JOURNAL OF FORMALIZED MATHEMATICS
Volume 7, Released 1995, Published 2003
Inst. of Computer Science, Univ. of Białystok

Categories without Uniqueness of cod and dom

Andrzej Trybulec
Warsaw University
Białystok

Summary. Category theory had been formalized in Mizar quite early [6]. This had been done closely to the handbook of S. McLane [10]. In this paper we use a different approach. Category is a triple

$$\langle O, \{\langle o_1, o_2 \rangle\}_{o_1, o_2 \in O}, \{\circ_{o_1,o_2,o_3}\}_{o_1,o_2,o_3 \in O}\rangle$$

where $\circ_{o_1,o_2,o_3} : \langle o_2, o_3 \rangle \times \langle o_1, o_2 \rangle \to \langle o_1, o_3 \rangle$ that satisfies usual conditions (associativity and the existence of the identities). This approach is closer to the way in which categories are presented in homological algebra (e.g. [1], pp.58-59). We do not assume that $\langle o_1, o_2 \rangle$'s are mutually disjoint. If f is simultaneously a morphism from o_1 to o_2 and o'_1 to o_2 ($o_1 \neq o'_1$) than different compositions are used ($\circ_{o_1,o_2,o_3}$ or $\circ_{o'_1,o_2,o_3}$) to compose it with a morphism g from o_2 to o_3. The operation $g \cdot f$ has actually six arguments (two visible and four hidden: three objects and the category).

We introduce some simple properties of categories. Perhaps more than necessary. It is partially caused by the formalization. The functional categories are characterized by the following properties:

- quasi-functional that means that morphisms are functions (rather meaningless, if it stands alone)
- semi-functional that means that the composition of morphism is the composition of functions, provided they are functions.
- pseudo-functional that means that the composition of morphisms is the composition of functions.

For categories pseudo-functional is just quasi-functional and semi-functional, but we work in a bit more general setting. Similarly the concept of a discrete category is split into two:

- quasi-discrete that means that $\langle o_1, o_2 \rangle$ is empty for $o_1 \neq o_2$ and
- pseudo-discrete that means that $\langle o, o \rangle$ is trivial, i.e. consists of the identity only, in a category.

We plan to follow Semadeni-Wiweger book [13], in the development the category theory in Mizar. However, the beginning is not very close to [13], because of the approach adopted and because we work in Tarski-Grothendieck set theory.

MML Identifier: ALTCAT_1.

WWW: http://mizar.org/JFM/Vol7/altcat_1.html

The articles [14], [7], [19], [15], [20], [2], [4], [5], [3], [12], [8], [9], [16], [17], [11], and [18] provide the notation and terminology for this paper.

1. Preliminaries

The following proposition is true

(1) For every non empty set A and for all sets B, C, D such that $[:A, B:] \subseteq [:C, D:]$ or $[:B, A:] \subseteq [:D, C:]$ holds $B \subseteq D$.

In the sequel i, j, k, x are sets.

Let A be a functional set. Note that every subset of A is functional.

Let f be a function yielding function and let C be a set. One can verify that $f \restriction C$ is function yielding.

Let f be a function. Observe that $\{f\}$ is functional.

The following propositions are true:

(2) For every set A holds $\mathrm{id}_A \in A^A$.

(3) $\emptyset^\emptyset = \{\mathrm{id}_\emptyset\}$.

(4) For all sets A, B, C and for all functions f, g such that $f \in B^A$ and $g \in C^B$ holds $g \cdot f \in C^A$.

(5) For all sets A, B, C such that $B^A \neq \emptyset$ and $C^B \neq \emptyset$ holds $C^A \neq \emptyset$.

(6) For all sets A, B and for every function f such that $f \in B^A$ holds $\mathrm{dom}\, f = A$ and $\mathrm{rng}\, f \subseteq B$.

(7) Let A, B be sets, F be a many sorted set indexed by $[:B, A:]$, C be a subset of A, D be a subset of B, and x, y be sets. If $x \in C$ and $y \in D$, then $F(y, x) = (F \restriction ([:D, C:]$ **qua** set$))(y, x)$.

In this article we present several logical schemes. The scheme *MSSLambda2* deals with sets $\mathcal{A}$, $\mathcal{B}$ and a binary functor $\mathcal{F}$ yielding a set, and states that:

> There exists a many sorted set M indexed by $[:\mathcal{A}, \mathcal{B}:]$ such that for all i, j such that $i \in \mathcal{A}$ and $j \in \mathcal{B}$ holds $M(i, j) = \mathcal{F}(i, j)$

for all values of the parameters.

