Zeitschrift: L'Enseignement Mathématique

Herausgeber: Commission Internationale de l'Enseignement Mathématique

Band: 27 (1981)

Heft: 1-2: L'ENSEIGNEMENT MATHÉMATIQUE

Artikel: FINITENESS THEOREMS IN GEOMETRIC CLASSFIELD THEORY

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Kapitel: II. Preliminaries

DOI: https://doi.org/10.5169/seals-51753

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II. PRELIMINARIES

Let S be a connected, locally noetherian scheme, and s a geometric point of S (i.e., s is a point of S with values in an algebraically closed field). The fundamental group π_1 (S, s) in the sense of SGA I is a profinite group which classifies the finite etale coverings of S. Given two geometric points s_1 and s_2 each choice of "chemin" $c(s_1, s_2)$ from s_1 to s_2 determines an isomorphism

$$c(s_1, s_2) : \pi_1(S, s_1) \cong \pi_1(S, s_2)$$

and formation of this isomorphism is compatible with composition of chemins. If we fix s_1 and s_2 but vary the chemin, this isomorphism will (only) change by an inner automorphism of, say, π_1 (S, s_2) .

Therefore the abelianization of π_1 (S, s) (in the category of profinite groups) is canonically independent of the auxiliary choice of base point; we will denote it π_1 $(S)^{ab}$. This profinite abelian group classifies (fppf) torsors over S with (variable) finite abelian structure group, i.e. for any finite abelian group G we have a canonical isomorphism

(1.1)
$$\operatorname{Hom}_{gp}\left(\pi_{1}\left(S\right)^{ab},\,G\right) \stackrel{\sim}{\to} H^{1}_{et}\left(S,\,G\right).$$

The total space of the G-torsor T/S is connected if and only if its classifying map $\pi_1(S)^{ab} \to G$ is surjective.

Given a morphism $f: X \to S$ between connected locally noetherian schemes, a geometric point x of X and its image s = f(x) in S, there is an induced homomorphism

$$\pi_1(X, x) \to \pi_1(S, s)$$

of fundamental groups. The induced homomorphism

$$\pi_1 (X)^{ab} \to \pi_1 (S)^{ab}$$

is independent of the choice of geometric point x; indeed for any finite abelian group G the transposed map

$$\operatorname{Hom}\left(\pi_1\left(S\right)^{ab},G\right)\to\operatorname{Hom}\left(\pi_1\left(X\right)^{ab},G\right)$$

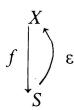
is naturally identified with the map "inverse image of G-torsors"

$$f^*: H^1_{et}(S; G) \to H^1_{et}(X; G)$$
.

We will denote by Ker (X/S) the kernel of the map of π_1^{ab} 's. Thus we have a tautological exact sequence

(1.2)
$$0 \to \text{Ker } (X/S) \to \pi_1(X)^{ab} \to \pi_1(S)^{ab}.$$

When X/S has a section

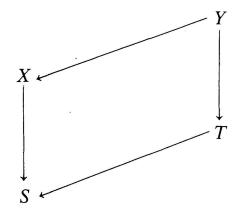


there is a simple interpretation of Ker (X/S); it classifies those torsors on X with finite abelian structure group whose inverse image via ε is trivial on S, i.e. whose restriction to the section, viewed as a subscheme of X, is completely decomposed. There is a natural product decomposition

(1.3)
$$\pi_1(X)^{ab} \simeq \pi_1(S)^{ab} \times \text{Ker } (X/S)$$

corresponding to the expression of a G-torsor on X as the "sum" of a G-torsor on X whose restriction to ε is completely decomposed and the inverse image by f of a G-torsor on S. In particular, given, a G-torsor T/X whose restriction to ε is completely decomposed, T is connected if and only if its classifying map $\operatorname{Ker}(X/S) \to G$ is surjective. In the absence of a section, there seems to be no simple physical interpretation of $\operatorname{Ker}(X/S)$.

There are two elementary functorialities it is convenient to formulate explicitly. Consider a commutative diagram of morphisms of connected, locally noetherian schemes



Proceeding down to the left, we have an exact sequence

$$(1.4) 0 \to \operatorname{Ker}(Y/X) \to \operatorname{Ker}(Y/S) \to \operatorname{Ker}(X/S).$$

Proceeding across, we have an induced map

(1.5)
$$\operatorname{Ker}(Y/T) \to \operatorname{Ker}(X/S)$$

which sits in a commutative diagram

$$0 \longrightarrow \operatorname{Ker} (Y/T) \longrightarrow \pi_1 (Y)^{ab} \longrightarrow \pi_1 (T)^{ab}$$

$$\downarrow \qquad \qquad \downarrow \qquad \qquad \downarrow$$

$$0 \longrightarrow \operatorname{Ker} (X/S) \longrightarrow \pi_1 (X)^{ab} \longrightarrow \pi_1 (S)^{ab}.$$

