A RELATIVE VERSION OF GIESEKER’S PROBLEM ON STRATIFICATIONS IN CHARACTERISTIC $p > 0$

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Abstract. We prove that the vanishing of the functoriality morphism for the étale fundamental group between smooth projective varieties over an algebraically closed field of characteristic $p > 0$ forces the same property for the fundamental groups of stratifications.

1. Introduction

In analogy with complex geometry, where according to Mal’cev-Grothendieck’s theorem ([Mal40], [Gro70]), a simply connected algebraic complex manifold has no non-trivial regular singular connections, Gieseker conjectured in [Gie75, p. 8] that simply connected smooth projective varieties defined over an algebraically closed characteristic $p > 0$ field have no non-trivial stratified bundles. This has been solved in the positive in [ES14, Thm. 1.1]. Gieseker in loc. cit. also conjectured that if the commutator of the étale fundamental group is a pro-$p$-group, irreducible stratified bundles have rank 1, and if the étale fundamental group is abelian with no non-trivial $p$-power quotient, then the category of stratified bundles is semi-simple with irreducible objects of rank 1. This is proven in [ES14, Thm. 3.9]. In [ES16, Thm. 3.2] we extended [EM10, Thm. 1.1] to the regular locus of a normal variety, assuming in addition that the ground field is $\bar{\mathbb{F}}_p$.

In this article we prove a relative version.

Theorem 1.1. Let $\pi : Y \to X$ be a morphism between smooth projective varieties over an algebraically closed field $k$ of characteristic $p > 0$, such that for any finite étale cover $Z \to X$, the pull-back cover $Y \times_X Z \to Y$ splits completely. Then for any stratified vector bundle $\mathcal{M}$ on $X$, the pull-back stratified bundle $\pi^*\mathcal{M}$ on $Y$ is trivial.

We can of course translate the theorem using the fundamental groups: if the homomorphism $f_* : \pi_1^\text{et}(Y) \to \pi_1^\text{et}(X)$ on the étale fundamental groups is the zero map, then so is the homomorphism $f_* : \pi_1^\text{strat}(Y) \to \pi_1^\text{strat}(X)$ on the $k$-Tannaka group-schemes of stratified bundles (we omit all the base points as this is irrelevant here).

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As in the other proofs in loc. cit., the key tool is the theorem of Hrushovski [Hru04 Cor. 1.2] on the density of preperiodic points by a correspondence over $\bar{\mathbb{F}}_p$. A complete proof of it in the framework of arithmetic geometry is due to Varshavsky [Var04 Thm. 0.1]. However, with this tool in the background, one needs a slightly different strategy as compared to the other proofs in loc. cit. Indeed, one can not argue directly on the moduli of objects the triviality of which one wants to prove. One important point here is that the triviality of a stratified bundle is recognized by the dimension of its space of stratified sections. This enables one to argue by semi-continuity arguments (see Lemma 2.1). Another point is that in the non-irreducible case, one has to deal with extensions which are not recognized on the moduli space. This also requires a new argument. See Section 5.

Acknowledgements: The theorem for irreducible stratified bundles was proved by Xiaotao Sun on 2013 in a unpublished note. He told us on January of 2017 that he and his student knew how to prove the general case based on an application of Simpson’s theorem on moduli of framed bundles, which so far exists in characteristic 0 only. We hope very much that he and his student shall soon write a characteristic $p > 0$ version of Simpson’s theorem and that this way one shall have a proof different from the one presented here. We thank him warmly for communicating his idea to us.

2. Some properties of vector bundles and their moduli

We use the standard notations: if $f : Y \to X$ and $X' \to X$ are any morphisms, one denotes by $Y_{X'} \to X'$ the base change $Y \times_X X' \to X$. If $Y$ has characteristic $p > 0$, one denotes by $F_X : X \to X$ the absolute Frobenius, by $f' : Y' = Y \times_{X,F_X} X \to X$ the pull-back of $f$ by $F_X$, by $Y \xrightarrow{f_{F_X/Y}} Y' \xrightarrow{f'} X$ the relative Frobenius above $X$.