The scheme *MSSLambda2D* deals with non empty sets $\mathcal{A}$, $\mathcal{B}$ and a binary functor $\mathcal{F}$ yielding a set, and states that:

> There exists a many sorted set M indexed by $[:\mathcal{A}, \mathcal{B}:]$ such that for every element i of $\mathcal{A}$ and for every element j of $\mathcal{B}$ holds $M(i, j) = \mathcal{F}(i, j)$

for all values of the parameters.

The scheme *MSSLambda3* deals with sets $\mathcal{A}$, $\mathcal{B}$, $\mathcal{C}$ and a ternary functor $\mathcal{F}$ yielding a set, and states that:

> There exists a many sorted set M indexed by $[:\mathcal{A}, \mathcal{B}, \mathcal{C}:]$ such that for all i, j, k such that $i \in \mathcal{A}$ and $j \in \mathcal{B}$ and $k \in \mathcal{C}$ holds $M(i, j, k) = \mathcal{F}(i, j, k)$

for all values of the parameters.

The scheme *MSSLambda3D* deals with non empty sets $\mathcal{A}$, $\mathcal{B}$, $\mathcal{C}$ and a ternary functor $\mathcal{F}$ yielding a set, and states that:

> There exists a many sorted set M indexed by $[:\mathcal{A}, \mathcal{B}, \mathcal{C}:]$ such that for every element i of $\mathcal{A}$ and for every element j of $\mathcal{B}$ and for every element k of $\mathcal{C}$ holds $M(i, j, k) = \mathcal{F}(i, j, k)$

for all values of the parameters.

One can prove the following propositions:

(8) Let A, B be sets and N, M be many sorted sets indexed by $[:A, B:]$. If for all i, j such that $i \in A$ and $j \in B$ holds $N(i, j) = M(i, j)$, then $M = N$.

(9) Let A, B be non empty sets and N, M be many sorted sets indexed by $[:A, B:]$. Suppose that for every element i of A and for every element j of B holds $N(i, j) = M(i, j)$. Then $M = N$.

(10) Let A be a set and N, M be many sorted sets indexed by $[:A, A, A:]$. Suppose that for all i, j, k such that $i \in A$ and $j \in A$ and $k \in A$ holds $N(i, j, k) = M(i, j, k)$. Then $M = N$.

(11) $[\langle i, j \rangle \mapsto k] = \langle i, j \rangle \dot{\longmapsto} k$.

(12) $[\langle i, j \rangle \mapsto k](i, j) = k$.

2. Graphs

We consider graphs as extensions of 1-sorted structure as systems
⟨ a carrier, arrows ⟩,
where the carrier is a set and the arrows constitute a many sorted set indexed by [:the carrier, the carrier:].

Let G be a graph. An object of G is an element of G.

Let G be a graph and let o_1, o_2 be objects of G. The functor $\langle o_1, o_2\rangle$ is defined by:

(Def. 2)[1] $\langle o_1, o_2\rangle = (\text{the arrows of } G)(o_1, o_2)$.

Let G be a graph and let o_1, o_2 be objects of G. A morphism from o_1 to o_2 is an element of $\langle o_1, o_2\rangle$.

Let G be a graph. We say that G is transitive if and only if:

(Def. 4)[2] For all objects o_1, o_2, o_3 of G such that $\langle o_1, o_2\rangle \neq \emptyset$ and $\langle o_2, o_3\rangle \neq \emptyset$ holds $\langle o_1, o_3\rangle \neq \emptyset$.

3. Many Sorted Binary Compositions

Let I be a set and let G be a many sorted set indexed by $[:I, I:]$. The functor $\{|G|\}$ yielding a many sorted set indexed by $[:I, I, I:]$ is defined as follows:

(Def. 5) For all i, j, k such that $i \in I$ and $j \in I$ and $k \in I$ holds $(\{|G|\})(i, j, k) = G(i, k)$.

Let H be a many sorted set indexed by $[:I, I:]$. The functor $\{|G, H|\}$ yields a many sorted set indexed by $[:I, I, I:]$ and is defined by:

(Def. 6) For all i, j, k such that $i \in I$ and $j \in I$ and $k \in I$ holds $(\{|G, H|\})(i, j, k) = [:H(j, k), G(i, j):]$.

Let I be a set and let G be a many sorted set indexed by $[:I, I:]$. A binary composition of G is a many sorted function from $\{|G, G|\}$ into $\{|G|\}$.

