

## DESCENT FOR COMPACT 0-DIMENSIONAL SPACES

*Dedicated to Walter Tholen on the occasion of his 60th birthday*

GEORGE JANELIDZE<sup>1</sup> AND MANUELA SOBRAL<sup>2</sup>

ABSTRACT. Using the reflection of the category  $\mathcal{C}$  of compact 0-dimensional topological spaces into the category of Stone spaces we introduce a concept of a fibration in  $\mathcal{C}$ . We show that: (i) effective descent morphisms in  $\mathcal{C}$  are the same as the surjective fibrations; (ii) effective descent morphisms in  $\mathcal{C}$  with respect to the fibrations are all surjections.

### Introduction

Our original intention was to describe effective descent morphisms in the category  $\mathcal{C}$  of compact 0-dimensional topological spaces by combining the following well-known facts:

- A compact 0-dimensional space is nothing but a set equipped with a surjection into a Stone space (see Theorem 2.1 for the precise formulation).
- The effective descent morphisms in the categories of sets and of Stone spaces are just surjections.

It is still the main purpose of the paper, although it turned out that:

- Not all pullbacks exist in  $\mathcal{C}$ . Therefore the definition of an effective descent morphism  $p$  in  $\mathcal{C}$  should include the requirement: *all pullbacks along  $p$  must exist* (see Definition 3.2).
- When  $p$  is surjective, that requirement holds if and only if  $p$  is a fibration in a suitable sense (see Definition 2.2), which is very different from what is happening in the situations studied by H. Herrlich [1], and which makes the descent problem much easier. In a somewhat different situation, this is made clear in [3].
- The surjectivity requirement does not create any problem since it is independently forced by the reflection of isomorphisms by the pullback functor along an effective descent morphism.

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- Therefore the problem of describing effective descent morphisms in  $\mathcal{C}$  has an easy solution: Theorem 3.3 says that they are the same as the surjective fibrations.
- However, this suggests a new question, namely, what are the effective descent morphisms with respect to fibrations? Fortunately there is a complete answer again: they are all surjections (Theorem 3.1).
- In particular, even though the spaces we consider are not necessarily Hausdorff spaces, which prevents their convergence relations to be maps, our characterization of their effective descent morphisms avoids using the Reiterman-Tholen characterization of effective descent morphisms in the category of all topological spaces [4].

Accordingly, the paper is organized as follows:

Section 1 contains preliminary categorical observations with no topology involved. The ground category  $\mathcal{C}$  there is constructed as a full subcategory in the comma category  $(\mathcal{S} \downarrow U)$ , where  $U : \mathcal{X} \rightarrow \mathcal{S}$  is a pullback preserving functor between categories with pullbacks, using also a distinguished class  $\mathbb{E}$  of morphisms in  $\mathcal{S}$ . This class is also used to define what we call fibrations in  $\mathcal{C}$ . The sufficient conditions for a morphism to be an effective descent morphism (globally or with respect to the class of fibrations) given in Section 1 will become also necessary in the topological context of Sections 2 and 3.

Section 2 begins by recalling relevant topological concepts, presents the category of compact 0-dimensional spaces as a special case of  $\mathcal{C}$  above, introduces fibrations of 0-dimensional spaces accordingly, and ends by proving that a surjective morphism in  $\mathcal{C}$  admits all pullbacks along morphisms with the same codomain if and only if it is a fibration.

The purpose of Section 3 is to formulate and prove the two main results, namely the above mentioned Theorems 3.1 and 3.3.

## 1. Categorical framework

We fix the following data: categories  $\mathcal{S}$  and  $\mathcal{X}$  with pullbacks, a pullback preserving functor  $U : \mathcal{X} \rightarrow \mathcal{S}$  and a class  $\mathbb{E}$  of morphisms in  $\mathcal{S}$  that has the following properties:

- contains all isomorphisms;
- is pullback stable;
- is closed under composition;
- forms a *stack* (=coincides with its *localization*), which means that if

$$\begin{array}{ccc} \cdot & \longrightarrow & \cdot \\ u \downarrow & & \downarrow v \\ \cdot & \xrightarrow{w} & \cdot \end{array}$$

is a pullback diagram with  $w$  being an effective descent morphism, then  $u \in \mathbb{E} \Rightarrow v \in \mathbb{E}$ .

