
Higher Category Theory

Assignment 5

Exercise 1

Proof. (1) Let $\mathcal{C} = [3]$. We see that $N([3]) = \Delta_3$, which has a non-degenerate 3-simplex given by id_{Δ_3} . On the other hand, by definition all of the simplices of $Sk_2(\Delta_3)$ of dimension > 2 are degenerate, hence the canonical inclusion $Sk_2(\Delta_3) \rightarrow \Delta_3$ is not an isomorphism.

(2) Since (co)limits of presheaves are defined pointwisely and a morphism of presheaves is a monomorphism if and only if every component of the natural transformation is, we only need to check that for all $a \in \text{Ob}(\mathcal{A})$ the pushout squares

$$\begin{array}{ccc} X_a & \xrightarrow{f_a} & Y_a \\ i_a \downarrow & & \downarrow i'_a \\ X'_a & \xrightarrow{g_a} & Y'_a \end{array}$$

are also pullback squares, so we shall be working solely in **Set**, allowing us to drop the a , without creating ambiguity.

Since the class of monomorphisms in **Set** is saturated, we know that i' is a monomorphism too. We will now verify that X has the universal property of the pullback by exhibiting the universal property.

Consider then $h_1: Z \rightarrow X'$, $h_2: Z \rightarrow Y$ making the diagram commute. We are forced to define a candidate factorization $h: Z \rightarrow X$ by mapping $z \in Z$ to the unique $x \in X$ such that $h_1(z) = i(x)$, which grants us the uniqueness of an eventual factorization. By construction, h is well-defined and $h_1 = i \cdot h$, so we only have to check that $h_2 = f \cdot h$. Notice that $i' \cdot h_2 = g \cdot h_1 = g \cdot i \cdot h = i' \cdot f \cdot h$ and, by injectivity of i' , we have the thesis. \square

Exercise 2

Proof. (1) Once more, we only need to check that for all objects $a \in \text{Ob}(\mathcal{A})$ the following is a coequalizer diagram.

$$X_a \times_{Y_a} X_a \xrightleftharpoons[q_a]{p_a} X_a \xrightarrow{\pi_a} \text{im}(f)_a$$

Here by π we refer to the morphism we get from f by restricting the codomain. From now on, like in the previous exercise, we shall work in **Set** and therefore drop every a .

We begin by noticing that $\text{im}(f) \cong X_{/\sim}$ under π , where $x \sim x'$ whenever $f(x) = f(x')$, because π is surjective by construction.

Consider then a function $g: X \rightarrow Z$ coequalizing p and q . All we have to do is show that π coequalizes p and q and, if $x \sim x'$, then $g(x) = g(x')$, since then g will factor through $\pi: X \rightarrow X_{/\sim}$ as $\tilde{g}: X_{/\sim} \rightarrow Z$, $[x] \mapsto g(x)$. By construction, $\tilde{g} \cdot \pi = g$, while the uniqueness of the factorization will follow from the surjectivity of π . To do this, we first characterize $X \times_Y X$ explicitly.

We claim that the pullback is given by $S = \{(x, x') \in X \times X \mid f(x) = f(x')\}$ with the obvious projection maps $\pi_1(x, x') = x$, $\pi_2(x, x') = x'$. Indeed, consider a pair of maps $h_1, h_2: Z \rightarrow X$ such that $f \cdot h_1 = f \cdot h_2$. Then, we may construct a factorization $h: Z \rightarrow S$ by setting $h(z) := (h_1(z), h_2(z))$. This is well-defined since $f(h_1(z)) = (f \cdot h_1)(z) = (f \cdot h_2)(z) = f(h_2(z))$ and therefore $(h_1(z), h_2(z)) \in S$. Also, by construction $\pi_i \cdot h = h_i$ and the uniqueness of the factorization follows from the fact that these last equations (which are satisfied by all factorizations) specify both entries of a candidate $h(z)$.

Notice that $(\pi \cdot p)(x, x') = \pi(p(x, x')) = \pi(x) = f(x) = f(x') = \pi(x') = \pi(q(x, x')) = (\pi \cdot q)(x, x')$ by our characterization of $X \times_Y X$, hence $\pi \cdot p = \pi \cdot q$. We now only have to check that the \tilde{g} we defined earlier is actually well-defined by checking that $x \sim x'$ implies $g(x) = g(x')$. This follows from the fact that $x \sim x'$ means $f(x) = f(x')$, thus $(x, x') \in X \times_Y X$ and $g(x) = g(p(x, x')) = (g \cdot p)(x, x') = (g \cdot q)(x, x') = g(q(x, x')) = g(x')$.

(2) Suppose T to be a representable presheaf, i.e. isomorphic to \mathcal{Y}_a for some $a \in \text{Ob}(\mathcal{A})$. Since \mathcal{A} is small, $\hat{\mathcal{A}}$ is locally small and therefore the hom-sets are actual sets. Writing equalities in place of natural isomorphisms, we have the following chain of identities: $\hat{\mathcal{A}}(T, Y) = \hat{\mathcal{A}}(\mathcal{Y}_a, Y) = Y_a = \bigcup_{i \in I} Y_{i,a} = \bigcup_{i \in I} \hat{\mathcal{A}}(\mathcal{Y}_a, Y_i) = \bigcup_{i \in I} \hat{\mathcal{A}}(T, Y_i)$. Here a natural transformation $s: T \cong \mathcal{Y}_a \rightarrow Y_i$ on the right is identified in $\bigcup_{i \in I} \hat{\mathcal{A}}(T, Y_i)$ with all other natural transformations $s': T \cong \mathcal{Y}_a \rightarrow Y_j$ such that $s = s' \in Y_a$ and the equality between the two extremes is exhibited by the map sending such a natural transformation $s: T \rightarrow Y_i$ to the one we get by composing with the inclusion $Y_i \rightarrow Y$, which is what we get if we follow the chain of identifications. \square