Let I be a non empty set, let G be a many sorted set indexed by $[:I, I:]$, let o be a binary composition of G, and let i, j, k be elements of I. Then $o(i, j, k)$ is a function from $[:G(j, k), G(i, j):]$ into $G(i, k)$.

Let I be a non empty set, let G be a many sorted set indexed by $[:I, I:]$, and let I_1 be a binary composition of G. We say that I_1 is associative if and only if the condition (Def. 7) is satisfied.

(Def. 7) Let i, j, k, l be elements of I and f, g, h be sets. Suppose $f \in G(i, j)$ and $g \in G(j, k)$ and $h \in G(k, l)$. Then $I_1(i, k, l)(h, I_1(i, j, k)(g, f)) = I_1(i, j, l)(I_1(j, k, l)(h, g), f)$.

We say that I_1 has right units if and only if the condition (Def. 8) is satisfied.

(Def. 8) Let i be an element of I. Then there exists a set e such that $e \in G(i, i)$ and for every element j of I and for every set f such that $f \in G(i, j)$ holds $I_1(i, i, j)(f, e) = f$.

We say that I_1 has left units if and only if the condition (Def. 9) is satisfied.

(Def. 9) Let j be an element of I. Then there exists a set e such that $e \in G(j, j)$ and for every element i of I and for every set f such that $f \in G(i, j)$ holds $I_1(i, j, j)(e, f) = f$.

4. Categories

We introduce category structures which are extensions of graph and are systems
⟨ a carrier, arrows, a composition ⟩,
where the carrier is a set, the arrows constitute a many sorted set indexed by [:the carrier, the carrier:], and the composition is a binary composition of the arrows.

Let us observe that there exists a category structure which is strict and non empty.

[1] The definition (Def. 1) has been removed.
[2] The definition (Def. 3) has been removed.

Let C be a non empty category structure and let o_1, o_2, o_3 be objects of C. Let us assume that $\langle o_1, o_2 \rangle \neq \emptyset$ and $\langle o_2, o_3 \rangle \neq \emptyset$. Let f be a morphism from o_1 to o_2 and let g be a morphism from o_2 to o_3. The functor $g \cdot f$ yields a morphism from o_1 to o_3 and is defined as follows:

(Def. 10) $g \cdot f =$ (the composition of $C)(o_1, o_2, o_3)(g, f)$.

Let I_1 be a function. We say that I_1 is compositional if and only if:

(Def. 11) If $x \in \operatorname{dom} I_1$, then there exist functions f, g such that $x = \langle g, f \rangle$ and $I_1(x) = g \cdot f$.

Let A, B be functional sets. Observe that there exists a many sorted function indexed by $[: A, B :]$ which is compositional.

Next we state the proposition

(13) Let A, B be functional sets, F be a compositional many sorted set indexed by $[: A, B :]$, and g, f be functions. If $g \in A$ and $f \in B$, then $F(g, f) = g \cdot f$.

Let A, B be functional sets.

(Def. 12) $\operatorname{FuncComp}(A, B)$ is a compositional many sorted function indexed by $[: B, A :]$.

The following propositions are true:

(14) For all sets A, B, C holds $\operatorname{rng} \operatorname{FuncComp}(B^A, C^B) \subseteq C^A$.

(15) For every set o holds $\operatorname{FuncComp}(\{\mathrm{id}_o\}, \{\mathrm{id}_o\}) = [\langle \mathrm{id}_o, \mathrm{id}_o \rangle \mapsto \mathrm{id}_o]$.

(16) For all functional sets A, B and for every subset A_1 of A and for every subset B_1 of B holds $\operatorname{FuncComp}(A_1, B_1) = \operatorname{FuncComp}(A, B) \restriction ([: B_1, A_1 :]$ **qua** set$)$.

Let C be a non empty category structure. We say that C is quasi-functional if and only if:

(Def. 13) For all objects a_1, a_2 of C holds $\langle a_1, a_2 \rangle \subseteq {a_2}^{a_1}$.

We say that C is semi-functional if and only if the condition (Def. 14) is satisfied.

(Def. 14) Let a_1, a_2, a_3 be objects of C. Suppose $\langle a_1, a_2 \rangle \neq \emptyset$ and $\langle a_2, a_3 \rangle \neq \emptyset$ and $\langle a_1, a_3 \rangle \neq \emptyset$. Let f be a morphism from a_1 to a_2, g be a morphism from a_2 to a_3, and f', g' be functions. If $f = f'$ and $g = g'$, then $g \cdot f = g' \cdot f'$.