Let X be a geometrically connected noetherian scheme over a field K, (i.e. $X \otimes \overline{K}$ is connected, where \overline{K} denotes an algebraic closure of K). Let \overline{x} be a geometric point of $X \otimes \overline{K}$, x its image in X, and s its image in Spec K. The fundamental exact sequence (SGA I, IX, 6.1)

$$(1.6) 0 \to \pi_1(X \otimes \overline{K}, \bar{x}) \to \pi_1(X, x) \to \pi_1(S, s) \to 0$$

yields, upon abelianization, an exact sequence

(1.7)
$$\pi_1(X \otimes \overline{K})^{ab} \to \pi_1(X)^{ab} \to \pi(S)^{ab} \to 0$$

The exact sequence (1.6) allows us to define an action "modulo inner automorphism" of $\pi_1(S, s)$ on $\pi_1(X \otimes \overline{K}, \overline{x})$ (given an element $\sigma \in \pi_1(S, s)$, choose $\tilde{\sigma} \in \pi_1(X, x)$ lying over it and conjugate $\pi_1(X \otimes \overline{K}, \overline{x})$ by this $\tilde{\sigma}$). The induced action of $\pi_1(S, s)$ on $\pi_1(X \otimes \overline{K})^{ab}$ is therefore well-defined. (This same action is well-defined, and trivial, on $\pi_1(X)^{ab}$.)

Therefore the map $\pi_1 (X \otimes \overline{K})^{ab} \to \pi_1 (X)^{ab}$ factors through the coinvariants of the action of $\pi_1 (S, s)$ on $\pi_1 (X \otimes \overline{K})^{ab}$: we have an exact sequence

(1.8)
$$(\pi_1 (X \otimes \overline{K})^{ab})_{\pi_1(S,s)} \to \pi_1 (X)^{ab} \to \pi_1 (S)^{ab} \to 0.$$

If we identify $\pi_1(S, s)$ for S = Spec(K) with the galois group Gal (K/K), (which we may do canonically (only) up to an inner automorphism), then this last exact sequence may be rewritten

$$(1.9) \qquad (\pi_1(X \otimes \overline{K})^{ab})_{\operatorname{Gal}(\overline{K}/K)} \to \pi(X)^{ab} \to \operatorname{Gal}(\overline{K}/K)^{ab} \to 0.$$

Consider the special case in which X has a K-rational point x_0 ; if we choose for \bar{x} the geometric point " x_0 viewed as having values in the overfield \bar{K} of K" then the morphism x_0 : Spec $(K) \to X$ which "is" x_0 gives a splitting of the exact sequence (1.6)

$$(1.10) 0 \to \pi_1 (X \otimes \overline{K}, \overline{x}) \to \pi_1 (X, \overline{x}) \to \pi_1 (S, s) \to 0$$

so that we have a semi-direct product decomposition

(1.11)
$$\pi_1(X, x) \simeq \pi_1(X \otimes \overline{K}, \overline{x}) \ltimes \operatorname{Gal}(\overline{K}/K).$$

"Physically", the action of Gal (\overline{K}/K) on π_1 $(X \otimes \overline{K}, \overline{x})$ is simply induced by the action of Gal (\overline{K}/K) on the coefficients of the defining equations of finite etale coverings of $X \otimes \overline{K}$; this action is well defined on π_1 $(X \otimes \overline{K}, \overline{x})$ precisely because \overline{x} is a \overline{K} -valued point which is fixed by Gal (\overline{K}/K) ; if \overline{x} were not fixed, an element $\sigma \in$ Gal would "only" define an isomorphism

$$\pi_1(X \otimes \overline{K}, \vec{x}) \cong \pi_1(X \otimes \overline{K}, \sigma(\vec{x})).$$

The semi-direct product decomposition (1.11) yields, upon abelianization, a product decomposition

$$(1.12) \pi_1(X)^{ab} \cong ((\pi_1(X \otimes \overline{K})^{ab})_{Gal(\overline{K}/K)} \times Gal(\overline{K}/K)^{ab};$$

in other words, the existence of a K-rational point on X assures that the right exact sequence (1.9) is actually a split short exact sequence

$$0 \to \left((\pi_1 (X \otimes \overline{K})^{ab})_{\operatorname{Gal}(\overline{K}/K)} \to \pi_1 (X)^{ab} \to \operatorname{Gal}(\overline{K}/K)^{ab} \to 0 \right).$$

For ease of later reference, we explicitly formulate the following lemma.

LEMMA 1. Let X be a geometrically connected noetherian scheme over a field K. Then $\operatorname{Ker}(X/K)$ is the image of $\pi_1(X \otimes \overline{K})^{ab}$ in $\pi_1(X)^{ab}$. The natural surjective homomorphism

$$\pi_1 (X \otimes \overline{K})^{ab} \to \text{Ker } (X/K)$$

factors through a surjection

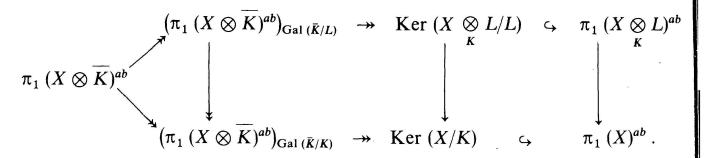
(1.14)
$$(\pi_1 (X \otimes \overline{K})^{ab})_{\text{Gal}(\overline{K}/K)} \twoheadrightarrow \text{Ker}(X/K)$$

which is an isomorphism if X has a K-rational point. Given any algebraic extension L/K, the natural map

(1.15)
$$\operatorname{Ker}(X \otimes L/L) \to \operatorname{Ker}(X/K)$$

is surjective.