If $E$ is a vector bundle over $Y$, one denotes by $E_{X'}$ the pull-back vector bundle over $Y_{X'}$ via $Y_{X'} \to Y$.

Recall that, from the theory of the Harder-Narasimhan filtration, any vector bundle $E$ on a smooth projective curve over an algebraically closed field has a unique maximal subbundle $F \subset E$ of maximal slope, and the slope of this subbundle $F$ is denoted by $\mu_{\max}(E)$. In particular, if $E$ has degree 0, then $\mu_{\max} \geq 0$, with equality precisely when $E$ is $\mu$-semistable.

Lemma 2.1. Let $C \to T$ be a smooth projective morphism, where $T$ is a Noetherian scheme and where the fibers are geometrically connected smooth projective curves. Let $E$ be a vector bundle of rank $r$ on $C$. Then the following holds.
(i) There is a constructible subset $T_0 \subset T$ so that for a point $t$ of $T$, it holds that

$$H^0(C_t, E_t) \otimes_{k(t)} \mathcal{O}_{C_t} \isomorph E_t$$
is a trivial bundle $\iff t$ is a point of $T_0$.

(ii) If moreover for every geometric point $t \in T$, $E_t$ is a semistable vector bundle of degree 0, then $T_0$ is closed. In particular, if $T_0$ contains a dense set of closed points of $T$, then $T_0 = T$.

(iii) As $t$ ranges over the points of $T$, the set of numbers $\mu_{\text{max}}(E_t)$ is bounded.

Proof. The semicontinuity theorem [EGAIII Thm. 7.7.5] gives (i), and also gives that for any geometric point $t$ in the closure of $T_0$, $\dim_{k(t)}H^0(C_t, E_t) \geq r$. For (ii), we note that $\dim_{k(t)}H^0(C_t, V) \leq r$ for any semistable vector bundle $V$ of rank $r$ and degree 0 on $C_t$, and equality holds if and only if $H^0(C_t, V) \otimes_{k(t)} \mathcal{O}_{C_t} \isomorph V$.

For (iii), note that if $T$ is integral, $\eta$ is a generic point, then for an open dense subset $U \subset T$, and any point $t \in U$, one has $\mu_{\text{max}}(E_\eta) = \mu_{\text{max}}(E_t)$. Now (iii) follows in general by Noetherian induction.

$\square$

Definition 2.2. Let $X$ be a smooth projective variety over an algebraically closed field $k$, and let $E$ be a vector bundle of rank $r$ on $X$.

(i) We say $E$ is unipotent if $E$ has a filtration by subbundles, the associated graded bundle of which is a trivial vector bundle.

(ii) We say $E$ is $F_X$-nilpotent of index $N$ for some natural number $N > 0$, if the $N$-th iterated Frobenius pullback $F_X^N E$ is a trivial vector bundle.

Lemma 2.3. Let $X$ be a smooth projective variety over an algebraically closed field $k$ of characteristic $p$, and let $E$ be a unipotent vector bundle of rank $r$, which is also $F_X$-nilpotent of some index. Then there is an $N = N(X, r)$, depending only the variety $X$ and the rank $r$, such that $E$ is $F_X$-nilpotent of index $N$.

Proof. We do induction on $r$, where the case $r = 1$ is trivial. If $E$ is unipotent of rank $r > 1$, there is an exact sequence

$$0 \to \mathcal{O}_X \to E \to E' \to 0$$

where $E'$ is unipotent of rank $r - 1$. Since $E$ is $F$-nilpotent of some index, it is easy to see that $E'$ is $F_X$-nilpotent of the same index, by taking that particular iterated Frobenius pullback of the above exact sequence, and noting that the quotient of a trivial bundle on $X$ by a trivial subbundle is also a trivial bundle. Hence by induction, there exists $N' = N'(X, r - 1)$ so that $F_X^{N'} E'$ is trivial. Then $F_X^{N'} E$ determines an element of

$$\text{Ext}^1_X(H^0(X, F_X^{N'} E') \otimes_k \mathcal{O}_X, \mathcal{O}_X) = H^0(X, F_X^{N'} E')^\vee \otimes_k H^1(X, \mathcal{O}_X).$$

The Frobenius $F_X$ sends a vector $v \otimes_k \gamma$ in this tensor product to $F_X^* v \otimes F_X^* k F_X^* \gamma$. It therefore suffices to note that if an element $\alpha \in H^1(X, \mathcal{O}_X)$ is $F_X$-nilpotent, then $F_X^g \alpha = 0$, where $g = \dim_k H^1(X, \mathcal{O}_X)$.

