Algebraic Geometry Buzzlist

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1 Algebraic Geometry

1.1 General properties

1.1.1 Complete variety

Let X be an integral, separated scheme over a field k. Then X is **complete** if is proper.

1.1.2 Crepant resolution

A **crepant resolution** is a resolution of singularities $f : X \to Y$ that does not change the canonical bundle, i.e. such that $\omega_X \simeq f^*(\omega_Y)$.

1.1.3 Normal variety

A variety X is **normal** if all its local rings are normal rings.

1.1.4 Proper morphism

A morphism $f : X \to Y$ is **proper** if it separated, of finite type, and universally closed.

1.1.5 Resolution of singularities

A morphism $f : X \to Y$ is a **resolution of singularities of Y** if X is non-singular and f is birational and proper.

1.1.6 Separated morphism

Let $f : X \to Y$ be a morphism of schemes. Let $\Delta : X \to X \times_Y X$ be the diagonal morphism. We say that f is **separated** if Δ is a closed immersion.

1.2 Results and theorems

1.2.1 Adjunction formula

Let X be a smooth algebraic variety Y a smooth subvariety. Let $i : Y \hookrightarrow X$ be the inclusion map, and let $\mathcal{I}$ be the corresponding ideal sheaf. Then $\omega_Y = i^*\omega_X \otimes_{\mathscr{O}_X} \det(\mathcal{I}/\mathcal{I}^2)^\vee$, where ω_Y is the canonical sheaf of Y.

In terms of canonical classes, the formula says that $K_D = (K_X + D)\big|_D$.

1.2.2 Bertini's Theorem

Let X be a nonsingular closed subvariety of $\mathbb{P}^n_k$, where $k = \bar{k}$. Then the set of of hyperplanes $H \subseteq \mathbb{P}^n_k$ such that $H \cap X$ is regular at every point) and such that $H \not\subseteq X$ is a dense open subset of the complete linear system $|H|$. See [1, Thm II.8.18].

1.2.3 Euler sequence

If A is a ring and $\mathbb{P}^n_A$ is projective n-space over A, then there is an exact sequence of sheaves on X:

$$0 \to \Omega_{\mathbb{P}^n_A/A} \to \mathscr{O}_{\mathbb{P}^n_A}(-1)^{n+1} \to \mathscr{O}_{\mathbb{P}^n_A} \to 0.$$

See [1, Thm II.8.13].

1.2.4 Kodaira vanishing

If k is a field of characteristic zero, X is a smooth and projective k-scheme of dimension d, and $\mathcal{L}$ is an ample invertible sheaf on X, then $H^q(X, \mathcal{L} \otimes_{\mathscr{O}_X} \Omega^p_{X/k}) = 0$ for $p + q > d$. In addition, $H^q(X, \mathcal{L}^{-1} \otimes_{\mathscr{O}_X} \Omega^p_{X/k}) = 0$ for $p + q < d$.

1.2.5 Lefschetz hyperplane theorem

Let X be an n-dimensional complex projective algebraic variety in $\mathbb{P}^n_{\mathbb{C}}$ and let Y be a hyperplane section of X such that $U = X \backslash Y$ is smooth. Then the natural map $H^k(X, \mathbb{Z}) \to H^k(Y, \mathbb{Z})$ in singular cohomology is an isomorphism for $k < n - 1$ and injective for $k = n - 1$.

1.2.6 Riemann-Roch for curves

The **Riemann-Roch theorem** relates the number of sections of a line bundle with the genus of a smooth curve C. Let $\mathcal{L}$ be a line bundle ω_C the canonical sheaf on C. Then

$$h^0(C, \mathcal{L}) - h^0(C, \mathcal{L}^{-1} \otimes_{\mathscr{O}_C} \omega_C) = \deg(\mathcal{L}) + 1 - g.$$

This is [1, Theorem IV.1.3].

