \psi\circ f, \qquad \begin{tikzcd} A \arrow[r, bend left, "\phi\circ f"] \arrow[r, bend right, "\psi\circ f"'] \arrow[r, phantom, "\beta\Downarrow"] & X \end{tikzcd}$$

of $C$, there exists a 2-morphism

$$\alpha\colon \phi \Longrightarrow \psi, \qquad \begin{tikzcd} B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & X \end{tikzcd}$$

of $C$ such that we have an equality

$$\begin{tikzcd} A \arrow[r, "f"] & B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & X \end{tikzcd} = \begin{tikzcd} A \arrow[r, bend left, "\phi\circ f"] \arrow[r, bend right, "\psi\circ f"'] \arrow[r, phantom, "\beta\Downarrow"] & X \end{tikzcd}$$

of pasting diagrams in $C$, i.e. such that we have

$$\beta = \alpha \star \mathrm{id}_f.$$

**Example 14.2.2.1.3.** Here are some examples of corepresentably full morphisms.

1. *Corepresentably Full Morphisms in* $\mathsf{Cats}_2$. The corepresentably full morphisms in $\mathsf{Cats}_2$ are characterised in Categories, Item 7 of Definition 11.6.2.1.2.

2. *Corepresentably Full Morphisms in* $\mathbf{Rel}$. The corepresentably full morphisms in $\mathbf{Rel}$ are characterised in Relations, Item 2 of Definition 8.5.13.1.1.

### 14.2.3 Corepresentably Fully Faithful Morphisms

Let $C$ be a bicategory.

**Definition 14.2.3.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **corepresentably fully faithful**[4] if the following equivalent conditions are satisfied:

1. The 1-morphism $f$ is corepresentably full (Definition 14.2.2.1.1) and corepresentably faithful (Definition 14.2.1.1.1).

2. For each $X \in \mathrm{Obj}(C)$, the functor

$$f^*\colon \mathsf{Hom}_C(B, X) \to \mathsf{Hom}_C(A, X)$$

given by precomposition by $f$ is fully faithful.

**Remark 14.2.3.1.2.** In detail, $f$ is corepresentably fully faithful if the conditions in Definition 14.2.1.1.2 and Definition 14.2.2.1.2 hold:

1. For all diagrams in $C$ of the form

$$\begin{tikzcd} A \arrow[r, "f"] & B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow\Downarrow\beta"] & X, \end{tikzcd}$$

if we have

$$\alpha \star \mathrm{id}_f = \beta \star \mathrm{id}_f,$$

then $\alpha = \beta$.

[4] *Further Terminology:* Corepresentably fully faithful morphisms have also been called **lax epimorphisms** in the literature (e.g. in [Adá+01]), though we will always use the name "corepresentably fully faithful morphism" instead in this work.

2. For each $X \in \mathrm{Obj}(C)$ and each 2-morphism

$$\beta \colon \phi \circ f \Longrightarrow \psi \circ f, \qquad \begin{tikzcd} A \arrow[r, bend left, "\phi\circ f"] \arrow[r, bend right, "\psi\circ f"'] \arrow[r, phantom, "\beta\Downarrow"] & X \end{tikzcd}$$

of $C$, there exists a 2-morphism

$$\alpha \colon \phi \Longrightarrow \psi, \qquad \begin{tikzcd} B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & X \end{tikzcd}$$

of $C$ such that we have an equality

$$\begin{tikzcd} A \arrow[r, "f"] & B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & X \end{tikzcd} = \begin{tikzcd} A \arrow[r, bend left, "\phi\circ f"] \arrow[r, bend right, "\psi\circ f"'] \arrow[r, phantom, "\beta\Downarrow"] & X \end{tikzcd}$$

of pasting diagrams in $C$, i.e. such that we have

$$\beta = \alpha \star \mathrm{id}_f .$$

**Example 14.2.3.1.3.** Here are some examples of corepresentably fully faithful morphisms.

1. *Corepresentably Fully Faithful Morphisms in* $\mathsf{Cats}_2$. The fully faithful epimorphisms in $\mathsf{Cats}_2$ are characterised in Categories, Item 10 of Definition 11.6.3.1.2.