$\square$
We also note for reference the following two properties. The first one is an easy consequence of the fact that the slope of a vector bundle gets multiplied by $p$ under the Frobenius pull-back and the second one is ultimately a consequence of this as well.

**Lemma 2.4.** Let $X$ be a smooth projective variety over an algebraically closed field $k$ of characteristic $p > 0$, with a chosen polarization, and let $E$ be a vector bundle with numerically trivial Chern classes. Let $E^{(m)}$ be a vector bundle such that $F_X^{p^n} E^{(m)} \cong E$, where $p^m > \mu_{\max}(E) \cdot \text{rank}(E)$. Then $E^{(m)}$ is $\mu$-semistable.

Recall that on a smooth projective scheme $X_S$ over a scheme $S$, a stratified bundle $M$ is defined by an infinite Frobenius descent sequence $(E_n, \tau_n)$, where $E_n$ is a vector bundle on the $n$-th Frobenius twist $X_S^{(n)}$ of $X_S$ over $S$ with isomorphisms $F_{X_S^{(n)}/S} E^n \xrightarrow{\tau_{n-1}} E^{n-1}$. If $S = \text{Spec}(k)$ where $k$ is a perfect characteristic $p > 0$ field, as an object we can also write $M = (E_m, \sigma_m)_{m \geq 0}$ where $E_m$ is a vector bundle on $X_k = X$ and $F_\mathbb{F}_{n-1} E_n \xrightarrow{\sigma_{n-1}} E_{n-1}$. If $M$ is given, and $n$ is a natural number, we denote by $M(n)$ the stratified bundle $M(n) = (E_{n+m}, \sigma_{n+m})_{m \geq 0}$.

**Lemma 2.5** ([EM10], Proposition 3.2). Let $X$ be a smooth projective variety. Any stratified bundle is filtered by stratified subbundles $M_i \subset M_{i-1} \subset \cdots \subset M_0 = M$ such that the associated graded stratified bundle $\bigoplus_i M_i/M_{i+1}$ has the property that $M_i/M_{i+1}$ is irreducible and for some $n$, all the underlying vector bundles of $(M_i/M_{i+1})(n)$ are $\mu$-stable with trivial numerical Chern classes.

In view of Lemma 2.4 and Lemma 2.5, we shall consider the moduli scheme of $\mu$-stable vector bundles. Given a natural number $r > 0$, $X_S \to S$ a smooth projective morphism, there is a coarse moduli quasi-projective scheme $M(r, X_S) \to S$ of $\mu$-stable bundles of rank $r$ with trivial numerical Chern classes, which universally corepresents the functor of families of geometrically stable bundles ([Lan04 Thm. 4.1]). In particular, if $T \to S$ is any morphism of schemes, the base change is an isomorphism

$$M(r, X_T) \xrightarrow{\cong} M(r, X_S) \times_S T. \tag{2.1}$$

While applied to $F_S : T = S \to S$, this yields the isomorphism

$$M(r, X'_S) \xrightarrow{\cong} M(r, X_S) \times_{S,F_S} S. \tag{2.2}$$

We finally note the following, which is immediate from Lemma 2.3.

**Corollary 2.6.** If $X$ is a smooth projective variety over an algebraically closed field $k$ of characteristic $p > 0$, and $M$ is a stratified bundle, such that for the underlying sequence $(E_m, \sigma_m)$, each $E_m$ is an $F$-nilpotent vector bundle, then $M$ is trivial as a stratified vector bundle.
3. Reduction to the curve case

Lemma 3.1. It suffices to prove Theorem 1.1 in the special case when $Y = C$ is a smooth projective curve, and $X$ is a smooth projective surface.

