

# Analytic Stacks

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## 1.4 Replete and locally weakly contractible topoi

Throughout this section the word "topos" refers to the category of sheaves on some site

**Definition 1.1** (Replete Topos). A topos  $X$  is *replete* if epimorphisms are closed under sequential limits, that is for a functor  $F : \mathbb{N}^{op} \rightarrow X$  with epimorphic transition maps  $F_{n+1} \twoheadrightarrow F_n$ , then the map  $\lim F \rightarrow F_n$  is epic for each  $n$

- Lemma 1.1.**
1.  $X$  is replete then for  $x \in X$ ,  $X/x$  is replete
  2.  $X$  is replete if and only if there is a surjection  $x \rightarrow 1$  and  $X/x$  is replete

*Proof.* To prove (1) we observe that the canonical functor  $X/x \rightarrow X$  preserves sequential limits and epimorphisms so in  $X/x$  an epi sequential limit corresponds to an epi sequential limit in  $X$  and the maps  $\lim F \rightarrow F_n$  are epi in  $X$  and hence epi in  $X/x$

To prove (2) we note that (1) proves the forward direction, then for the other direction the map  $g: x \rightarrow 1$  induced a base change map  $g^*: X \cong X/1 \rightarrow X/x$  defined by  $t \mapsto (t \times x \rightarrow x)$  which preserves limits and epimorphisms so the same argument at (1) applies  $\square$

- Proposition 1.2** (Exactness in replete topoi).
1. For  $X$  a replete topos and  $H: F \rightarrow G$  a map in  $\text{Fun}(\mathbb{N}^{op}, X)$  where the components  $h_i: F_i \rightarrow G_i$  and the induced maps  $(f_{i+1}, h_{i+1}): F_{i+1} \rightarrow F_i \times_{G_i} G_{i+1}$  are epimorphisms for all  $i$ . Then  $\lim F \rightarrow \lim G$  is an epimorphism<sup>1</sup>
  2. Countable products are exact in a replete topos
  3. If  $X$  is a replete topos then the functor of  $\mathbb{N}^{op}$ -indexed limits has cohomological dimension 1
  4. If  $X$  is a replete topos and  $F : \mathbb{N}^{op} \rightarrow \mathcal{A}\mathcal{B}(X)$  is a diagram with  $F_{n+1} \rightarrow F_n$  surjective for every  $n$  then  $\lim F_n \cong R\lim F_n$

*Proof.* To prove (1) Take any  $A \in X$  and any map  $s: A \rightarrow \lim G$  we want to find an epimorphism  $A' \rightarrow A$  that lifts  $s$ . To do so we construct a tower of epimorphisms

$$\cdots \rightarrow A_i \rightarrow A_{i-1} \rightarrow \cdots \rightarrow A_0 \rightarrow A$$

Such that there are maps  $t_n: A_i \rightarrow F_i$  that lift the maps  $s_n: A \rightarrow G_i$ . We can construct one as follows, due to the fact that the pullback of an epimorphism is an epimorphism in a topos let  $X_0 = X \times_{G_0} F_0$  we get an epimorphism  $X_0 \rightarrow X$

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<sup>1</sup>can this be reduced to  $F_0 \rightarrow G_0$  surjective and the product thing?

that lifts  $s_0$ , we can continue inductively with  $X_{i+1} = X_i \times_{F_i \times_{G_i} G_{i+1}} F_{i+1}$ . Diagrammatically

$$\begin{array}{ccc}
A_{i+1} & \xrightarrow{t_{i+1}} & F_{i+1} \\
\downarrow & \lrcorner & \downarrow (f_{i+1}, h_{i+1}) \\
A_i & \xrightarrow{(t_i, s_i \circ \pi_i)} & F_i \times_{G_i} G_{i+1} \longrightarrow F_i \\
\downarrow \pi_i & & \downarrow \lrcorner \\
A & \xrightarrow{s_{i+1}} & G_{i+1} \xrightarrow{g_{i+1}} G_i
\end{array}$$

Since  $X$  is replete taking the limit over this tower gives an epimorphism  $\lim A_i \rightarrow A$  so that  $s$  factors through  $h$ , that is

$$\begin{array}{ccc}
\lim A_i & \longrightarrow & \lim F \\
\downarrow & & \downarrow \\
A & \longrightarrow & \lim G
\end{array}$$

Taking then  $A = \lim G$  and  $s = id$  proves the claim

This allows us to prove (2) quite simply as products are already left exact so we just need to check that for epimorphisms  $h_n : F_n \rightarrow G_n$  we have  $\prod_n F_n \rightarrow \prod_n G_n$  is epi. This follows from (1) by taking  $\prod_n F_n = \lim \prod_{i < n} F_i$  and noting that finite products preserve epis already and the map

$$\prod_{i < n+1} F_i \rightarrow \prod_{i < n} F_i \times_{\prod_{i < n} G_i} \prod_{i < n+1} G_i$$