We say that C is pseudo-functional if and only if:

(Def. 15) For all objects o_1, o_2, o_3 of C holds (the composition of $C)(o_1, o_2, o_3) = \operatorname{FuncComp}({o_2}^{o_1}, {o_3}^{o_2}) \restriction [: \langle o_2, o_3 \rangle, \langle o_1, o_2 \rangle :]$.

Let X be a non empty set, let A be a many sorted set indexed by $[: X, X :]$, and let C be a binary composition of A. Note that $\langle X, A, C \rangle$ is non empty.

One can check that there exists a non empty category structure which is strict and pseudo-functional.

We now state two propositions:

(17) Let C be a non empty category structure and a_1, a_2, a_3 be objects of C. Then (the composition of $C)(a_1, a_2, a_3)$ is a function from $[: \langle a_2, a_3 \rangle, \langle a_1, a_2 \rangle :]$ into $\langle a_1, a_3 \rangle$.

(18) Let C be a pseudo-functional non empty category structure and a_1, a_2, a_3 be objects of C. Suppose $\langle a_1, a_2 \rangle \neq \emptyset$ and $\langle a_2, a_3 \rangle \neq \emptyset$ and $\langle a_1, a_3 \rangle \neq \emptyset$. Let f be a morphism from a_1 to a_2, g be a morphism from a_2 to a_3, and f', g' be functions. If $f = f'$ and $g = g'$, then $g \cdot f = g' \cdot f'$.

Let A be a non empty set. The functor Ens_A yielding a strict pseudo-functional non empty category structure is defined by:

(Def. 16) The carrier of $\mathrm{Ens}_A = A$ and for all objects a_1, a_2 of Ens_A holds $\langle a_1, a_2 \rangle = {a_2}^{a_1}$.

Let C be a non empty category structure. We say that C is associative if and only if:

(Def. 17) The composition of C is associative.

We say that C has units if and only if:

(Def. 18) The composition of C has left units and right units.

Let us note that there exists a non empty category structure which is transitive, associative, and strict and has units.

One can prove the following two propositions:

(20)[3] Let C be a transitive non empty category structure and a_1, a_2, a_3 be objects of C. Then $\mathrm{dom}(\text{the composition of } C)(a_1, a_2, a_3) = [:\langle a_2, a_3\rangle, \langle a_1, a_2\rangle:]$ and $\mathrm{rng}(\text{the composition of } C)(a_1, a_2, a_3) \subseteq \langle a_1, a_3\rangle$.

(21) For every non empty category structure C with units and for every object o of C holds $\langle o, o\rangle \neq \emptyset$.

Let A be a non empty set. One can verify that Ens_A is transitive and associative and has units.

Let us observe that every non empty category structure which is quasi-functional, semi-functional, and transitive is also pseudo-functional and every non empty category structure which is pseudo-functional and transitive and has units is also quasi-functional and semi-functional.

A category is a transitive associative non empty category structure with units.

5. Identities

Let C be a non empty category structure with units and let o be an object of C. The functor id_o yields a morphism from o to o and is defined as follows:

(Def. 19) For every object o' of C such that $\langle o, o'\rangle \neq \emptyset$ and for every morphism a from o to o' holds $a \cdot \mathrm{id}_o = a$.

The following three propositions are true:

(23)[4] For every non empty category structure C with units and for every object o of C holds $\mathrm{id}_o \in \langle o, o\rangle$.

(24) Let C be a non empty category structure with units and o_1, o_2 be objects of C. If $\langle o_1, o_2\rangle \neq \emptyset$, then for every morphism a from o_1 to o_2 holds $\mathrm{id}_{(o_2)} \cdot a = a$.

(25) Let C be an associative transitive non empty category structure and o_1, o_2, o_3, o_4 be objects of C. Suppose $\langle o_1, o_2\rangle \neq \emptyset$ and $\langle o_2, o_3\rangle \neq \emptyset$ and $\langle o_3, o_4\rangle \neq \emptyset$. Let a be a morphism from o_1 to o_2, b be a morphism from o_2 to o_3, and c be a morphism from o_3 to o_4. Then $c \cdot (b \cdot a) = (c \cdot b) \cdot a$.

6. Discrete categories

Let C be a category structure. We say that C is quasi-discrete if and only if:

(Def. 20) For all objects i, j of C such that $\langle i, j\rangle \neq \emptyset$ holds $i = j$.

We say that C is pseudo-discrete if and only if:

(Def. 21) For every object i of C holds $\langle i, i\rangle$ is trivial.

Next we state the proposition

[3] The proposition (19) has been removed.

[4] The proposition (22) has been removed.