Proof. Let $C \subset Y$ be a nonsingular complete intersection of very ample divisors in $Y$. By [ES16, Thm. 3.5], the homomorphism $\pi_1^{\text{strat}}(C) \to \pi_1^{\text{strat}}(Y)$ is surjective. On the other hand, the homomorphism $\pi_1^\text{ét}(C) \to \pi_1^\text{ét}(X)$ factors through $\pi_1^\text{ét}(Y) \to \pi_1^\text{ét}(X)$, and so $C \to X$ satisfies the hypotheses of Theorem 1.1. This proves the first part of the lemma. We assume now $Y = C$.

On the other hand, we can make an embedding resolution of the close embedding $C \to X$ by a sequence of blow ups at closed points. So the morphism $C \to X$ factors as a composition $C \overset{\bar{\pi}}{\to} \bar{X} \overset{f}{\to} X$, where $\bar{\pi} : C \to \bar{X}$ has smooth image, and $f : \bar{X} \to X$ is a composition of blow ups at closed points. Thus $f_* : \pi_1^\text{ét}(\bar{X}) \to \pi_1^\text{ét}(X)$ is an isomorphism. Hence, it suffices to prove Theorem 1.1 for morphisms $C \to X$, where $C$ is a smooth curve, and $\pi(C) = D \subset X$ is a smooth curve as well. By Bertini theorem [Joa83, Thm. 6.3], there is a smooth projective surface $X' \subset X$ which is a complete intersection of very ample divisors, and with $D \subset X'$. Then $\pi_1^\text{ét}(X') \to \pi_1^\text{ét}(X)$ is an isomorphism [SGA2, X, Thm. 3.10]. This finishes the proof. $\square$

4. Proof of Theorem 1.1 in the irreducible case

The aim of this section is to prove Theorem 1.1 for stratified bundles which are irreducible. So $C \to X$ is a projective morphism between a smooth projective curve $C$ and a smooth projective surface over an algebraically closed field $k$ of characteristic $p > 0$. As the triviality of $\pi^*\mathcal{M}$ is equivalent to the triviality of $\pi^*\mathcal{M}(n)$ for any natural number $n$, Lemma 2.5 enables us to assume that $\mathcal{M} = (E_m, \sigma_m)_{m \geq 0}$ has underlying $E_m$ being $\mu$-stable with trivial numerical Chern classes. Let $\mathcal{S}_X(r)$ be the set of isomorphism classes $[\mathcal{M}]$ of irreducible stratified vector bundles $\mathcal{M}$ of rank $r$, all of whose underlying vector bundles are $\mu$-stable. Let $S_r(n) \subset M(r, X)(k)$ be the set of all moduli points $[E] \in M(r, X)(k)$ such that $E$ is one of the underlying bundles of $\mathcal{M}(n)$, for some $[\mathcal{M}]$ of $\mathcal{S}_X(r)$. We denote by $\overline{S_r(n)} \subset M(r, X)$ the Zariski closure, which is a reduced closed subscheme. This defines a decreasing sequence of closed subschemes

$$M_{r, X} \supset \overline{S_r} \supset \overline{S_r(1)} \supset \overline{S_r(2)} \supset \cdots$$

which, by Noetherianity, becomes stationary at some finite stage. Set

$$\mathcal{N}_r = \mathcal{N} = \cap_{n \geq 1} \overline{S_r(n)} = \overline{S_r(N)}$$

for some $N \geq 0$.