2. *Corepresentably Fully Faithful Morphisms in* $\mathbf{Rel}$. The corepresentably fully faithful morphisms of $\mathbf{Rel}$ coincide (Relations, Item 3 of Definition 8.5.13.1.1) with the corepresentably full morphisms in $\mathbf{Rel}$, which are characterised in Relations, Item 2 of Definition 8.5.13.1.1.

### 14.2.4 Morphisms Corepresentably Faithful on Cores

Let $C$ be a bicategory.

**Definition 14.2.4.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **corepresentably faithful on cores** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f^*\colon \mathsf{Core}(\mathsf{Hom}_C(B,X)) \to \mathsf{Core}(\mathsf{Hom}_C(A,X))$$

given by precomposition by $f$ is faithful.

**Remark 14.2.4.1.2.** In detail, $f$ is corepresentably faithful on cores if, for all diagrams in $C$ of the form

$$\begin{tikzcd} A \arrow[r, "f"] & B \arrow[r, bend left, "\phi"{name=U}] \arrow[r, bend right, "\psi"'{name=D}] & X, \arrow[from=U, to=D, phantom, "\alpha\Downarrow\Downarrow\beta"] \end{tikzcd}$$

if $\alpha$ and $\beta$ are 2-isomorphisms and we have

$$\alpha \star \mathrm{id}_f = \beta \star \mathrm{id}_f,$$

then $\alpha = \beta$.

## 14.2.5 Morphisms Corepresentably Full on Cores

Let $C$ be a bicategory.

**Definition 14.2.5.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **corepresentably full on cores** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f^*\colon \mathsf{Core}(\mathsf{Hom}_C(B,X)) \to \mathsf{Core}(\mathsf{Hom}_C(A,X))$$

given by precomposition by $f$ is full.

**Remark 14.2.5.1.2.** In detail, $f$ is corepresentably full on cores if, for each $X \in \mathrm{Obj}(C)$ and each 2-isomorphism

$$\beta\colon \phi \circ f \overset{\sim}{\Longrightarrow} \psi \circ f, \qquad \begin{tikzcd} A \arrow[r, bend left, "\phi\circ f"{name=U}] \arrow[r, bend right, "\psi\circ f"'{name=D}] & X \arrow[from=U, to=D, phantom, "\beta\Downarrow"] \end{tikzcd}$$

of $C$, there exists a 2-isomorphism

$$\alpha\colon \phi \overset{\sim}{\Longrightarrow} \psi, \qquad \begin{tikzcd} B \arrow[r, bend left, "\phi"{name=U}] \arrow[r, bend right, "\psi"'{name=D}] & X \arrow[from=U, to=D, phantom, "\alpha\Downarrow"] \end{tikzcd}$$

of $C$ such that we have an equality

$$\begin{tikzcd} A \arrow[r, "f"] & B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & X \end{tikzcd} = \begin{tikzcd} A \arrow[r, bend left, "\phi\circ f"] \arrow[r, bend right, "\psi\circ f"'] \arrow[r, phantom, "\beta\Downarrow"] & X \end{tikzcd}$$

of pasting diagrams in $C$, i.e. such that we have

$$\beta = \alpha \star \mathrm{id}_f .$$

## 14.2.6 Morphisms Corepresentably Fully Faithful on Cores

Let $C$ be a bicategory.

**Definition 14.2.6.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **corepresentably fully faithful on cores** if the following equivalent conditions are satisfied:

1. The 1-morphism $f$ is corepresentably full on cores (Definition 14.2.5.1.1) and corepresentably faithful on cores (Definition 14.2.1.1.1).
2. For each $X \in \mathrm{Obj}(C)$, the functor

   $$f^*\colon \mathsf{Core}(\mathsf{Hom}_C(B, X)) \to \mathsf{Core}(\mathsf{Hom}_C(A, X))$$

   given by precomposition by $f$ is fully faithful.

