

Types of Morphisms in Bicategories

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Ø19H 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 *pseudomononic 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.

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019J 14.1 Monomorphisms in Bicategories

019K 14.1.1 Representably Faithful Morphisms

Let C be a bicategory.

019L DEFINITION 14.1.1.1.1 ► REPRESENTABLY FAITHFUL MORPHISMS

A 1-morphism $f: A \rightarrow B$ of C is **representably faithful**¹ if, for each $X \in \text{Obj}(C)$, the functor

$$f_*: \text{Hom}_C(X, A) \rightarrow \text{Hom}_C(X, B)$$

given by postcomposition by f is faithful.

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

019M REMARK 14.1.1.1.2 ► UNWINDING DEFINITION 14.1.1.1.1

In detail, f is representably faithful if, for all diagrams in C of the form

$$X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \Downarrow \beta \\ \xrightarrow{\psi} \end{array} A \xrightarrow{f} B,$$

if we have

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

then $\alpha = \beta$.

019N

EXAMPLE 14.1.1.3 ► EXAMPLES OF REPRESENTABLY FAITHFUL MORPHISMS

Here are some examples of representably faithful morphisms.

019P

1. *Representably Faithful Morphisms in \mathbf{Cats}_2* . The representably faithful morphisms in \mathbf{Cats}_2 are precisely the faithful functors; see [Categories](#), [Item 2](#) of [Proposition 11.6.1.1.2](#).

019Q

2. *Representably Faithful Morphisms in \mathbf{Rel}* . Every morphism of \mathbf{Rel} is representably faithful; see [Relations](#), [??](#) of [??](#).

019R 14.1.2 Representably Full Morphisms

Let C be a bicategory.

019S

DEFINITION 14.1.2.1.1 ► REPRESENTABLY FULL MORPHISMS

A 1-morphism $f: A \rightarrow B$ of C is **representably full**¹ if, for each $X \in \mathrm{Obj}(C)$, the functor

$$f_*: \mathrm{Hom}_C(X, A) \rightarrow \mathrm{Hom}_C(X, B)$$

given by postcomposition by f is full.

¹*Further Terminology:* Also called simply a **full morphism**, based on [Item 1](#) of [Example 14.1.2.1.3](#).

019T

REMARK 14.1.2.1.2 ► UNWINDING DEFINITION 14.1.2.1.1

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

$$\beta: f \circ \phi \Longrightarrow f \circ \psi, \quad X \begin{array}{c} \xrightarrow{f \circ \phi} \\ \beta \Downarrow \\ \xrightarrow{f \circ \psi} \end{array} B$$

of C , there exists a 2-morphism

$$\alpha: \phi \Longrightarrow \psi, \quad X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} A$$

of C such that we have an equality

$$X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} A \xrightarrow{f} B = X \begin{array}{c} \xrightarrow{f \circ \phi} \\ \beta \Downarrow \\ \xrightarrow{f \circ \psi} \end{array} B$$

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

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

019U

EXAMPLE 14.1.2.1.3 ► EXAMPLES OF REPRESENTABLY FULL MORPHISMS

Here are some examples of representably full morphisms.

019V

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

019W

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

019X 14.1.3 Representably Fully Faithful Morphisms

Let C be a bicategory.

DEFINITION 14.1.3.11 Representably Fully Faithful Morphisms

019Y

A 1-morphism $f: A \rightarrow B$ of C is **representably fully faithful**¹ if the following equivalent conditions are satisfied:

- 019Z 1. The 1-morphism f is representably faithful (Definition 14.1.1.1) and representably full (Definition 14.1.2.1).
- 01A0 2. For each $X \in \text{Obj}(C)$, the functor

$$f_*: \text{Hom}_C(X, A) \rightarrow \text{Hom}_C(X, B)$$

given by postcomposition by f is fully faithful.

¹*Further Terminology:* Also called simply a **fully faithful morphism**, based on Item 1 of Example 14.1.3.1.3.

01A1 **REMARK 14.1.3.1.2 ► UNWINDING REPRESENTABLY FULLY FAITHFUL MORPHISMS**

In detail, f is representably fully faithful if the conditions in Remark 14.1.1.1.2 and Remark 14.1.2.1.2 hold:

1. For all diagrams in C of the form

$$X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \beta \\ \xrightarrow{\psi} \end{array} A \xrightarrow{f} B,$$

if we have

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

then $\alpha = \beta$.