The assignment

$$\Phi : \mathcal{N} \to \mathcal{N}, \ E \mapsto F^* \chi E$$

(4.1)
induces a dominant rational morphism which does not commute with the structure morphism \( N \rightarrow \text{Spec}(k) \). One can reinterpret \( \Phi \) as follows. Let \( N' \subset M(r, X') \) be defined in the same way as \( N \subset M(r, X) \). Via the diagram (2.2), one obtains a morphism
\[
F_k : N \times_k F_k k \rightarrow N',
\]
which is an isomorphism over \( k \) as we assumed \( k \) to be algebraically closed. One has a factorization
\[
\begin{array}{ccc}
N & \xrightarrow{F_k^{-1}} & N' \\
\downarrow & & \downarrow \\
\text{Spec}(k) & \xrightarrow{F_k^{-1}} & \text{Spec}(k)
\end{array}
\]
Now \( \Phi' \) is a dominant morphism of \( k \)-schemes
\[
\Phi' : N' \rightarrow N, \ [E] \mapsto [F_{X/k}^* E].
\]

Let \( W \) be a scheme of finite type over \( \mathbb{P}_p \) over which our data \((\pi : C \rightarrow X, N' \subset M(r, X'), N \subset M(r, X), \Phi')\) have a flat model. We use the notation \((\pi_W : C_W \rightarrow X_W, N_W' \subset M(r, X_W), N_W \subset M(r, X_W), \Phi_W : N'_W \rightarrow N_W)\), where we use (2.2) for \( M(r, X_W) \) and \( M(r, X'_W) \). We assume in addition that \( C_W \rightarrow W \) and \( X_W \rightarrow W \) are smooth and projective. The rational map of \( W \)-schemes
\[
\Phi'_W : N'_W \rightarrow N_W, \ [E] \mapsto [F_{X_W/W}^* E]
\]
is dominant. So shrinking \( W \) is necessary, for all closed points \( t \in W \), the restriction \( \Phi_t : N'_t \rightarrow N_t \) is a dominant rational map of \( k(t) \)-schemes which is defined by \([E] \mapsto [F_{X_t/t}^* E]\). Let \( p^a \) be the cardinality of \( k(t) \). Then
\[
\Phi_t^a : N_t \rightarrow N_t, \ [E] \mapsto [F_{X_t/t}^* E]
\]
is rational dominant. Using now Hrushovski’s essential theorem [Hru04, Cor. 1.2], one proves as in [EM10, Thm. 3.14], by first taking a finite extension of \( k(t) \) so as to separate the components of \( \mathcal{N}_t \), and by taking the corresponding power of \( \Phi_t \) which stabilizes the components, that the set of closed moduli points \([E] \in \mathcal{N}_t\) which are stable under a power of the Frobenius of the residue field \( k(t) \), and in particular are trivialized by a finite étale cover of \( X_t \), is dense.

Let \( T_W \rightarrow \mathcal{N}_W \) be a surjective morphism induced by a bundle \( E \) on \( X_W \times_W T_W \) such that the induced moduli map \( T_W \rightarrow M(r, X_W) \) factors through \( \mathcal{N}_W \hookrightarrow M(r, X_W) \). Let \( V = (\pi_W \times_W \text{id}_T)^* E \) be the pull-back of \( E \) on \( C_W \times_W T_W \). Lemma 2.1 (i) applied to \( V \) and the projection \( C_W \times_W T_W \rightarrow T_W \) implies that there is an open \( T_W^0 \subset T_W \) such that for all points \( t \in T_W \), \( V_t \) is the trivial bundle on \( C_t \). Lemma 2.4 together with Lemma 2.1 (ii) imply that \( T_W^0 \) contains the pull-back in \( T_W \) of a non-empty open dense subscheme \( \mathcal{N}^0 \hookrightarrow \mathcal{N} \). By Lemma 2.1
(iii) applied to \( V \) and the morphism \( C_W \times_w T_W \to T_W \), and Lemma 2.3, we may assume \( T_W^0 \) contains \( S_r(N_r) \) for some sufficiently large \( N_r \). Thus the restriction to \( C \) of any irreducible stratified bundle on \( X \) of rank \( r \) is trivial. This finishes the proof.

**Remark 4.1.** We single out the last property for later use: there is a non-empty open dense subscheme \( \mathcal{N}^0 \to \mathcal{N} \) such that \( S_r(N_r) \subset \mathcal{N}^0 \), and for any \( [E] \in \mathcal{N}^0 =: \mathcal{N}_r \) (thus on \( k \)), \( \pi^* E = H^0(C, \pi^* E) \otimes_k \mathcal{O}_C \).