**Remark 14.2.6.1.2.** In detail, $f$ is corepresentably fully faithful on cores if the conditions in Definition 14.2.4.1.2 and Definition 14.2.5.1.2 hold:

1. For all diagrams in $C$ of the form

   $$\begin{tikzcd} A \arrow[r, "f"] & B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow\Downarrow\beta"] & X, \end{tikzcd}$$

   if $\alpha$ and $\beta$ are 2-isomorphisms and we have

   $$\alpha \star \mathrm{id}_f = \beta \star \mathrm{id}_f,$$

   then $\alpha = \beta$.

2. For each $X \in \mathrm{Obj}(\mathcal{C})$ and each 2-isomorphism

$$\beta\colon \phi \circ f \overset{\sim}{\Longrightarrow} \psi \circ f, \qquad \begin{tikzcd} A \arrow[r, bend left, "\phi\circ f"] \arrow[r, bend right, "\psi\circ f"'] \arrow[r, phantom, "\beta\Downarrow"] & X \end{tikzcd}$$

of $\mathcal{C}$, there exists a 2-isomorphism

$$\alpha\colon \phi \overset{\sim}{\Longrightarrow} \psi, \qquad \begin{tikzcd} B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & X \end{tikzcd}$$

of $\mathcal{C}$ such that we have an equality

$$\begin{tikzcd} A \arrow[r, "f"] & B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & X \end{tikzcd} = \begin{tikzcd} A \arrow[r, bend left, "\phi\circ f"] \arrow[r, bend right, "\psi\circ f"'] \arrow[r, phantom, "\beta\Downarrow"] & X \end{tikzcd}$$

of pasting diagrams in $\mathcal{C}$, i.e. such that we have

$$\beta = \alpha \star \mathrm{id}_f .$$

## 14.2.7 Corepresentably Essentially Injective Morphisms

Let $\mathcal{C}$ be a bicategory.

**Definition 14.2.7.1.1.** A 1-morphism $f\colon A \to B$ of $\mathcal{C}$ is **corepresentably essentially injective** if, for each $X \in \mathrm{Obj}(\mathcal{C})$, the functor

$$f^*\colon \mathsf{Hom}_{\mathcal{C}}(B, X) \to \mathsf{Hom}_{\mathcal{C}}(A, X)$$

given by precomposition by $f$ is essentially injective.

**Remark 14.2.7.1.2.** In detail, $f$ is corepresentably essentially injective if, for each pair of morphisms $\phi, \psi\colon B \rightrightarrows X$ of $\mathcal{C}$, the following condition is satisfied:

($\star$) If $\phi \circ f \cong \psi \circ f$, then $\phi \cong \psi$.

### 14.2.8 Corepresentably Conservative Morphisms

Let $C$ be a bicategory.

**Definition 14.2.8.1.1.** A 1-morphism $f\colon A \to B$ of $C$ is **corepresentably conservative** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f^*\colon \mathsf{Hom}_C(B,X) \to \mathsf{Hom}_C(A,X)$$

given by precomposition by $f$ is conservative.

**Remark 14.2.8.1.2.** In detail, $f$ is corepresentably conservative if, for each pair of morphisms $\phi, \psi\colon B \rightrightarrows X$ and each 2-morphism

$$\alpha\colon \phi \overset{\sim}{\Longrightarrow} \psi, \qquad \begin{tikzcd} B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & X \end{tikzcd}$$

of $C$, if the 2-morphism

$$\alpha \star \mathrm{id}_f\colon \phi \circ f \Longrightarrow \psi \circ f, \qquad \begin{tikzcd} A \arrow[r, bend left, "\phi\circ f"] \arrow[r, bend right, "\psi\circ f"'] \arrow[r, phantom, "\Downarrow \alpha\star\mathrm{id}_f"] & X \end{tikzcd}$$

is a 2-isomorphism, then so is $\alpha$.

### 14.2.9 Strict Epimorphisms

Let $C$ be a bicategory.

**Definition 14.2.9.1.1.** A 1-morphism $f\colon A \to B$ is a **strict epimorphism in $C$** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f^*\colon \mathsf{Hom}_C(B,X) \to \mathsf{Hom}_C(A,X)$$

given by precomposition by $f$ is injective on objects, i.e. its action on objects

$$f_*\colon \mathrm{Obj}(\mathsf{Hom}_C(B,X)) \to \mathrm{Obj}(\mathsf{Hom}_C(A,X))$$

is injective.

