

6. The analytic proof

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that the image of $t - s$ in $J(C)$ is a constant section which completes the proof. $\square$

6. THE ANALYTIC PROOF

In this section we will suppose $K = \mathbf{C}$.

a. The Poincaré Lemma

Suppose $(\mathcal{S}, \nabla)$ is a sheaf on S^{an} with integrable connection. Then by the Poincaré lemma for integrable connections, it follows that the complex of sheaves

$$\mathcal{S} \xrightarrow{\nabla} \Omega_{San}^1 \otimes \mathcal{S} \xrightarrow{\nabla} \Omega_{San}^2 \otimes \mathcal{S} \xrightarrow{\nabla} \dots$$

is a resolution of the sheaf $\mathcal{S}^\nabla$. Hence,

PROPOSITION 1.6.1. $H^i(\mathcal{S}, \nabla)$ is naturally isomorphic to $H^i(S, \mathcal{S}^\nabla)$.

Remark. As in Proposition 1.1.1, $H^1(\mathcal{S}, \nabla)$ is isomorphic to $\text{Ext}(\mathcal{S}^\vee, \mathcal{O}_{San})$. We can describe the isomorphism from $H^1(\mathcal{S}, \nabla)$ to $H^1(S, \mathcal{S}^\nabla)$ explicitly as follows: Let h be an element of $H^1(\mathcal{S}, \nabla)$. Let $\mathcal{U}$ be a covering of S by open disks. Suppose $\mathcal{E}$ is an extension of $\mathcal{S}^\vee$ by $\mathcal{O}_{San}$ corresponding to h . Then $\mathcal{E}^\vee$ is an extension of $\mathcal{O}_{San}$ by $\mathcal{S}$. For each $U \in \mathcal{U}$, there exists an $s_U \in \mathcal{E}^\vee(U)^\nabla$ which maps to 1 in $\mathcal{O}_{San}(U)$. Then the image h in $H^1(S, \mathcal{S}^\nabla)$ is the class of the cocycle $\{(U, V) \rightarrow s_U - s_V\}$.

Suppose, X is a smooth proper S -scheme and Z is a subscheme of X which is either empty or finite over S . We will define the Betti homology sheaf $\mathcal{H}_i(X/S, Z, \mathbf{Z})$ on S^{an} as follows. If Z is smooth over S , we define $\mathcal{H}_i(X/S, Z, \mathbf{Z})$ to be the sheaf associated to the presheaf

$$U \rightarrow H_i(f^{-1}(U), f^{-1}(U) \cap Z, \mathbf{Z}),$$

(this latter group is the Betti homology of $f^{-1}(U)$ relative to $f^{-1}(U) \cap Z$). More generally, let S' be a non-empty affine open subset of S such that $Z' = Z \times_S S'$ is étale over S' . Let $X' = X \times_S S'$ and let ι denote the inclusion morphisms $X' \rightarrow X$, $Z' \rightarrow Z$ and $S' \rightarrow S$. We set

$$\mathcal{H}_i(X/S, Z, \mathbf{Z}) = \iota_* \mathcal{H}_i(X'/S', Z', \mathbf{Z}).$$

This is independent of the choice of S' . We also set

$$\mathcal{H}_i(X/S, \mathbf{Z}) = \mathcal{H}_i(X/S, \emptyset, \mathbf{Z}) \text{ and } \mathcal{H}_i(X/S, Z, \mathbf{C}) = \mathcal{H}_i(X/S, Z, \mathbf{Z}) \otimes \underline{\mathbf{C}}.$$

Suppose s and t are two distinct sections of X/S and $Z = s \cup t$. Suppose S' is an affine open of S such that Z' is étale over S' in the notation of the previous paragraph. We have exact sequences

$$0 \rightarrow \mathcal{H}_1(X/S, \mathbf{Z}) \rightarrow \mathcal{H}_1(X/S, \mathbf{Z}, \mathbf{Z}) \rightarrow \iota_* \mathcal{H}_0(Z'/S', \mathbf{Z}) \rightarrow \mathcal{H}_0(X/S, \mathbf{Z}) \rightarrow 0 .$$

and

$$0 \rightarrow \mathcal{H}_0(S'/S', \mathbf{Z}) \rightarrow \mathcal{H}_0(Z'/S', \mathbf{Z}) \rightarrow \mathcal{H}_0(X'/S', \mathbf{Z}) ,$$

where the first map is $t_* - s_*$. From which we derive the short exact sequence

$$0 \rightarrow \mathcal{H}_1(X/S, \mathbf{Z}) \rightarrow \mathcal{H}_1(X/S, \mathbf{Z}, \mathbf{Z}) \rightarrow \underline{\mathbf{Z}} \rightarrow 0 .$$

since $\iota_* \underline{\mathbf{Z}}|_{S'^{an}} \cong \underline{\mathbf{Z}}$. In particular, if U is an open disk in S^{an} , we have an exact sequence

$$0 \rightarrow \mathcal{H}_1(X/S, \mathbf{Z})(U) \rightarrow \mathcal{H}_1(X/S, \mathbf{Z}, \mathbf{Z})(U) \rightarrow \mathbf{Z} \rightarrow 0$$

We define the Betti cohomology sheaf $\mathcal{H}^1(X/S, \mathbf{Z}, \mathbf{C})$ in the same way and it is easy to see that $\mathcal{H}^1(X/S, \mathbf{Z}, \mathbf{C}) \cong \text{Hom}(\mathcal{H}_1(X/S, \mathbf{Z}, \mathbf{C}), \underline{\mathbf{C}})$. Also, it is known that if Z is étale over S then $\mathcal{H}^1(X/S, \mathbf{Z}, \mathbf{C}) \cong R_{f*}^1 \mathcal{S}_Z$ where $\mathcal{S}_Z$ is the subsheaf of $\underline{\mathbf{C}}$ whose sections vanish on Z .