Let  $\mathcal{C} = \mathcal{C}[\mathcal{X}, \mathcal{S}, U, \mathbb{E}]$  be the full subcategory in the comma category  $(\mathcal{S} \downarrow U)$  with objects all triples  $A = (A_1, e_A, A_0)$ , in which  $e_A : A_1 \rightarrow U(A_0)$  is in  $\mathbb{E}$ ; accordingly, a morphism  $A \rightarrow B$  in  $\mathcal{C}$  is a pair  $f = (f_1, f_0)$ , in which  $f_1 : A_1 \rightarrow B_1$  and  $f_0 : A_0 \rightarrow B_0$  are morphisms in  $\mathcal{S}$  and  $\mathcal{X}$  respectively,

$$\begin{array}{ccc} A_1 & \xrightarrow{e_A} & U(A_0) \\ f_1 \downarrow & & \downarrow U(f_0) \\ B_1 & \xrightarrow{e_B} & U(B_0) \end{array}$$

such that  $U(f_0)e_A = e_B f_1$ .

1.1. DEFINITION. A morphism  $f : A \rightarrow B$  in  $(\mathcal{S} \downarrow U)$  is said to be a fibration if the morphism

$$\langle f_1, e_A \rangle : A_1 \rightarrow B_1 \times_{U(B_0)} U(A_0)$$

is in  $\mathbb{E}$ .

1.2. OBSERVATION. If  $f : A \rightarrow B$  is a fibration, and  $B$  is in  $\mathcal{C}$ , then, since the class  $\mathbb{E}$  is pullback stable,  $A$  also is in  $\mathcal{C}$ .

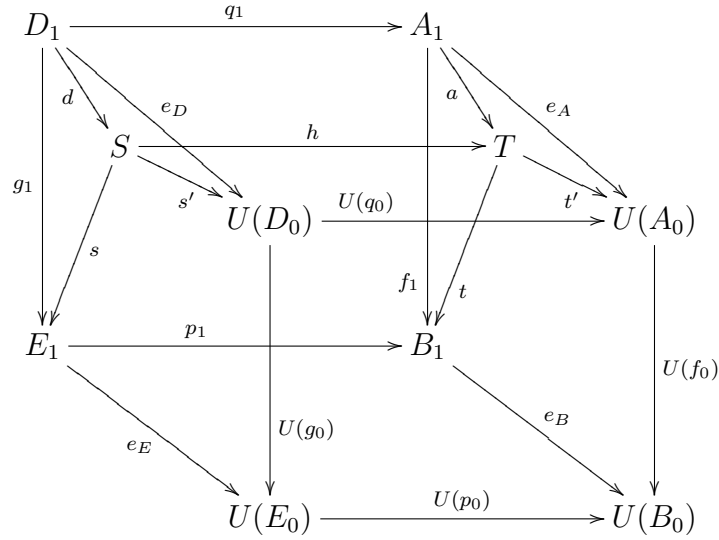
1.3. PROPOSITION. Let

$$(1.1) \quad \begin{array}{ccc} D & \xrightarrow{q} & A \\ g \downarrow & & \downarrow f \\ E & \xrightarrow{p} & B \end{array}$$

be a pullback diagram in  $(\mathcal{S} \downarrow U)$  with  $p : E \rightarrow B$  in  $\mathcal{C}$ . Then:

- (a) If  $f$  is a fibration, then so is  $g$ .
- (b) If  $g$  is a fibration, and  $p_1$  is an effective descent morphism in  $\mathcal{S}$ , then  $f$  also is a fibration.
- (c) If  $p$  is a fibration and  $A$  is in  $\mathcal{C}$ , then  $D$  is in  $\mathcal{C}$ .
- (d) If  $\mathbb{E}$  has the (weak left) cancellation property ( $e', e \cdot e' \in \mathbb{E} \Rightarrow e \in \mathbb{E}$ ) and  $p_1$  and  $U(p_0)$  are in  $\mathbb{E}$  and  $D$  is in  $\mathcal{C}$ , then  $A$  is in  $\mathcal{C}$ .

