Chapter 3, Section 3

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1. Let X be a Noetherian scheme. Show that X is affine if and only if X_{red} (II, Ex. 2.3) is affine.

Proof. One direction is clear. Suppose $X_{\text{red}} = \operatorname{Spec} A$ where A is a Noetherian ring with no nilpotent elements, let $f : X_{\text{red}} \to X$ be the natural map, and let $\mathscr{F}$ be any quasi-coherent sheaf on X. Following the hint, consider the filtration

$$\mathscr{F} \supseteq \mathscr{N} \cdot \mathscr{F} \supseteq \mathscr{N}^2 \cdot \mathscr{F} \supseteq \cdots,$$

where $\mathscr{N}$ is the sheaf of nilpotent elements on X. Note that $X \cong X_{\text{red}}$ as topological space, and the associated morphism of sheaves $\mathscr{O}_X \to f_* \mathscr{O}_{X_{\text{red}}}$ is surjective with kernel $\mathscr{N}$. Thus, each of the quotients of this filtration can be naturally viewed as A-modules. In particular, we have a natural isomorphism (2.10)

$$H^i(X, \mathscr{N}^r \cdot \mathscr{F} / \mathscr{N}^{r+1} \mathscr{F}) \cong H^i(X_{\text{red}}, f^*(\mathscr{N}^r \cdot \mathscr{F} / \mathscr{N}^{r+1} \cdot \mathscr{F})).$$

Also, the nilradical of a Noetherian ring is nilpotent, so there exists a positive integer $r > 0$ such that $\mathscr{N}^r = 0$ (A.M. 7.15). Using our hypothesis and (3.7), we climb up the filtration and deduce that $H^1(X, \mathscr{F}) = 0$. Hence, X is affine by (3.7). $\square$

2. Let X be a reduced Noetherian scheme. Show that X is affine if and only if each irreducible component is affine.

Proof. Suppose $X = \operatorname{Spec} A$ is affine for some reduced Noetherian ring A. The irreducible components of X correspond to the minimal prime ideals $\mathfrak{p}$ of A (A.M. Ex. 1.20). In particular, the irreducible components of X are precisely $\operatorname{Spec} A/\mathfrak{p}$. Conversely, let $X_i = \operatorname{Spec} A_i$ be the irreducible components of X, where A_i is a reduced Noetherian ring for each $i = 1, \ldots, n$, and let $\mathscr{F}$ be any quasi-coherent sheaf on X. We have $\mathscr{F}\big|_{U_i} \cong \widetilde{M_i}$ for some A_i-module M_i, and we have a natural map $\mathscr{F} \to j_* \mathscr{F}\big|_{X_i} = j_* j^* \mathscr{F}$ (I, Ex. 1.18). Thus, we have a natural map of $\mathscr{O}_X$-modules $\phi : \mathscr{F} \to \bigoplus_{i=1}^n j_* \mathscr{F}\big|_{X_i}$. Each $j_* \mathscr{F}\big|_{X_i}$ has vanishing cohomology for $i > 0$ by (2.10) and (3.5). Cohomology commutes with direct sums (2.9), so it suffices to show ϕ is an isomorphism. It is clearly injective. Conversely, let $(f_1, \ldots, f_n) \in \bigoplus_{i=1}^n j_* \mathscr{F}\big|_{X_i}$, where f_i is an element belonging to some localization of M_i.

$\square$

6. Let X be a Noetherian scheme.

(a) Show that the sheaf $\mathscr{G}$ constructed in the proof of (3.6) is an injective object in the category $\mathfrak{Qco}(X)$ of quasi-coherent sheaves on X. Thus, $\mathfrak{Qco}(X)$ has enough injectives.

(b) Show that any injective object of $\mathfrak{Qco}(X)$ is flasque.

(c) Conclude that one can compute cohomology as the derived functors of $\Gamma(X, \cdot)$, considered as a functor $\mathfrak{Qco}(X)$ to $\mathfrak{Ab}$.

Proof.

(a) The Hom functor commutes with finite direct sums in the second argument, so we can assume $\mathscr{G} = j_* \tilde{I}$, where $j : U = \operatorname{Spec} A \to X$ is an open immersion, and I is an injective A-module. Suppose $\mathscr{N} \to \mathscr{M}$ is an injective map of $\mathscr{O}_X$-modules, and we are given any $f : \mathscr{N} \to j_* \tilde{I}$. Since j^* is left exact, the induced map of A-modules $j^* \mathscr{N} \to j^* \mathscr{M}$ is also injective. For any such f there is an associated morphism of A-modules $g : j^* \mathscr{N} \to \tilde{I}$ by adjointness of j_*, so there exists an extension of g to $j^* \mathscr{M}$ by injectivity of $\tilde{I}$. By adjointness of j^* again, we obtain a morphism $\mathscr{M} \to j_* \tilde{I}$ that naturally extends $f : \mathscr{N} \to j_* \tilde{I}$, which is what we wanted to show.

(b) Let $\mathscr{I}$ be an injective object of $\mathfrak{Qco}(X)$.

(c)

$\square$

7. Let A be a Noetherian ring, let $X = \operatorname{Spec} A$, let $\mathfrak{a} \subseteq A$ be an ideal, and let $U \subseteq X$ be the open set $X - V(\mathfrak{a})$.

(a) For any A-module M, establish the following formula of Deligne:

$$\Gamma(U, \tilde{M}) \cong \varinjlim_n \operatorname{Hom}_A(\mathfrak{a}^n, M).$$

(b) Apply this in the case of an injective A-module I, to give another proof of (3.4).

Proof.

(a)

(b)

$\square$