Suppose X is proper over S with connected fibers. Let

$$(\mathcal{H}_{DR}^1(X/S, \mathbf{Z}), \nabla) = \mathcal{O}_{S^{an}} \otimes \mathcal{O}_S (H_{DR}^1(X/S, \mathbf{Z}), \nabla) .$$

We claim, for $Z \subseteq X$ finite over S .

$$(\mathcal{H}_{DR}^1(X/S, \mathbf{Z}), \nabla) \cong (\mathcal{O}_{S^{an}} \otimes \mathcal{H}^1(X/S, \mathbf{Z}, \mathbf{C}), d \otimes id)$$

This follows from the relative Poincaré lemma above on S' and hence on all of S since both sides are integrable connections. Hence,

LEMMA 1.6.2. *There is a natural isomorphism*

$$(\mathcal{H}_{DR}^1(X/S, \mathbf{Z})^\vee, \check{\nabla}) \cong (\mathcal{O}_{S^{an}} \otimes \mathcal{H}_1(X/S, \mathbf{Z}, \mathbf{C}), d \otimes id) .$$

In particular

$$H^i(\mathcal{H}_{DR}^1(X/S, \mathbf{Z})^\vee, \check{\nabla}) \cong H^i(S^{an}, \mathcal{H}_1(X/S, \mathbf{Z}, \mathbf{C})) .$$

We conclude, using this, Proposition 1.1.1 and GAGA that

THEOREM 1.6.3. *There exists a natural isomorphism*

$$\beta: \text{Ext}(H_{DR}^1(X/S), \mathcal{O}_S) \rightarrow H^1(S^{an}, \mathcal{H}_1(X/S, \mathbf{C})) .$$

b. *End of Analytic Proof*

Now suppose X is an Abelian scheme over S . We have an exact sequence of sheaves over S^{an} ,

$$0 \rightarrow \mathcal{H}_1(X/S, \mathbf{Z}) \rightarrow \mathcal{L}ie_{X^{an}/S^{an}} \rightarrow \underline{X^{an}} \rightarrow 0.$$

From the corresponding long exact sequence of cohomology groups we obtain an exact sequence

$$\mathcal{L}ie_{X^{an}/S^{an}}(S^{an}) \rightarrow X^{an}(S^{an}) \xrightarrow{\delta} H^1(S^{an}, \mathcal{H}_1(X/S, \mathbf{Z})).$$

We may describe $\delta(s)$ as follows: Suppose $e \neq s$. Let $Z = e \cup s$. Then as $f_*(\Omega_{X^{an}/S^{an}}^1)$ maps into $\mathcal{H}_{DR}^1(X/S)$, $\mathcal{H}_1(X/S, \mathbf{Z})$ maps into

$$f_*(\Omega_{X^{an}/S^{an}}^1)^\vee = \mathcal{L}ie_{X^{an}/S^{an}}$$

so that the diagram

$$\begin{array}{ccc} & \mathcal{H}_1(X/S, \mathbf{Z}, \mathbf{Z}) & \\ & \uparrow \quad \searrow & \\ \mathcal{H}_1(X/S, \mathbf{Z}) & \rightarrow & \mathcal{L}ie_{X^{an}/S^{an}} \end{array}$$

commutes. Let $\mathcal{U}$ be an ordered covering of S by open disks. For each $U \in \mathcal{U}$ let $\gamma_U \in \mathcal{H}_1(X/S, \mathbf{Z}, \mathbf{Z})(U)$ such that $\gamma_U \rightarrow 1$ under the map $\mathcal{H}_1(X/S, \mathbf{Z})(U) \rightarrow \mathbf{Z}$. Then the image of γ_U in $X(U)$ is $s(U)$. Hence $\delta(s)$ is represented by the one cocycle $\{(U, V) \rightarrow \gamma_U - \gamma_V\}$.

Now, it follows from this and the remark after Proposition 1.6.1 that $\beta \circ M$ is equal to the composition of δ and the natural map

$$H^1(S^{an}, \mathcal{H}_1(X/S, \mathbf{Z})) \rightarrow H^1(S^{an}, \mathcal{H}_1(X/S, \mathbf{C})) \cong H^1(S^{an}, \mathcal{H}_1(X/S, \mathbf{Z})) \otimes \mathbf{C}.$$

Hence, if $s \in X^{an}(S^{an})$, $M(s) = 0$ iff there exists a positive integer n such that $\delta(ns) = n\delta(s) = 0$. Hence ns is in the image of $\mathcal{L}ie_{X^{an}/S^{an}}(S^{an}) \rightarrow X^{an}(S^{an})$ and so is an infinitely divisible element of $X^{an}(S^{an})$.

Suppose $s \in X(S)$. We claim ns is an infinitely divisible element of $X(S)$. Let m be a positive integer. Let $t \in X^{an}(S^{an})$ such that $mt = ns$. There exists a finite étale Galois covering $\tilde{S}$ of S such that $t \in X(\tilde{S})$. If $\sigma \in \text{Gal}(\tilde{S}/S)$, then $t^\sigma = t$ because $t^\sigma(x) = t(\sigma^{-1}(x))$ for $x \in \tilde{S}(\mathbf{C})$. It follows that $t \in X(S)$. This establishes our claim.

Finally, it follows from the function field Mordell-Weil Theorem [LN] that the image of ns in $X_{\mathbf{C}(S)}(\mathbf{C}(S))$ is a constant section X/S . Theorem 1.4.3 now follows immediately. $\square$