PROOF. Consider the diagram



in which:

- the enveloping cube represents the diagram (1.1);
- $e_E s = U(g_0) s'$  and  $e_B t = U(f_0) t'$  are pullbacks;
- $d = \langle g_1, e_D \rangle$ ,  $a = \langle f_1, e_A \rangle$ , and  $h = p_1 \times U(q_0)$  are the suitable induced morphisms.

Since the front square  $U(p_0)U(g_0) = U(f_0)U(q_0)$  and the quadrilaterals  $e_E s = U(g_0) s'$  and  $e_B t = U(f_0) t'$  are pullbacks, so is the quadrilateral  $p_1 s = t h$ . Next, since  $p_1 g_1 = f_1 q_1$  and  $p_1 s = t h$  are pullbacks, so is  $h d = a q_1$ . This proves (a).

(b): Since  $p_1$  is an effective descent morphism and  $p_1 s = t h$  is a pullback,  $h$  also is an effective descent morphism ([5], Theorem 3.1). Since  $h d = a q_1$  is a pullback, this proves (b).

For (c) and (d), in order to use the same observations, let us “turn the diagram (1.1) around the diagonal connecting  $D$  and  $B$ ”, i.e. let us reformulate (c) and (d) as follows:

- (c') If  $f$  is a fibration and  $E$  is in  $\mathcal{C}$ , then  $D$  is in  $\mathcal{C}$ .
- (d') If  $f_1$  and  $U(f_0)$  are in  $\mathbb{E}$  and  $D$  is in  $\mathcal{C}$ , then  $E$  is in  $\mathcal{C}$ .

*Proof of (c')*:

- Since  $f$  is a fibration,  $a$  is in  $\mathbb{E}$ .
- Since  $E$  is in  $\mathcal{C}$  and  $e_E s = U(g_0) s'$  is a pullback,  $s'$  is in  $\mathbb{E}$ .
- Since  $a$  and  $s'$  are in  $\mathbb{E}$ , so is  $e_D$ , i.e.  $D$  is in  $\mathcal{C}$ .

*Proof of (d')*:

- Since  $f_1$  and  $U(f_0)$  are in  $\mathbb{E}$ , so are  $g_1$  and  $U(g_0)$ .
- Since  $g_1, U(g_0)$  and  $e_D$  are in  $\mathbb{E}$ , the cancellation property of (d') implies that  $e_E$  is in  $\mathbb{E}$ , as desired.

■

From Observation 1.2 and Proposition 1.3(a) we obtain:

1.4. COROLLARY. *The category  $\mathcal{C}$  is closed in  $(\mathcal{S} \downarrow U)$  under pullbacks along fibrations; that is, if (1.1) is a pullback diagram in  $(\mathcal{S} \downarrow U)$  with  $f$  in  $\mathcal{C}$  and  $p$  being a fibration in  $\mathcal{C}$ , then it is a pullback diagram in  $\mathcal{C}$ .*

When  $\mathcal{S}$  has coequalizers of equivalence relations, all effective descent morphisms in  $\mathcal{S}$  are regular epimorphisms. Using this fact it is easy to show that if  $p : E \rightarrow B$  is a morphism in  $(\mathcal{S} \downarrow U)$ , for which  $p_0$  and  $p_1$  are effective descent morphisms in  $\mathcal{X}$  and in  $\mathcal{S}$  respectively, then  $p$  itself is an effective descent morphism. After that, using Proposition 1.3 and Corollary 1.4, we obtain:

1.5. PROPOSITION. *If  $\mathcal{S}$  has coequalizers of equivalence relations and  $p : E \rightarrow B$  is a morphism in  $\mathcal{C}$ , for which  $p_0$  and  $p_1$  are effective descent morphisms in  $\mathcal{X}$  and in  $\mathcal{S}$  respectively, then*

- (a)  *$p$  is an effective  $\mathbb{F}$ -descent morphism in  $\mathcal{C}$ , where  $\mathbb{F}$  is the class of all fibrations (in  $\mathcal{C}$ ).*
- (b) *if  $p$  is a fibration, then it is an effective descent morphism in  $\mathcal{C}$ .*