Proof. The only new assertion is the surjectivity of (1.15), and this follows immediately from the surjectivity of the indicated maps in the commutative diagram



Now consider a normal, connected locally noetherian scheme S with generic point η and function field K. We fix an algebraic closure \overline{K} of K, and denote by $\overline{\eta}$ the corresponding geometric point of S. The fundamental group π_1 $(S, \overline{\eta})$ is then a quotient of the Galois group Gal (\overline{K}/K) ; the functor "fibre over η "

 $\{\text{connected finite etale coverings of } S\} \rightarrow \{\text{finite separable extensions } L/K\}$

is fully faithful, with image those finite separable extensions L/K for which the normalization of S in L is finite etale over S.

LEMMA 2. Let S be normal, connected and locally noetherian, with generic point η and function field K. Let $f: X \to S$ be a smooth surjective morphism of finite type, whose geometric generic fibre $X_{\bar{\eta}}$ is connected. Then

- (1) X is normal and connected.
- (2) For any geometric point \bar{x} in $X_{\bar{\eta}}$ with image x in X and s in S, the sequence

$$\pi_1(X_{\bar{n}}, \bar{X}) \rightarrow \pi_1(X, x) \rightarrow \pi_1(S, s) \rightarrow 0$$

is exact.

- (3) Ker (X/S) is the image of $\pi_1(X_{\bar{\eta}})^{ab}$ in $\pi_1(X)^{ab}$.
- (4) The natural map

$$\operatorname{Ker}(X_n/K) \to \operatorname{Ker}(X/S)$$

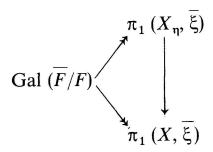
is surjective.

Proof. (1) Because X is smooth over a normal scheme, it is itself normal (SGAI, Exp II, 3.1). To see that X is connected, we argue as follows. The map f, being flat (because smooth) and of finite type over a locally noetherian scheme, is open (SGAI, Exp IV, 6.6). Therefore any nonvoid open set $U \subset X$ meets X_{η} (because f(U) is open and non-empty in S, so contains η). But X_{η} is connected (because $X_{\bar{\eta}}$ is!) and therefore the intersection of any two-non-empty open sets in X meets X_{η} .

(2) Because X is normal and connected, it has a generic point ξ and a function field F, and its function field F is none other than the function field of X_{η} (itself normal (because smooth over K) and connected). Therefore the natural map

$$\pi_1(X_{\bar{n}}, \overline{\xi}) \to \pi_1(X, \overline{\xi})$$

must be surjective, because it sits in the commutative diagram



Comparing our putative exact sequence with its analogue for X_{η}/K , we have a commutative diagram

$$0 \longrightarrow \pi_{1}(X_{\bar{\eta}}, \bar{x}) \longrightarrow \pi_{1}(X_{\eta}, x) \longrightarrow \operatorname{Gal}(\overline{K}/K) \longrightarrow 0$$

$$\parallel \qquad \qquad \downarrow \qquad \qquad \downarrow$$

$$\pi_{1}(X_{\bar{\eta}}, \bar{x}) \stackrel{\alpha}{\longrightarrow} \pi_{1}(X, x) \stackrel{\beta}{\longrightarrow} \pi_{1}(S, s) \longrightarrow 0$$

(3) This follows immediately from the exact sequence established in (2), by abelianization.

(4) This follows immediately from (3), and the commutativity of the diagram of maps induced by the obvious inclusions

$$\pi_1 (X_{\eta})^{ab} \longrightarrow \pi_1 (X_{\eta})^{ab}$$

$$\pi_1 (X)^{ab} .$$

LEMMA 3. Let X be a smooth geometrically connected variety of finite type over a field K, and let $U \subset X$ be any non-empty open set. Then the natural map

$$Ker(U/K) \rightarrow Ker(X/K)$$

is surjective.

Proof. The variety $X \otimes \overline{K}$ is normal and connected, as is the non-empty open $U \otimes \overline{K}$ in it. Therefore the natural map $\pi_1 (U \otimes \overline{K}) \to \pi_1 (X \otimes \overline{K})$ is surjective (because both source and target are quotients of the galois group of their common function field). The result now follows from the indicated surjectivities in the commutative diagram

II. THE MAIN THEOREM

Recall that a field K is said to be absolutely finitely generated if it is a finitely generated extension of its prime field, i.e. of \mathbf{Q} or of \mathbf{F}_p .

THEOREM 1. Let S be a normal, connected, locally noetherian scheme, whose function field K is an absolutely finitely generated field. Let $f: X \to S$ be a smooth surjective morphism of finite type, whose geometric generic fibre is connected. Then the group Ker(X/S) is finite if K has characteristic zero, and it is the product of a finite group with a pro-p group in case K has characteristic p.