## 5. Proof of Theorem 1.1 in the general case

The aim of this section is to prove Theorem 1.1 in the general case. The notation are as in Section 4. Applying Lemma 2.5, we are reduced to considering all stratified bundles \( \mathbb{M} = (E_m, \sigma_m)_{m \geq 0} \) on \( X \) of some rank \( r \), which are filtered by stratified subbundles \( \mathbb{M}^i \subset \mathbb{M}^{i-1} \subset \mathbb{M}^0 = \mathbb{M} \) such that the associated graded stratified bundle \( \oplus_{i=0}^{s-1} \mathbb{M}^i / \mathbb{M}^{i+1} \) has the property that \( \mathbb{M}^i / \mathbb{M}^{i+1} = (E_{i-m}, \sigma_{i-m})_{m \geq 0} \) is irreducible of rank say \( r_i \), and all the underlying vector bundles \( E_{i-m} \) are \( \mu \)-stable with trivial numerical Chern classes. By Theorem 1.1 in the irreducible case, we then have the property that \( \pi^* \mathbb{M}^i / \mathbb{M}^{i+1} \) is trivial.

We now start the proof. We fix a partition \( r = r_0 + \ldots + r_{s-1} \). We set

\[
(5.1) \quad \Phi' := \Phi'_0 \times_k \ldots \times_k \Phi'_{s-1} : \mathcal{N}' = \mathcal{N}'_{r_0} \times_k \ldots \times_k \mathcal{N}'_{r_{s-1}} \to \mathcal{N} := \mathcal{N}_{r_0} \times_k \ldots \times_k \mathcal{N}_{r_{s-1}}
\]

and denote by \( U' = V_0' \times_k \ldots \times_k V'_{s-1} \subset \mathcal{N}' \) the dense product open on which the dominant rational map \( \Phi' \) is defined, and is given by \(([E_0], \ldots, [E_{s-1}]) \mapsto ([F_0^k E_0], \ldots, [F_0^k E_{s-1}]), V_i = F_i(V_i')\) via (4.3) and \( U = V_0 \times_k \ldots \times_k V_{s-1} \). We note that \( \mathcal{N}_{r_i} \subset V_i \) for each \( 0 \leq i < s \).

**Definition 5.1.** In \( \mathcal{N}(k) \), define the set

\[
A = \{ ([E_0], \ldots, [E_{s-1}] ) \in \mathcal{N}'(k) \}
\]

such that

1) there is a bundle \( E \) with a filtration such that its associated graded is isomorphic to \( \oplus_{i=1}^{s-1} E_i \);
2) \( \pi^* E \) is not \( F \)-nilpotent.

We define \( A' = F_k^{-1}(A) \subset \mathcal{N}(k) \) via (4.3).

**Lemma 5.2.** The following properties hold.

(i) The set \( A \) is a constructible subset of \( \mathcal{N} \).
(ii) \( \Phi'(U' \cap A') \subset A, \quad \Phi(U \cap A) \subset A \).

**Proof.** The property (ii) is by definition. For (i), note that for \( s = 1 \), there is nothing to prove \( (A = 0) \). So we may assume \( s \geq 2 \). Repeatedly using standard properties of \( \text{Ext} \) groups, we can find a surjective morphism \( h : T \to \mathcal{N} \) (where \( T \) may not be connected), together with a vector bundle \( E_T \) on \( X \times_k T \),
with the property that $E_T$ has an $s$-step filtration by subbundles, with quotients $E_{0,T}, \ldots, E_{s-1,T}$, satisfying the following property:

1) for each geometric point $t$ of $T$, the vector bundles $E_{0,t}, \ldots, E_{s-1,t}$ obtained by restriction to $X_t$ are stable, of ranks $(r_0, \ldots, r_{s-1})$ respectively, and the induced morphism $T \to M(r_0, X) \times_k \cdots \times_k M(r_s, X)$ determined by the sequence $(E_{0,T}, \ldots, E_{s-1,T})$ regarded as a sequence of flat families of vector bundles on $X$ is the given morphism $h$ composed with the inclusion $\mathcal{N} \subset M(r_0, X) \times_k \cdots \times_k M(r_s, X);$ 

2) if $E$ is any vector bundle on $X$, with an $s$-step filtration, and quotients $E_0, \ldots, E_{s-1}$ with $[E_i] \in \mathcal{N}_{r_i} \subset M(r_i, X)$, then there is a point $t$ of $T$ such that $E \cong E_t$.