## 2. The category of compact 0-dimensional spaces

For a topological space  $A$ , we shall write  $Open(A)$  for the set of open subsets in  $A$  and  $Clopen(A)$  for the set of those subsets in  $A$  that are *clopen*, i.e. closed and open at the same time. Let us recall the definitions of the following full subcategories of the category  $\mathcal{T}op$  of topological spaces:

–  $\mathcal{T}op_0$ , the category of  $T_0$ -spaces; a space  $A$  is a  $T_0$ -space if, for every two distinct points  $a$  and  $a'$  in  $A$ , either there exists  $U \in Open(A)$  with  $a \in U$  and  $a' \notin U$ , or there exists  $U \in Open(A)$  with  $a' \in U$  and  $a \notin U$ . Note that  $\mathcal{T}op_0$  is a reflective subcategory in  $\mathcal{T}op$ , with the reflection given by

$$(2.1) \quad A \mapsto A_0 = A / \sim, \text{ where } a \sim a' \Leftrightarrow \forall U \in Open(A) (a \in U \Leftrightarrow a' \in U).$$

–  $0\text{-Dim}\mathcal{T}op$ , the category of 0-dimensional spaces; a space is 0-dimensional if it has a basis of clopen subsets, i.e. if every open subset in it can be presented as a union of clopen subsets.

– The category of compact 0-dimensional spaces, which is the category of interest in this paper, will be simply denoted by  $\mathcal{C}$ ; hence

$$\mathcal{C} = \mathit{CompTop} \cap 0\text{-DimTop}$$

where  $\mathit{CompTop}$  is the category of compact spaces.

– *Stone*, the category of Stone spaces = spaces that occur as spectra of Boolean algebras = spaces that occur as limits of finite discrete spaces = compact Hausdorff 0-dimensional spaces = compact spaces  $A$ , such that for every two distinct points  $a$  and  $a'$  in  $A$ , there exists  $U \in \mathit{Clopen}(A)$  with  $a \in U$  and  $a' \notin U$ . The  $T_0$ -reflection (2.1) of course induces a reflection

$$(2.2) \quad \mathcal{C} \mapsto \mathit{Stone}, A \mapsto A_0.$$

The following theorem is a reformulation of well-known results (see also Example 3.3 in [2] for the same result for arbitrary topological spaces, which, together with other similar results was mentioned already in [1]):

**2.1. THEOREM.** *The category  $\mathcal{C}$  of compact 0-dimensional spaces is equivalent to the category  $\mathcal{C}[\mathcal{X}, \mathcal{S}, U, \mathbb{E}]$  (see Section 1), for  $\mathcal{X} = \mathit{Stone}$ ,  $\mathcal{S} = \mathit{Set}$ ,  $U : \mathit{Stone} \rightarrow \mathit{Set}$ ,  $U$  being the usual forgetful functor into the category of sets and  $\mathbb{E}$  being the class of all surjective maps. Under this equivalence a space  $A$  corresponds to the triple  $(A_1, e_A, A_0)$ , in which  $A_1$  is the underlying set of  $A$ ,  $A_0$  is the  $T_0$ -reflection of  $A$ , and  $e_A : A_1 \rightarrow U(A_0)$  is the canonical map (and we write again  $A = (A_1, e_A, A_0)$ ). Conversely, the space corresponding to a triple  $(A_1, e_A, A_0)$  has  $A_1$  as its underlying set and the inverse  $e_A$ -images of open sets in  $A_0$  as its open subsets.*

According to this theorem and Definition 1.1, we introduce:

**2.2. DEFINITION.** *A morphism  $f : A \rightarrow B$  in  $\mathcal{C}$  is said to be a fibration if so is the corresponding morphism in  $\mathcal{C}[\mathcal{X}, \mathcal{S}, U, \mathbb{E}]$  of Theorem 2.1, i.e. if for every  $a$  in  $A$  and  $b$  in  $B$  with  $f(a) \sim b$  there exists  $a'$  in  $A$  with  $a' \sim a$  and  $f(a') = b$ .*

After that Proposition 1.3 helps to prove:

**2.3. THEOREM.** *Let  $p : E \rightarrow B$  be a morphism in  $\mathcal{C}$ . If  $p$  is surjective, then the following conditions are equivalent:*

- (a) every morphism  $f : A \rightarrow B$  in  $\mathcal{C}$  admits pullback along  $p$ ;
- (b)  $p$  is a fibration.