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

$$\beta: f \circ \phi \Rightarrow f \circ \psi, \quad X \begin{array}{c} \xrightarrow{f \circ \phi} \\ \beta \Downarrow \\ \xrightarrow{f \circ \psi} \end{array} B$$

of C , there exists a 2-morphism

$$\alpha: \phi \Rightarrow \psi, \quad X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} A$$

of C such that we have an equality

$$X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} A \xrightarrow{f} B = X \begin{array}{c} \xrightarrow{f \circ \phi} \\ \beta \Downarrow \\ \xrightarrow{f \circ \psi} \end{array} B$$

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

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

01A2

EXAMPLE 14.1.3.1.3 ► EXAMPLES OF REPRESENTABLY FULLY FAITHFUL MORPHISMS

Here are some examples of representably fully faithful morphisms.

01A3

1. *Representably Fully Faithful Morphisms in \mathbf{Cats}_2 .* The representably fully faithful morphisms in \mathbf{Cats}_2 are precisely the fully faithful functors; see [Categories](#), [Item 6](#) of [Proposition 11.6.3.1.2](#).

01A4

2. *Representably Fully Faithful Morphisms in \mathbf{Rel} .* The representably fully faithful morphisms of \mathbf{Rel} coincide ([Relations](#), ?? of ??) with the representably full morphisms in \mathbf{Rel} , which are characterised in [Relations](#), ?? of ??.

01A5 14.1.4 Morphisms Representably Faithful on Cores

Let C be a bicategory.

01A6

DEFINITION 14.1.4.1.1 ► MORPHISMS REPRESENTABLY FAITHFUL ON CORES

A 1-morphism $f: A \rightarrow B$ of C is **representably faithful on cores** if, for each $X \in \text{Obj}(C)$, the functor

$$f_*: \text{Core}(\text{Hom}_C(X, A)) \rightarrow \text{Core}(\text{Hom}_C(X, B))$$

given by postcomposition by f is faithful.

01A7 REMARK 14.1.4.1.2 ► UNWINDING DEFINITION 14.1.4.1.1

In detail, f is representably faithful on cores if, for all diagrams in C of the form

$$X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \Downarrow \beta \\ \xrightarrow{\psi} \end{array} A \xrightarrow{f} B,$$

if α and β are 2-isomorphisms and we have

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

then $\alpha = \beta$.

01A8 14.1.5 Morphisms Representably Full on Cores

Let C be a bicategory.

01A9 DEFINITION 14.1.5.1.1 ► MORPHISMS REPRESENTABLY FULL ON CORES

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

$$f_*: \mathrm{Core}(\mathrm{Hom}_C(X, A)) \rightarrow \mathrm{Core}(\mathrm{Hom}_C(X, B))$$

given by postcomposition by f is full.

01AA REMARK 14.1.5.1.2 ► UNWINDING DEFINITION 14.1.5.1.1

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

$$\beta: f \circ \phi \xrightarrow{\sim} f \circ \psi, \quad X \begin{array}{c} \xrightarrow{f \circ \phi} \\ \beta \Downarrow \\ \xrightarrow{f \circ \psi} \end{array} B$$

of C , there exists a 2-isomorphism

$$\alpha: \phi \xRightarrow{\sim} \psi, \quad X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} A$$

of C such that we have an equality

$$X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} A \xrightarrow{f} B = X \begin{array}{c} \xrightarrow{f \circ \phi} \\ \beta \Downarrow \\ \xrightarrow{f \circ \psi} \end{array} B$$

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

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

01AB 14.1.6 Morphisms Representably Fully Faithful on Cores

Let C be a bicategory.

01AC DEFINITION 14.1.6.1.1 ► MORPHISMS REPRESENTABLY FULLY FAITHFUL ON CORES

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

- 01AD 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](#)).
- 01AE 2. For each $X \in \text{Obj}(C)$, the functor

$$f_*: \text{Core}(\text{Hom}_C(X, A)) \rightarrow \text{Core}(\text{Hom}_C(X, B))$$

given by postcomposition by f is fully faithful.