(26) Let C be a non empty category structure with units. Then C is pseudo-discrete if and only if for every object o of C holds $\langle o,o\rangle = \{\mathrm{id}_o\}$.

Let us mention that every category structure which is trivial and non empty is also quasi-discrete.

One can prove the following proposition

(27) Ens_1 is pseudo-discrete and trivial.

Let us note that there exists a category which is pseudo-discrete, trivial, and strict.

Let us observe that there exists a category which is quasi-discrete, pseudo-discrete, trivial, and strict.

A discrete category is a quasi-discrete pseudo-discrete category.

Let A be a non empty set. The functor $\mathrm{DiscrCat}(A)$ yielding a quasi-discrete strict non empty category structure is defined as follows:

(Def. 22) The carrier of $\mathrm{DiscrCat}(A) = A$ and for every object i of $\mathrm{DiscrCat}(A)$ holds $\langle i,i\rangle = \{\mathrm{id}_i\}$.

Let us observe that every category structure which is quasi-discrete is also transitive.

The following propositions are true:

(28) Let A be a non empty set and o_1, o_2, o_3 be objects of $\mathrm{DiscrCat}(A)$. If $o_1 \neq o_2$ or $o_2 \neq o_3$, then (the composition of $\mathrm{DiscrCat}(A))(o_1, o_2, o_3) = \emptyset$.

(29) For every non empty set A and for every object o of $\mathrm{DiscrCat}(A)$ holds (the composition of $\mathrm{DiscrCat}(A))(o, o, o) = [\langle\mathrm{id}_o, \mathrm{id}_o\rangle \mapsto \mathrm{id}_o]$.

Let A be a non empty set. Note that $\mathrm{DiscrCat}(A)$ is pseudo-functional, pseudo-discrete, and associative and has units.

REFERENCES

[1] Stanisław Balcerzyk. *Wstęp do algebry homologicznej*, volume 34 of *Biblioteka Matematyczna*. PWN, Warszawa, 1972.

[2] Józef Białas. Group and field definitions. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/realset1.html.

[3] Czesław Byliński. Binary operations. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/binop_1.html.

[4] Czesław Byliński. Functions and their basic properties. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/funct_1.html.

[5] Czesław Byliński. Functions from a set to a set. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/funct_2.html.

[6] Czesław Byliński. Introduction to categories and functors. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/cat_1.html.

[7] Czesław Byliński. Some basic properties of sets. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/zfmisc_1.html.

[8] Czesław Byliński. A classical first order language. *Journal of Formalized Mathematics*, 2, 1990. http://mizar.org/JFM/Vol2/cqc_lang.html.

[9] Czesław Byliński. Cartesian categories. *Journal of Formalized Mathematics*, 4, 1992. http://mizar.org/JFM/Vol4/cat_4.html.

[10] Saunders Mac Lane. *Categories for the Working Mathematician*, volume 5 of *Graduate Texts in Mathematics*. Springer Verlag, New York, Heidelberg, Berlin, 1971.

[11] Beata Madras. Product of family of universal algebras. *Journal of Formalized Mathematics*, 5, 1993. http://mizar.org/JFM/Vol5/pralg_1.html.

[12] Michał Muzalewski and Wojciech Skaba. Three-argument operations and four-argument operations. *Journal of Formalized Mathematics*, 2, 1990. http://mizar.org/JFM/Vol2/multop_1.html.

[13] Zbigniew Semadeni and Antoni Wiweger. *Wstęp do teorii kategorii i funktorów*, volume 45 of *Biblioteka Matematyczna*. PWN, Warszawa, 1978.

[14] Andrzej Trybulec. Tarski Grothendieck set theory. *Journal of Formalized Mathematics*, Axiomatics, 1989. http://mizar.org/JFM/Axiomatics/tarski.html.

[15] Andrzej Trybulec. Tuples, projections and Cartesian products. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/mcart_1.html.

[16] Andrzej Trybulec. Function domains and Frænkel operator. *Journal of Formalized Mathematics*, 2, 1990. http://mizar.org/JFM/Vol2/fraenkel.html.

[17] Andrzej Trybulec. Many-sorted sets. *Journal of Formalized Mathematics*, 5, 1993. http://mizar.org/JFM/Vol5/pboole.html.

[18] Andrzej Trybulec. Many sorted algebras. *Journal of Formalized Mathematics*, 6, 1994. http://mizar.org/JFM/Vol6/msualg_1.html.

[19] Zinaida Trybulec. Properties of subsets. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/subset_1.html.

[20] Edmund Woronowicz. Relations and their basic properties. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/relat_1.html.

Received February 28, 1995

Published January 2, 2004