**Remark 14.2.9.1.2.** In detail, $f$ is a strict epimorphism if, for each diagram in $C$ of the form

$$A \xrightarrow{f} B \underset{\psi}{\overset{\phi}{\rightrightarrows}} X,$$

if $\phi \circ f = \psi \circ f$, then $\phi = \psi$.

**Example 14.2.9.1.3.** Here are some examples of strict epimorphisms.

1. *Strict Epimorphisms in* $\mathsf{Cats}_2$. The strict epimorphisms in $\mathsf{Cats}_2$ are characterised in Categories, Item 1 of Definition 11.7.3.1.2.

2. *Strict Epimorphisms in* **Rel**. The strict epimorphisms in **Rel** are characterised in Relations, Definition 8.5.12.1.1.

### 14.2.10 Pseudoepic Morphisms

Let $C$ be a bicategory.

**Definition 14.2.10.1.1.** A 1-morphism $f: A \to B$ of $C$ is **pseudoepic** if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f^*: \mathsf{Hom}_C(B, X) \to \mathsf{Hom}_C(A, X)$$

given by precomposition by $f$ is pseudomonic.

**Remark 14.2.10.1.2.** In detail, a 1-morphism $f: A \to B$ of $C$ is pseudoepic if it satisfies the following conditions:

1. For all diagrams in $C$ of the form

$$\begin{tikzcd} A \arrow[r, "f"] & B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow\Downarrow\beta"] & X, \end{tikzcd}$$

   if we have

$$\alpha \star \mathrm{id}_f = \beta \star \mathrm{id}_f,$$

   then $\alpha = \beta$.

2. For each $X \in \mathrm{Obj}(\mathcal{C})$ and each 2-isomorphism

$$\beta\colon \phi \circ f \overset{\sim}{\Longrightarrow} \psi \circ f, \qquad \begin{tikzcd} A \arrow[r, bend left, "\phi\circ f"] \arrow[r, bend right, "\psi\circ f"'] \arrow[r, phantom, "\beta\Downarrow"] & X \end{tikzcd}$$

of $\mathcal{C}$, there exists a 2-isomorphism

$$\alpha\colon \phi \overset{\sim}{\Longrightarrow} \psi, \qquad \begin{tikzcd} B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & X \end{tikzcd}$$

of $\mathcal{C}$ such that we have an equality

$$\begin{tikzcd} A \arrow[r, "f"] & B \arrow[r, bend left, "\phi"] \arrow[r, bend right, "\psi"'] \arrow[r, phantom, "\alpha\Downarrow"] & X \end{tikzcd} = \begin{tikzcd} A \arrow[r, bend left, "\phi\circ f"] \arrow[r, bend right, "\psi\circ f"'] \arrow[r, phantom, "\beta\Downarrow"] & X \end{tikzcd}$$

of pasting diagrams in $\mathcal{C}$, i.e. such that we have

$$\beta = \alpha \star \mathrm{id}_f .$$

**Proposition 14.2.10.1.3.** Let $f\colon A \to B$ be a 1-morphism of $\mathcal{C}$.

1. *Characterisations.* The following conditions are equivalent:

   (a) The morphism $f$ is pseudoepic.

   (b) The morphism $f$ is corepresentably full on cores and corepresentably faithful.

   (c) We have an isococomma square of the form

$$B \overset{\text{eq.}}{\cong} B \overset{\leftrightarrow}{\coprod}_A B, \qquad \begin{tikzcd} B & B \arrow[l, "\mathrm{id}_B"'] \\ B \arrow[u, "\mathrm{id}_B"] & A \arrow[l, "F"] \arrow[u, "F"'] \arrow[ul, phantom, "\Leftrightarrow"] \end{tikzcd}$$

   in $\mathcal{C}$ up to equivalence.

*Proof.* *Item 1, Characterisations*: Omitted. □

# Appendices

## A Other Chapters



## References

[Adá+01] Jiří Adámek, Robert El Bashir, Manuela Sobral, and Jiří Velebil. "On Functors Which Are Lax Epimorphisms". In: *Theory Appl. Categ.* 8 (2001), pp. 509–521. ISSN: 1201-561X (cit. on p. 14).