**PROOF.** (a) $\Rightarrow$ (b): Suppose  $p$  is not a fibration. This means that there are  $e$  in  $E$  and  $b$  in  $B$  with

$$(2.3) \quad p(e) \sim b \text{ and } (x \in p^{-1}(b) \Rightarrow \exists_{U_x \in \mathit{Clopen}(E)} (x \in U_x \text{ and } e \notin U_x)).$$

We choose  $U_x$  as in (2.3) for each  $x$  in  $p^{-1}(b)$ , and consider two cases:

*Case 1.* There exists a finite subset  $Y$  in  $X$ , for which

$$p^{-1}(b) \subseteq \bigcup_{x \in Y} U_x.$$

*Case 2.* There is no such  $Y$ .

In *Case 1* we take

$$V = \bigcap_{x \in Y} (E \setminus U_x),$$

and observe that since  $Y$  is finite,  $V$  is clopen; and of course  $V$  contains  $e$  and has empty intersection with  $p^{-1}(b)$ . After that we take

$$A = \{n^{-1} | n = 1, 2, 3, \dots\} \cup \{0\}$$

with the topology induced from the real line, and define  $f : A \rightarrow B$  by  $f(n^{-1}) = b$  and  $f(0) = p(e)$ . Suppose the pullback of  $p$  and  $f$  does exist, and let us write it as the diagram (1.1). Using the universal property of this pullback with respect to maps from a one-point space, we easily conclude that it is preserved by the forgetful functor into the category of sets. In particular, since  $V$  contains  $e$  and has empty intersection with  $p^{-1}(b)$ , we have

$$q(g^{-1}(E \setminus V)) = \{n^{-1} | n = 1, 2, 3, \dots\}.$$

This is a contradiction since  $g^{-1}(E \setminus V)$  being clopen in  $D$  must be compact in it, while  $\{n^{-1} | n = 1, 2, 3, \dots\}$  is not compact in  $A$ .

In *Case 2* we take  $A = \{a\}$  to be a one-point space, and define  $f : A \rightarrow B$  by  $f(a) = b$ . Then, using (1.1) as above, we observe that  $g(D) = p^{-1}(b)$  – which is again a contradiction because now  $p^{-1}(b)$  is not compact.

That is, whenever  $p$  is not a fibration, there exists a morphism  $f : A \rightarrow B$  in  $\mathcal{C}$  that has no pullback along  $p$ .

(b) $\Rightarrow$ (a) follows from Corollary 1.4 and Theorem 2.1. ■

### 3. $\mathbb{F}$ -Descent and global descent

Let  $\mathcal{C}$  be as in Section 2.

3.1. THEOREM. *The following conditions on a morphism  $p : E \rightarrow B$  in  $\mathcal{C}$  are equivalent:*

- (a)  $p$  is an effective  $\mathbb{F}$ -descent morphism in  $\mathcal{C}$ ;
- (b)  $p$  is a surjective map.

PROOF. (a) $\Rightarrow$ (b): Suppose  $p$  is not surjective, and choose  $b \in B \setminus p(E)$ . Let  $A$  be the equivalence class of  $b$  with respect to the equivalence relation  $\sim$  (see (2.1)). We take

$$A' = (A \setminus \{b\}) \cup \{b\} \times \{1, 2\}$$

equipped with the indiscrete topology, and define  $\alpha : A' \rightarrow A$  by  $\alpha(a) = a$ , for  $a \in A$ , and  $\alpha(b, 1) = b = \alpha(b, 2)$ ; then  $\alpha$  becomes a morphism  $(A', \alpha f) \rightarrow (A, f)$ , where  $f : A \rightarrow B$  is

the inclusion map, in the category  $\mathbb{F}(B)$  of fibrations over  $B$  (in  $\mathcal{C}$ ). Since the image of this morphism under the pullback functor  $p^* : F(B) \rightarrow F(E)$  is an isomorphism,  $p$  cannot be an effective  $\mathbb{F}$ -descent morphism in  $\mathcal{C}$ .