Exercise 3

Proof. (1) Recall that the nerve functor N being a right adjoint, preserves products, and thus $\Delta^p \times \Delta^q \cong N([p] \times [q])$. For any n -simplex $s: \Delta^n \rightarrow \Delta^p \times \Delta^q$, under the adjunction

$$\text{Hom}_{\mathbf{Cat}}([n], [p] \times [q]) \cong \text{Hom}_{\mathbf{sSet}}(\Delta^n, \Delta^p \times \Delta^q)$$

it corresponds to a unique $s': [n] \rightarrow [p] \times [q]$. Suppose that s is not a monomorphism. Then s' is not either, which implies that s' factorizes through some $[m]$ ($m < n$), say, into $[n] \xrightarrow{f'} [m] \xrightarrow{t'} [p] \times [q]$. Indeed, since the image $s'([n]) \subseteq [p] \times [q]$ is a finite totally ordered set and s' is not injective, there exists some $m < n$ such that $[m] \cong s'([n])$, and

we may just take f' to be the composition $[n] \rightarrow s'([n]) \cong [m]$ and $t': [m] \rightarrow [p] \times [q]$ to be the inclusion of a subset. Again f', t' correspond to some $f: \Delta^n \rightarrow \Delta^m$ and $t: \Delta^m \rightarrow \Delta^p \times \Delta^q$ via the adjunction $\tau \dashv N$, and one has $s = tf = f^*(t)$. This shows that s is degenerate. Hence the proof.

(2) We claim that if $\Delta \rightarrow X$ and $\Delta^n \rightarrow Y$ are both degenerate, then so is $\Delta^n \rightarrow X \times Y$. To see this, assume they are degenerate and then $\Delta^n \rightarrow X$ and $\Delta^n \rightarrow Y$ factorize through Δ^k, Δ^l for some $0 \leq k, l < n$ respectively. Without loss of generality, one may further assume that $k \leq l$, then $\Delta^n \rightarrow \Delta^k$ factorizes through Δ^l . We obtain a morphism $\Delta^k \rightarrow X \times Y$ by the universal property of products, through which $\Delta^n \rightarrow X \times Y$ factorizes, as depicted below:

$$\begin{array}{ccccc}
 \Delta^n & \xrightarrow{\quad} & \Delta^l & & \\
 \downarrow & \searrow & \swarrow & \searrow & \\
 \Delta^k & \xrightarrow{\quad} & X \times Y & \xrightarrow{\quad} & Y \\
 & \searrow & \downarrow & & \\
 & & X & &
 \end{array}$$

Hence $\Delta^n \rightarrow X \times Y$ is degenerate, and this confirms our claim.

Therefore, if $\Delta^n \rightarrow X \times Y$ is non-degenerate, then either $\Delta^n \rightarrow X$ or $\Delta^n \rightarrow Y$ is degenerate, which implies that either $\Delta^n \rightarrow X$ or $\Delta^n \rightarrow Y$ is a monomorphism by the regularity of X and Y . We thus may assume that $\Delta^n \rightarrow X$ is monic. Then by definition, $\Delta^n([m]) \rightarrow X_m$ is an injective map of sets for all $m \geq 0$, and this in turn entails that

$$\Delta^n([m]) \rightarrow X_m \times Y_m = (X \times Y)_m$$

is an injective map of sets. Consequently $\Delta^n \rightarrow X \times Y$ is a monomorphism.

(3) Consider the diagram $F: I \rightarrow \mathbf{sSet}$ where I is finite and $X^i := F(i)$ is regular for each $i \in I$. Recall that finite limits can be exhibited by finite products and equalizers:

$$\lim_I F = \text{eq} \left(\prod_{i \in I} X_i \rightrightarrows \prod_{i \rightarrow j} X_i \right)$$

and by (2) plus induction we know that $\prod_{i \in I} X_i$ is regular if each X_i is.

Thus the case is reduced to equalizers: in other words, it suffices to show that for any diagram $X \rightrightarrows Y$ in \mathbf{sSet} , the equalizer

$$K := \text{eq}(X \rightrightarrows Y)$$

is a regular simplicial set if X is so. To this end, suppose that an n -simplex $s: \Delta^n \rightarrow K$ is not a monomorphism. Then the composition $\Delta^n \rightarrow K \rightarrow X$ is not a monomorphism (since it will not be injective over some $[l]$) as well, and by the fact that X is regular,

the composite $\Delta^n \rightarrow X$ factors through some Δ^m .

$$\begin{array}{ccccc}
 & K & \longrightarrow & X & \rightrightarrows & Y \\
 & \uparrow s & & \nearrow & & \\
 & \Delta^n & & & & \\
 & \downarrow t & & \nwarrow & & \\
 & \Delta^m & & & &
 \end{array}$$

u (curved arrow from Δ^m to K)

From this we can see that $\Delta^m \rightarrow X$ equalizes $X \rightrightarrows Y$, and by the universal property of equalizers, there is a unique morphism $u: \Delta^m \rightarrow K$. Using the universal property of equalizers again yields that $ut = s$, which means $s: \Delta^n \rightarrow K$ being degenerate. \square