01AF

REMARK 14.1.6.1.2 ► UNWINDING DEFINITION 14.1.6.1.1

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

1. For all diagrams in C of the form

$$X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \Downarrow \beta \\ \xrightarrow{\psi} \end{array} A \xrightarrow{f} B,$$

if α and β 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

$$\beta: f \circ \phi \xrightarrow{\sim} f \circ \psi, \quad X \begin{array}{c} \xrightarrow{f \circ \phi} \\ \beta \Downarrow \Downarrow \\ \xrightarrow{f \circ \psi} \end{array} B$$

of C , there exists a 2-isomorphism

$$\alpha: \phi \xrightarrow{\sim} \psi, \quad X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \Downarrow \\ \xrightarrow{\psi} \end{array} A$$

of C such that we have an equality

$$X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \Downarrow \\ \xrightarrow{\psi} \end{array} A \xrightarrow{f} B = X \begin{array}{c} \xrightarrow{f \circ \phi} \\ \beta \Downarrow \Downarrow \\ \xrightarrow{f \circ \psi} \end{array} B$$

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

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

01AG 14.1.7 Representably Essentially Injective Morphisms

Let C be a bicategory.

01AH DEFINITION 14.1.7.1.1 ► REPRESENTABLY ESSENTIALLY INJECTIVE MORPHISMS

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

$$f_*: \text{Hom}_C(X, A) \rightarrow \text{Hom}_C(X, B)$$

given by postcomposition by f is essentially injective.

01AJ REMARK 14.1.7.1.2 ► UNWINDING DEFINITION 14.1.7.1.1

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

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

01AK 14.1.8 Representably Conservative Morphisms

Let C be a bicategory.

01AL DEFINITION 14.1.8.1.1 ► REPRESENTABLY CONSERVATIVE MORPHISMS

A 1-morphism $f: A \rightarrow B$ of C is **representably conservative** if, for each $X \in \text{Obj}(C)$, the functor

$$f_*: \text{Hom}_C(X, A) \rightarrow \text{Hom}_C(X, B)$$

given by postcomposition by f is conservative.

01AM REMARK 14.1.8.1.2 ► UNWINDING DEFINITION 14.1.8.1.1

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

$$\alpha: \phi \Rightarrow \psi, \quad X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} A$$

of C , if the 2-morphism

$$\mathrm{id}_f \star \alpha: f \circ \phi \Rightarrow f \circ \psi, \quad X \begin{array}{c} \xrightarrow{f \circ \phi} \\ \parallel \\ \mathrm{id}_f \star \alpha \Downarrow \\ \xrightarrow{f \circ \psi} \end{array} B$$

is a 2-isomorphism, then so is α .

01AN 14.1.9 Strict Monomorphisms

Let C be a bicategory.

01AP DEFINITION 14.1.9.1.1 ► STRICT MONOMORPHISMS

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

$$f_*: \mathrm{Hom}_C(X, A) \rightarrow \mathrm{Hom}_C(X, B)$$

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

$$f_*: \mathrm{Obj}(\mathrm{Hom}_C(X, A)) \rightarrow \mathrm{Obj}(\mathrm{Hom}_C(X, B))$$

is injective.

01AQ REMARK 14.1.9.1.2 ► UNWINDING DEFINITION 14.1.9.1.1

In detail, f is a strict monomorphism in C if, for each diagram in C of the form

$$X \begin{array}{c} \xrightarrow{\phi} \\ \xrightarrow{\psi} \end{array} A \xrightarrow{f} B,$$

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

01AR EXAMPLE 14.1.9.1.3 ► EXAMPLES OF STRICT MONOMORPHISMS

Here are some examples of strict monomorphisms.

- 01AS 1. *Strict Monomorphisms in \mathbf{Cats}_2* . The strict monomorphisms in \mathbf{Cats}_2 are precisely the functors which are injective on objects and injective on morphisms; see [Categories, Item 1](#) of [Proposition 11.7.2.1.2](#).
- 01AT 2. *Strict Monomorphisms in \mathbf{Rel}* . The strict monomorphisms in \mathbf{Rel} are characterised in [Relations, ??](#).

01AU 14.1.10 Pseudomonic Morphisms

Let C be a bicategory.

01AV DEFINITION 14.1.10.1.1 ► PSEUDOMONIC MORPHISMS

A 1-morphism $f: A \rightarrow B$ of C is **pseudomonic** if, for each $X \in \text{Obj}(C)$, the functor

$$f_*: \text{Hom}_C(X, A) \rightarrow \text{Hom}_C(X, B)$$

given by postcomposition by f is pseudomonic.