By Lemma 2.3, combined with Lemma 2.1, the pull-back vector bundle $(\pi \times_k \text{Id}_T)^*E_T$ on $C \times_k T$ has the property that the set of points $t \in T$, such that $\bigoplus_i \pi^*E_{i,t}$ is trivial and $\pi^*E_t$ is $F$-nilpotent, is a constructible subset of $T$. This implies that its complement $\Sigma$ in $T$ is constructible as well. By definition, $A = h(\Sigma) \subset \mathcal{N}$. Thus $A$ is constructible.

In order to finish the proof, it will be shown that $A$ is not dense in $\mathcal{N}$ (a more precise assertion is given in Lemma 5.3). To this aim, we use Lemma 5.2 (ii) to yet again define in it a locus stable by $\Phi$. By construction, $U$ is a dense open subset of $\mathcal{N}$, and $\Phi : U \to \mathcal{N}$ is a morphism with dense image. Set $U_1 = U$, and for $m \geq 2$, inductively define dense open subsets $U_m \subset \mathcal{N}$ by

$$U_m = \Phi^{-1}(U_{m-1}).$$

Then

$$V_0 \times_k \cdots \times_k V_{s-1} \supset U = U_1 \supset U_2 \supset U_3 \supset \cdots$$

is a decreasing sequence of open sets in $\mathcal{N}$.

**Lemma 5.3.** There is a natural number $m_1 \neq 0$ such that $U_m \cap A = \emptyset$, for all $m \geq m_1$.

**Proof.** Suppose $U_m \cap A \neq \emptyset$ for all $m$. Define

$$A_m = \overline{U_m \cap A} \subset A,$$

where the Zariski closure is taken relative to $A$. Then

$$A = A_0 \supset A_1 \supset A_2 \supset \cdots$$

is a decreasing sequence of closed, nonempty subsets. Hence by the Noetherian property, there exists $m_0$ so that

$$A_{m_0} = A_{m_0+1} = \cdots =: A_\infty$$

is a nonempty closed subset of $A$. By construction, $U_r \cap A_m$ is dense for any $m \geq r$, and so the rational map $\Phi^r$ is defined as a rational map on $A_m$, for all
$m \geq r$, and satisfies $\Phi'(A_m) \subset A_{m-r}$. Hence $\Phi' : A_{\infty} \to A_{\infty}$ is a well-defined rational map, for each $r \geq 0$. Define

$$B_r = \overline{\Phi'(A_{\infty})} \neq \emptyset,$$

where the closure is again relative to $A$. Then

$$A_{\infty} = B_0 \supset B_1 \supset B_2 \supset \cdots$$

is a decreasing sequence of nonempty closed subsets. Hence there exists $m_1$ such that

$$B_{m_1} = B_{m_1+1} = \cdots := B_{\infty} \neq \emptyset$$

is a closed subset of $A$. By construction, $\Phi$ is a rational map defined on $B_r$, for each $r \geq 0$, and further satisfies

$$\Phi(B_r) = \overline{\Phi'(A_{\infty})} = \Phi(\Phi'(A_{\infty})) = \Phi(\Phi(\Phi'(A_{\infty}))) = \Phi(r+1)(A_{\infty}) = B_{r+1}.$$}

The first equality is by definition, the second equality is true for all continuous maps of topological spaces, the third one is again by definition. Hence $\Phi : B_{\infty} \to B_{\infty}$ is a dominant rational self-map.