Can be checked to be epimorphic using the internal language of the topos as the fiber product is just  $\{((g_0, \dots, g_n), (f_0, \dots, f_{n-1})) | g_i = h_i f_i\}$  so surjectivity is clear

To prove (3) we've already shown that the product agrees with the derived product so for any limit for a diagram with  $t_n : f_{n+1} \rightarrow f_n$  we can write it as the limit of

$$\prod_n F_n \xrightarrow{t - id} \prod_n F_n$$

Hence giving an exact triangle

$$R\lim F_n \rightarrow \prod_n F_n \rightarrow \prod_n F_n \rightarrow$$

and so as the products are concentrated in degree 0,  $R\lim F_n$  is concentrated in degrees 0, 1

To prove (4) then we use the same exact triangle from before

$$R\lim F_n \rightarrow \prod_n F_n \rightarrow \prod_n F_n \rightarrow$$

It suffices to show that this  $t - id$  is surjective as then  $R\lim F_n$  will be concentrated in degree 0. For the sake of making this easier to read we suggestively define  $F_n = G_n$  and  $t - id$  is assumed to be a map

$$\prod_n F_n \rightarrow \prod_n G_n$$

So maps  $F \rightarrow G$  are defined by this, and maps  $F \rightarrow F, G \rightarrow G$  are understood to be identities/projections. The surjectivity of  $t$  means that the map induced by  $t - id$

$$\prod_{i \leq n+1} F_i \rightarrow \prod_{i \leq n} G_i$$

is surjective as we can show this inductively using the internal language. Additionally as we did before the induced map

$$\prod_{i \leq n+2} F_i \rightarrow \prod_{i \leq n+1} G_i \times_{\prod_{i \leq n} G_i} \prod_{i \leq n+1} F_i$$

Is also surjective, this means by (1) the whole map is surjective  $\square$

**Definition 1.2.** An object in  $a$  a topos is called

1. Compact if the ‘underlying geometric structure’ is compact, ie if the geometric morphism  $X/a \rightarrow \text{Sh}(*) = \mathcal{S}\text{et}$  is proper
2. Stable if for all morphisms  $Y \rightarrow X$  with  $Y$  compact, the domain of the kernel pair  $R \rightrightarrows Y$  of  $f$  is also compact
3. Coherent if it is compact and stable

I dont understand this notion so this section is hard

**Definition 1.3** (Locally Weakly Contractible Topos). An object  $F$  in a topos  $X$  is called weakly contractible if every epimorphism  $G \twoheadrightarrow F$  has a section. We say that  $X$  is *locally weakly contractible* if each  $a \in X$  admits an epimorphism  $\bigsqcup Y_i \twoheadrightarrow X$  with  $Y_i$  coherent and weakly contractible

**Proposition 1.3.** Let  $X$  be a locally weakly contractible topos. Then

1.  $X$  is replete
2. The derived category  $D(X, \mathbb{Z})$  is compactly generated
3. Postnikov towers converge in the associated hypercomplete  $\infty$ -topos

**Proposition 1.4.** If  $X$  is a replete topos, then  $D(X)$  is left-complete

**Proposition 1.5.** Let  $f: A_\bullet \rightarrow A$  by a hyper cover in a replete topos  $X$ , then

1. The adjunction  $\text{id} \rightarrow f_* f^*$  is an equivalence on  $D(A)$
2. The adjunction  $f_! f^* \rightarrow \text{id}$  is an equivalence on  $D(X)$
3.  $f^*$  induces an equivalence  $D(X) \cong D_{\text{cart}}(X_\bullet) \subset D(X_\bullet)$  where  $D(X_\bullet)$  is the derived category of the simplicial topos defined by  $X_\bullet$  and  $D_{\text{cart}}(X_\bullet)$  is the full subcategory spanned by cartesian complexes

## 2 Lawvere Theories on Topoi

**Definition 2.1.** A *Lawvere Theory* is a category  $C$  with finite products and a distinguished element  $x$  so that each object is isomorphic to a finite power of  $x$ , ie  $\forall y, y \cong x^{\times n}$

**Definition 2.2.** For a Lawvere theory  $C$ , and a category with products  $S$ , a *model in  $S$*  is a product preserving functor  $C \rightarrow S$ . We define the category of such models as a full subcategory of the category of functors  $C \rightarrow S$  and denote it

$$\text{Fun}^\times(C, S)$$

**Example 2.1.** 1. On the category of finitely generated free groups we have that  $F(n) \sqcup F(m) \cong F(m+n)$  so the opposite category of finitely generated free groups is a Lawvere theory with distinguished object  $\mathbb{Z}$ . A functor  $F : \text{FiniteFreeGroups}^{\text{op}} \rightarrow \text{Set}$  then picks out a specific set  $F(\mathbb{Z})$  along with a multiplication map  $F(\mathbb{Z}) \times F(\mathbb{Z}) \rightarrow F(\mathbb{Z})$  induced by the map  $1 \mapsto ab$  that satisfies the group laws by the pushforward of these laws in  $\text{FiniteFreeGroups}^{\text{op}}$