01AW REMARK 14.1.10.1.2 ► UNWINDING DEFINITION 14.1.10.1.1

In detail, a 1-morphism $f: A \rightarrow B$ of C is pseudomonic if it satisfies the following conditions:

01AX

1. For all diagrams in C of the form

$$X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \Downarrow \beta \\ \xrightarrow{\psi} \end{array} A \xrightarrow{f} B,$$

if we have

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

then $\alpha = \beta$.

01AY

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

$$\beta: f \circ \phi \xRightarrow{\sim} f \circ \psi, \quad X \begin{array}{c} \xrightarrow{f \circ \phi} \\ \beta \Downarrow \Downarrow \\ \xrightarrow{f \circ \psi} \end{array} B$$

of C , there exists a 2-isomorphism

$$\alpha: \phi \xRightarrow{\sim} \psi, \quad X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \Downarrow \\ \xrightarrow{\psi} \end{array} A$$

of C such that we have an equality

$$X \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \Downarrow \\ \xrightarrow{\psi} \end{array} A \xrightarrow{f} B = X \begin{array}{c} \xrightarrow{f \circ \phi} \\ \beta \Downarrow \Downarrow \\ \xrightarrow{f \circ \psi} \end{array} B$$

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

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

01AZ

PROPOSITION 14.1.10.1.3 ► PROPERTIES OF PSEUDOMONOID MORPHISMS

Let $f: A \rightarrow B$ be a 1-morphism of C .

01B0

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

01B1

(a) The morphism f is pseudomonic.

01B2

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

01B3

(c) We have an isocomma square of the form

$$A \stackrel{\text{eq.}}{\cong} A \times_B A, \quad \begin{array}{ccc} A & \xrightarrow{\text{id}_A} & A \\ \text{id}_A \downarrow & \nearrow \text{dashed} & \downarrow F \\ A & \xrightarrow{F} & B \end{array}$$

in \mathcal{C} up to equivalence.

01B4

2. *Interaction With Cotensors.* If \mathcal{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

$$A \stackrel{\text{eq.}}{\cong} A \times_{\mathbb{1} \pitchfork F} B, \quad \begin{array}{ccc} A & \hookrightarrow & \mathbb{1} \pitchfork A \\ F \downarrow & \nearrow \text{dashed} & \downarrow \mathbb{1} \pitchfork F \\ B & \hookrightarrow & \mathbb{1} \pitchfork B \end{array}$$


in \mathcal{C} up to equivalence.

PROOF 14.1.10.1.4 ► PROOF OF PROPOSITION 14.1.10.1.3

Item 1: Characterisations

Omitted.

Item 2: Interaction With Cotensors

Omitted. 01B5 **14.2 Epimorphisms in Bicategories**01B6 **14.2.1 Corepresentably Faithful Morphisms**Let C be a bicategory.01B7 **DEFINITION 14.2.1.1.1 ► COREPRESENTABLY FAITHFUL MORPHISMS**

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

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

given by precomposition by f is faithful.

01B8 **REMARK 14.2.1.1.2 ► UNWINDING DEFINITION 14.2.1.1**

In detail, f is corepresentably faithful if, for all diagrams in C of the form

$$A \xrightarrow{f} B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \Downarrow \beta \\ \xrightarrow{\psi} \end{array} X,$$

if we have

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

then $\alpha = \beta$.

01B9 **EXAMPLE 14.2.1.1.3 ► EXAMPLES OF COREPRESENTABLY FAITHFUL MORPHISMS**

Here are some examples of corepresentably faithful morphisms.

- 01BA 1. *Corepresentably Faithful Morphisms in Cats_2 .* The corepresentably faithful morphisms in Cats_2 are characterised in [Categories, Item 5](#)

of **Proposition 11.6.1.1.2**.

01BB

2. *Corepresentably Faithful Morphisms in Rel*. Every morphism of **Rel** is corepresentably faithful; see **Relations**, ?? of ??.

01BC

14.2.2 Corepresentably Full Morphisms

Let C be a bicategory.