We now define $B'_{\infty} = F_k(B_{\infty}) \subset N'$ via (4.3). Then

$$(5.2) \quad \Phi' : B'_{\infty} \to B_{\infty}, \oplus_{i=0}^{s-1}[E_i] \to \oplus_{i=0}^{s-1}[F^{s}_X/k E_i]$$

is a dominant rational map. One defines $T'$ as the Frobenius twist of $T$, and the bundle $E'$ on $T \times_k X'$ as the pull back of $E$ on $X \times_k T$ via the Frobenius twist $F_k : X' \times_k T' \to X \times_k T$. Then (5.2) implies that the bundle $(F^{s}_X/k E_i)_{T'_{\infty}}$ is defined on $X \times_k T_{B_{\infty}}$ outside of a locus $X \times_k \Sigma$ with $\Sigma \subset T_{B_{\infty}}$ mapping to a codimension $\geq 1$ constructible subset of $B_{\infty}$.

Applying again Hrushovski’s theorem [Hru04, Cor. 1.2] as in Section 4 replacing (4.4) to (5.2), we obtain a model $B_{\infty, W}$ of $B_{\infty}$, and for any closed point of $t \in W$ a dense set of closed points $e = \oplus_{i=0}^{s-1}[E_i]$ in $B_{\infty, t}$ which are stabilized by a power of the Frobenius of $k(t)$. Choosing now $W$ such that $h : T_{B_{\infty}} \to B_{\infty}$ has a model $h_W : T_{B_{\infty}, W} \to B_{\infty, W}$, the fiber $T_{e}$ above $e \in B_{\infty, t}$ where $t$ is a closed point of $W$ has the property:

for any closed point $\tau \in T_{e}$, there is at least another closed point $\tau' \in T_{e}$ such that $F^{d(t)}_{X_{1}} E_{X_{1} \times_t \tau}$, where $d(t)$ divides the degree of $t$, is isomorphic to $F^{d(t)}_{X_{1}} E_{X_{1} \times_t \tau'}$. Indeed, we know that for any closed point $\tau$, the moduli point of the graded bundle of $F^{d(t)}_{X_{1}} E_{X_{1} \times_t \tau}$ in $B_{\infty, \tau}$ is isomorphic over $\overline{F}_{p}$, to the graded bundle associated to $E_{X_{1} \times_t \tau}$, and thus there are isomorphic over $\tau$ (see [EK16 Lem. 2.4]). By finiteness of the rational points of $T_{e}$ over finite extensions of $k(e)$, we conclude that for any closed point $e \in B_{\infty, t}$, there is a closed point $\tau \in T_{e}$ such that $F^{b}_{X_{1}} E_{X_{1} \times_t \tau}$ for some natural number $b \geq 1$. This shows in particular that $E_{X_{1} \times_t \tau}$ is trivialized by a finite étale cover. We now argue as in Section 4.
Let $V = (\pi_W \times_W \text{id}_{T_{B_{\infty},W}})^* E$ be the pull-back of $E$ on $C_W \times_W T_{B_{\infty},W}$. Lemma 2.1 (i) applied to $V$ and the projection $C_W \times_W T_{B_{\infty},W} \to T_{B_{\infty},W}$ implies that there is a constructible subset $T^0 \subset T_{B_{\infty},W}$, mapping surjectively to all closed points of $B_{\infty},W$, such that for all points $t \in T^0$, $V_t$ is the trivial bundle on $C_t$. Thus this constructible set contains points of $B_{\infty}$, which contradicts the definition of $B_{\infty}$.

This finishes the proof. □

Now if $M$ is any stratified bundle on $X$ of rank $r$ with irreducible filtered constituents $M^i/M^{i+1}$ of ranks $r_i$, for $0 \leq i < s$, we may, after replacing $M$ by some $M(n)$ if necessary, assume that the associated sequences of vector bundles $E_{im}$ (for $m \geq 0$) satisfy that $(\ldots, [E_{im}], \ldots) \in \mathcal{N}^0 \cap U_{m_1}$, where $m_1$ is as in Lemma 5.3, and hence lies in the complement of $A$. Thus $M$ has corresponding sequence $(E_m, \sigma_m)$ such that $\pi^* E_m$ is $F$-nilpotent on $C$. Hence by Corollary 2.6, $\pi^* M$ is trivial as a stratified bundle.

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