2. Similarly a ring is just a model in sets of the Lawvere theory of integer polynomial rings
3. Additionally for a field  $k$  a  $k$ -algebra is a model in sets of the  $k$ -polynomial rings

**Lemma 2.1.** For  $C$  a Lawvere theory. Suppose in addition it's coextensive, ie for any  $m, n$  the diagram

$$\begin{array}{ccc} x^0 & \longleftarrow & x^n \\ \uparrow & & \uparrow \\ x^m & \longleftarrow & x^m \times x^n \end{array}$$

Is a pushout square.

For any topos  $X = \text{Sh}(S)$  the following categories are equivalent

1.  $\text{Fun}^\times(C, X)$

## 2. $\text{Sh}(S, \text{Fun}^\times(C, \mathcal{S}et))$

*Proof.* First we put a topology on  $C^{op}$  so that everything here can be considered as sheaves. Define the topology  $\tau_G$  on  $C^{op}$  the covers of  $A$  are finite families of morphisms  $\{A_\lambda \leftarrow A\}_{\lambda \in \Lambda}$  so that the induced map

$$A \rightarrow \prod_{\Lambda} A_\lambda A_\lambda$$

Is an isomorphism, this is known as the Gaeta topology on  $C^{op}$ . Sheaves for this topology are thus functors  $F: C \rightarrow \mathcal{S}et$  so that for any finite family  $\{A_\lambda\}_{\lambda \in \Lambda}$  we have the equaliser

$$F(A) \rightarrow \prod_{\lambda \in \Lambda} F(A_\lambda) \rightrightarrows \prod_{\mu \lambda \in \Lambda} F(A_\mu \sqcup_A A_\lambda)$$

Where  $A \cong \prod_{\lambda \in \Lambda} A_\lambda$ . If each  $F(A_\mu \sqcup_A A_\lambda)$  is terminal then we're ready as this is an equiliser if and only if  $F(\prod_{\lambda \in \Lambda} A_\lambda) \cong \prod_{\lambda \in \Lambda} F(A_\lambda)$ . Note that  $x^0$  admits the empty cover so must map to a terminal object. So inductively it suffices to show that  $x^0 \cong \text{colim}(x^n \leftarrow x^n \times x^m \rightarrow x^m)$ , this is true by assumption<sup>2</sup>

From here the proof is clear as the product of sites is well behaved so

$$\begin{aligned} \text{Fun}^\times(C, X) &\cong \text{Sh}(C^{op}, \text{Sh}(S, \mathcal{S}et)) \\ &\cong \text{Sh}(C^{op} \times S, \mathcal{S}et) \\ &\cong \text{Sh}(S, \text{Sh}(C^{op})) && \cong \text{Sh}(S, \text{Fun}^\times(C, \mathcal{S}et)) \end{aligned}$$

□

This allows us to define algebraic structures internal to a topos

**Lemma 2.2.** *As written for all the examples*

*Proof.* Any object  $F$  of (4) gives an object of (3) by taking as an object

$$F(\text{Free}(1))$$

and for an  $n$ -ary operation  $(\cdot, \dots, \cdot)$ , the morphism induced by

$$\text{Free}(1) \rightarrow \text{Free}(n)$$

that is in turn induced by

$$1 \mapsto (1, \dots, n)$$

The diagrams are satisfied as they hold in the Lawvere Theory. In addition any object of the Lawvere theory embeds in (3) as the image of the hom functor

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<sup>2</sup>I'm not 100% on if this needs to be assumed, i can concieve of a world where  $x$  is a cone over the diagram but there is no morphism  $x^0 \rightarrow x$  but I haven't written it down

under this association and so (3) embeds in (4) by the restricted internal hom functor giving an equivalence. Note these embeddings are mutual inverses as the double compositions preserve the fundamental object and the maps on this object are precisely the images of the maps on the free objects by pulling back the map

$$\hom(\underline{\text{Free}}(n), M^k) \rightarrow \hom(\underline{\text{Free}}(m), M^j)$$

to a map

$$\hom(\underline{\text{Free}}(nk), M) \rightarrow \hom(\underline{\text{Free}}(mj), M)$$

Which by yoneda is just the data of some map in our original category so double application is an isomorphism on (3), and double application on (4) is precisely the yoneda mapping so an isomorphism

(3) is equivalent to (2) by pushing forward and pulling back the structure morphisms through hom.

(4) is equivalent to (1) by lemma

□