01BD

DEFINITION 14.2.2.1.1 ► COREPRESENTABLY FULL MORPHISMS

A 1-morphism $f: A \rightarrow B$ of C is **corepresentably full** if, for each $X \in \text{Obj}(C)$, the functor

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

given by precomposition by f is full.

01BE

REMARK 14.2.2.1.2 ► UNWINDING DEFINITION 14.2.2.1.1

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

$$\beta: \phi \circ f \Rightarrow \psi \circ f, \quad A \begin{array}{c} \xrightarrow{\phi \circ f} \\ \beta \Downarrow \\ \xrightarrow{\psi \circ f} \end{array} X$$

of C , there exists a 2-morphism

$$\alpha: \phi \Rightarrow \psi, \quad B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} X$$

of C such that we have an equality

$$A \xrightarrow{f} B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} X = A \begin{array}{c} \xrightarrow{\phi \circ f} \\ \beta \Downarrow \\ \xrightarrow{\psi \circ f} \end{array} X$$

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

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

01BF

EXAMPLE 14.2.2.1.3 ► EXAMPLES OF COREPRESENTABLY FULL MORPHISMS

Here are some examples of corepresentably full morphisms.

01BG

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

01BH

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

01BJ

14.2.3 Corepresentably Fully Faithful Morphisms

Let C be a bicategory.

01BK

DEFINITION 14.2.3.1.1 ► COREPRESENTABLY FULLY FAITHFUL MORPHISMS

A 1-morphism $f: A \rightarrow B$ of C is **corepresentably fully faithful**¹ if the following equivalent conditions are satisfied:

01BL

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

01BM

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

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

given by precomposition by f is fully faithful.

¹*Further Terminology:* Corepresentably fully faithful morphisms have also been called **lax epimorphisms** in the literature (e.g. in [Adá+o1]), though we will always use the name “corepresentably fully faithful morphism” instead in this work.

01BN

REMARK 14.2.3.1.2 ► UNWINDING DEFINITION 14.2.3.1.1

In detail, f is corepresentably fully faithful if the conditions in Remark 14.2.1.1.2 and Remark 14.2.2.1.2 hold:

1. For all diagrams in C of the form

$$A \xrightarrow{f} B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \beta \\ \xrightarrow{\psi} \end{array} X,$$

if we have

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

then $\alpha = \beta$.

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

$$\beta: \phi \circ f \Rightarrow \psi \circ f, \quad A \begin{array}{c} \xrightarrow{\phi \circ f} \\ \beta \Downarrow \\ \xrightarrow{\psi \circ f} \end{array} X$$

of C , there exists a 2-morphism

$$\alpha: \phi \Rightarrow \psi, \quad B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} X$$

of C such that we have an equality

$$A \xrightarrow{f} B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} X = A \begin{array}{c} \xrightarrow{\phi \circ f} \\ \beta \Downarrow \\ \xrightarrow{\psi \circ f} \end{array} X$$

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

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

01BP

EXAMPLE 14.2.3.1.3 ► EXAMPLES OF COREPRESENTABLY FULLY FAITHFUL MORPHISMS

Here are some examples of corepresentably fully faithful morphisms.

01BQ

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

01BR

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

01BS 14.2.4 Morphisms Corepresentably Faithful on Cores

Let C be a bicategory.

01BT

DEFINITION 14.2.4.1.1 ► MORPHISMS COREPRESENTABLY FAITHFUL ON CORES

A 1-morphism $f: A \rightarrow B$ of C is **corepresentably faithful on cores** if, for each $X \in \text{Obj}(C)$, the functor

$$f^*: \text{Core}(\text{Hom}_C(B, X)) \rightarrow \text{Core}(\text{Hom}_C(A, X))$$

given by precomposition by f is faithful.

01BU

REMARK 14.2.4.1.2 ► UNWINDING DEFINITION 14.2.4.1.1

In detail, f is corepresentably faithful on cores if, for all diagrams in C of the form

$$A \xrightarrow{f} B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \Downarrow \beta \\ \xrightarrow{\psi} \end{array} X,$$

if α and β are 2-isomorphisms and we have

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

then $\alpha = \beta$.

01BV 14.2.5 Morphisms Corepresentably Full on Cores

Let C be a bicategory.