(b) $\Rightarrow$ (a): Let  $(p_1, p_0) : (E_1, e_E, E_0) \rightarrow (B_1, e_B, B_0)$  be the morphism in  $\mathcal{C}[\mathcal{X}, \mathcal{S}, U, \mathbb{E}]$  corresponding to  $p$  under the category equivalence of Theorem 2.1, where  $X = Stone$ ,  $\mathcal{S} = Set$ ,  $U : Stone \rightarrow Set$  being the usual forgetful functor into the category of sets, and  $\mathbb{E}$  being the class of all surjective maps. Then  $p_1$  is surjective and this makes  $p_0$  surjective too. Since in both  $Stone$  and  $Set$  surjections are effective descent morphisms, this makes  $p$  an effective  $\mathbb{F}$ -descent morphism by Proposition 1.5(a). ■

Since  $\mathcal{C}$  does not admit some pullbacks, we define effective (global-)descent morphisms in  $\mathcal{C}$  as follows:

**3.2. DEFINITION.** *A morphism  $p : E \rightarrow B$  in  $\mathcal{C}$  is said to be an effective descent morphism if every morphism  $f : A \rightarrow B$  in  $\mathcal{C}$  admits pullback along  $p$ , and the pullback functor*

$$p^* : (\mathcal{C} \downarrow B) \rightarrow (\mathcal{C} \downarrow E)$$

*is monadic.*

**3.3. THEOREM.** *The following conditions on a morphism  $p : E \rightarrow B$  in  $\mathcal{C}$  are equivalent:*

- (a)  *$p$  is an effective descent morphism;*
- (b)  *$p$  is a surjective fibration.*

**PROOF.** (a) $\Rightarrow$ (b): Surjectivity can be proved in the same way as in the proof of Theorem 3.1 (or even much simpler by considering the empty and one-point space instead of  $A'$  and  $A$  there). The fact that  $p$  must be a fibration follows from the implication (a) $\Rightarrow$ (b) of Theorem 2.3.

(b) $\Rightarrow$ (a) can be deduced from Proposition 1.5(b) and Theorem 2.1 with the same arguments as in the proof of Theorem 3.1(b) $\Rightarrow$ (a). ■

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*Dept. Math. and Appl. Math.  
University of Cape Town  
Rondebosh 7701, Cape Town  
South Africa*

*Departamento de Matemática  
Universidade de Coimbra  
Ap. 3008, 3001-454 Coimbra  
Portugal*

Email: `janelidg@maths.uct.ac.za`  
`sobral@mat.uc.pt`

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Susan Niefield, Union College: [niefiels@union.edu](mailto:niefiels@union.edu)

Robert Paré, Dalhousie University: [pare@mathstat.dal.ca](mailto:pare@mathstat.dal.ca)

Jiri Rosicky, Masaryk University: [rosicky@math.muni.cz](mailto:rosicky@math.muni.cz)

Brooke Shipley, University of Illinois at Chicago: [bshipley@math.uic.edu](mailto:bshipley@math.uic.edu)

James Stasheff, University of North Carolina: [jds@math.unc.edu](mailto:jds@math.unc.edu)

Ross Street, Macquarie University: [street@math.mq.edu.au](mailto:street@math.mq.edu.au)

Walter Tholen, York University: [tholen@mathstat.yorku.ca](mailto:tholen@mathstat.yorku.ca)

Myles Tierney, Rutgers University: [tierney@math.rutgers.edu](mailto:tierney@math.rutgers.edu)

Robert F. C. Walters, University of Insubria: [robert.walters@uninsubria.it](mailto:robert.walters@uninsubria.it)

R. J. Wood, Dalhousie University: [rjwood@mathstat.dal.ca](mailto:rjwood@mathstat.dal.ca)