01BW DEFINITION 14.2.5.1.1 ► MORPHISMS COREPRESENTABLY FULL ON CORES

A 1-morphism $f: A \rightarrow B$ of C is **corepresentably full on cores** if, for each $X \in \text{Obj}(C)$, the functor

$$f^*: \text{Core}(\text{Hom}_C(B, X)) \rightarrow \text{Core}(\text{Hom}_C(A, X))$$

given by precomposition by f is full.

01BX REMARK 14.2.5.1.2 ► UNWINDING DEFINITION 14.2.5.1.1

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

$$\beta: \phi \circ f \xRightarrow{\sim} \psi \circ f, \quad A \begin{array}{c} \xrightarrow{\phi \circ f} \\ \beta \Downarrow \\ \xrightarrow{\psi \circ f} \end{array} X$$

of C , there exists a 2-isomorphism

$$\alpha: \phi \xRightarrow{\sim} \psi, \quad B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} X$$

of C such that we have an equality

$$A \xrightarrow{f} B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} X = A \begin{array}{c} \xrightarrow{\phi \circ f} \\ \beta \Downarrow \\ \xrightarrow{\psi \circ f} \end{array} X$$

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

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

01BY 14.2.6 Morphisms Corepresentably Fully Faithful on Cores

Let C be a bicategory.

01BZ DEFINITION 14.2.6.1.1 ► MORPHISMS COREPRESENTABLY FULLY FAITHFUL ON CORES

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

- 01C0 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).

- 01C1 2. For each $X \in \text{Obj}(C)$, the functor

$$f^*: \text{Core}(\text{Hom}_C(B, X)) \rightarrow \text{Core}(\text{Hom}_C(A, X))$$

given by precomposition by f is fully faithful.

01C2 REMARK 14.2.6.1.2 ► UNWINDING DEFINITION 14.2.6.1.1

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

1. For all diagrams in C of the form

$$A \xrightarrow{f} B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \Downarrow \beta \\ \xrightarrow{\psi} \end{array} X,$$

if α and β are 2-isomorphisms and we have

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

then $\alpha = \beta$.

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

$$\beta: \phi \circ f \xRightarrow{\sim} \psi \circ f, \quad A \begin{array}{c} \xrightarrow{\phi \circ f} \\ \beta \Downarrow \\ \xrightarrow{\psi \circ f} \end{array} X$$

of C , there exists a 2-isomorphism

$$\alpha: \phi \xRightarrow{\sim} \psi, \quad B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} X$$

of C such that we have an equality

$$A \xrightarrow{f} B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} X = A \begin{array}{c} \xrightarrow{\phi \circ f} \\ \beta \Downarrow \\ \xrightarrow{\psi \circ f} \end{array} X$$

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

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

01C3 14.2.7 Corepresentably Essentially Injective Morphisms

Let C be a bicategory.

01C4 DEFINITION 14.2.7.1.1 ► COREPRESENTABLY ESSENTIALLY INJECTIVE MORPHISMS

A 1-morphism $f: A \rightarrow B$ of C is **corepresentably essentially injective** if, for each $X \in \text{Obj}(C)$, the functor

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

given by precomposition by f is essentially injective.

01C5 REMARK 14.2.7.1.2 ► UNWINDING DEFINITION 14.2.7.1.1

In detail, f is corepresentably essentially injective if, for each pair of morphisms $\phi, \psi: B \rightrightarrows X$ of C , the following condition is satisfied:

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

01C6 14.2.8 Corepresentably Conservative Morphisms

Let C be a bicategory.

01C7 DEFINITION 14.2.8.1.1 ► COREPRESENTABLY CONSERVATIVE MORPHISMS

A 1-morphism $f: A \rightarrow B$ of C is **corepresentably conservative** if, for each $X \in \text{Obj}(C)$, the functor

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

given by precomposition by f is conservative.

01C8 REMARK 14.2.8.1.2 ► UNWINDING DEFINITION 14.2.8.1.1

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

$$\alpha: \phi \rightrightarrows \psi, \quad B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} X$$

of C , if the 2-morphism

$$\alpha \star \text{id}_f: \phi \circ f \rightrightarrows \psi \circ f, \quad A \begin{array}{c} \xrightarrow{\phi \circ f} \\ \parallel \\ \alpha \star \text{id}_f \Downarrow \\ \xrightarrow{\psi \circ f} \end{array} X$$

is a 2-isomorphism, then so is α .

01C9 14.2.9 Strict Epimorphisms

Let C be a bicategory.

01CA

DEFINITION 14.2.9.1.1 ► STRICT EPIMORPHISMS

A 1-morphism $f: A \rightarrow B$ is a **strict epimorphism in C** if, for each $X \in \text{Obj}(C)$, the functor

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

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

$$f_*: \text{Obj}(\text{Hom}_C(B, X)) \rightarrow \text{Obj}(\text{Hom}_C(A, X))$$

is injective.

01CB

REMARK 14.2.9.1.2 ► UNWINDING DEFINITION 14.2.9.1.1

In detail, f is a strict epimorphism if, for each diagram in C of the form

$$A \xrightarrow{f} B \begin{matrix} \xrightarrow{\phi} \\ \xrightarrow{\psi} \end{matrix} X,$$

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

01CC

EXAMPLE 14.2.9.1.3 ► EXAMPLES OF STRICT EPIMORPHISMS

Here are some examples of strict epimorphisms.

01CD

1. *Strict Epimorphisms in Cats_2* . The strict epimorphisms in Cats_2 are characterised in **Categories**, **Item 1** of **Proposition 11.7.3.1.2**.

01CE

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

01CF 14.2.10 Pseudoepic Morphisms

Let C be a bicategory.

01CG

DEFINITION 14.2.10.1.1 ► PSEUDOEPIC MORPHISMS

A 1-morphism $f: A \rightarrow B$ of C is **pseudoepic** if, for each $X \in \text{Obj}(C)$, the functor

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

given by precomposition by f is pseudomonic.

01CH

REMARK 14.2.10.1.2 ► UNWINDING DEFINITION 14.2.10.1.1

In detail, a 1-morphism $f: A \rightarrow B$ of C is pseudoepic if it satisfies the following conditions:

01CJ

1. For all diagrams in C of the form

$$A \xrightarrow{f} B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \beta \\ \xrightarrow{\psi} \end{array} X,$$

if we have

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

then $\alpha = \beta$.

01CK

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

$$\beta: \phi \circ f \xrightarrow{\sim} \psi \circ f, \quad A \begin{array}{c} \xrightarrow{\phi \circ f} \\ \beta \Downarrow \\ \xrightarrow{\psi \circ f} \end{array} X$$

of C , there exists a 2-isomorphism

$$\alpha: \phi \xrightarrow{\sim} \psi, \quad B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} X$$

of C such that we have an equality

$$A \xrightarrow{f} B \begin{array}{c} \xrightarrow{\phi} \\ \alpha \Downarrow \\ \xrightarrow{\psi} \end{array} X = A \begin{array}{c} \xrightarrow{\phi \circ f} \\ \beta \Downarrow \\ \xrightarrow{\psi \circ f} \end{array} X$$

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

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

01CL

PROPOSITION 14.2.10.1.3 ► PROPERTIES OF PSEUDOEPIC MORPHISMS

Let $f: A \rightarrow B$ be a 1-morphism of C .

01CM

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

01CN

(a) The morphism f is pseudoepic.

01CP

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

01CQ

(c) We have an isococoma square of the form

$$B \xrightarrow{\text{eq.}} B \coprod_A B, \quad \begin{array}{ccc} B & \xleftarrow{\text{id}_B} & B \\ \text{id}_B \uparrow & \nearrow \text{dashed} & \uparrow F \\ B & \xleftarrow{F} & A \end{array}$$

in C up to equivalence.

PROOF 14.2.10.1.4 ► PROOF OF PROPOSITION 14.2.10.1.3

Item 1: Characterisations

Omitted.



Appendices

A Other Chapters

Preliminaries

1. [Introduction](#)
2. [A Guide to the Literature](#)

Sets

3. [Sets](#)
4. [Constructions With Sets](#)
5. [Monoidal Structures on the Category of Sets](#)
6. [Pointed Sets](#)
7. [Tensor Products of Pointed Sets](#)

Relations

8. [Relations](#)
9. [Constructions With Relations](#)

10. [Conditions on Relations](#)

Categories

11. [Categories](#)
12. [Presheaves and the Yoneda Lemma](#)

Monoidal Categories

13. [Constructions With Monoidal Categories](#)

Bicategories

14. [Types of Morphisms in Bicategories](#)

Extra Part

15. [Notes](#)

References

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