1.2.7 Semi-continuity theorem

Let $f : X \to Y$ be a projective morphism of noetherian schemes, and let $\mathscr{F}$ be a coherent sheaf on X, flat over Y. Then for each $i \geq 0$, the function $h^i(y, \mathscr{F}) = \dim_{k(y)} H^(X_y, \mathscr{F}_y)$ is an upper semicontinuous function on Y. See [1, Chapter III, Theorem 12.8].

1.2.8 Serre vanishing

One form of Serre vanishing states that if X is a proper scheme over a noetherian ring A, and $\mathcal{L}$ is an ample sheaf, then for any coherent sheaf $\mathscr{F}$ on X, there exists an integer n_0 such that for each $i > 0$ and $n \geq n_0$ the group $H^i(X, \mathscr{F} \otimes_{\mathscr{O}_X} \mathcal{L}^n) = 0$ vanishes. See [1, Proposition III.5.3].

1.3 Sheaves and bundles

1.3.1 Ample line bundle

A line bundle $\mathcal{L}$ is **ample** if for any coherent sheaf $\mathscr{F}$ on X, there is an integer n (depending on $\mathscr{F}$) such that $\mathscr{F} \otimes_{\mathscr{O}_X} \mathcal{L}^{\otimes n}$ is generated by global sections. Equivalently, a line bundle $\mathcal{L}$ is ample if some tensor power of it is very ample.

1.3.2 Invertible sheaf

A locally free sheaf of rank 1 is called **invertible**. If X is normal, then, invertible sheaves are in $1-1$ correspondence with line bundles.

1.3.3 Anticanonical sheaf

The **anticanonical sheaf** ω_X^{-1} is the inverse of the canonical sheaf ω_X, that is $\omega_X^{-1} = \mathscr{H}om_{\mathscr{O}_X}(\omega_X, \mathscr{O}_X)$.

1.3.4 Canonical divisor

The **canonical divisor** K_X is the class of the canonical sheaf ω_X in the divisor class group.

1.3.5 Canonical sheaf

If X is a smooth algebraic variety of dimension n, then the canonical sheaf is $\omega := \wedge^n \Omega^1_{X/k}$ the n'th exterior power of the cotangent bundle of X.

1.3.6 Normal sheaf

Let $Y \hookrightarrow X$ be a closed immersion of schemes, and let $\mathcal{I} \subseteq \mathscr{O}_X$ be the ideal sheaf of Y in X. Then $\mathcal{I}/\mathcal{I}^2$ is a sheaf on Y, and we define the sheaf $\mathcal{N}_{Y/X}$ by $\mathscr{H}\!om_{\mathscr{O}_Y}(\mathcal{I}/\mathcal{I}^2, \mathscr{O}_Y)$.

1.3.7 Reflexive sheaf

A sheaf $\mathscr{F}$ is **reflexive** if the natural map $\mathscr{F} \to \mathscr{F}^{\vee\vee}$ is an isomorpism. Here $\mathscr{F}^{\vee}$ denotes the sheaf $\mathscr{H}\!om_{\mathscr{O}_X}(\mathscr{F}, \mathscr{O}_X)$.

1.3.8 Very ample line bundle

A line bundle $\mathcal{L}$ is **very ample** if there is an embedding $i : X \hookrightarrow \mathbb{P}^n_S$ such that the pullback of $\mathscr{O}_{\mathbb{P}^n_S}(1)$ is isomorphic to $\mathcal{L}$. In other words, there should be an isomorphism $i^* \mathscr{O}_{\mathbb{P}^n_S}(1) \simeq \mathcal{L}$.

1.4 Toric geometry

1.4.1 Polarized toric variety

A toric variety equipped with an ample T-invariant divisor.

1.5 Types of varieties

1.5.1 Calabi-Yau variety

In algebraic geometry, a **Calabi-Yau** variety is a smooth, proper variety X over a field k such that the canonical sheaf is trivial, that is, $\omega_X \simeq \mathscr{O}_X$, and such that $H^j(X, \mathscr{O}_X) = 0$ for $1 \leq j \leq n-1$.

1.5.2 Fano variety

A variety X is **Fano** if the anticanonical sheaf ω_X^{-1} is ample.

1.5.3 K3 surface

A **K3 surface** is a complex algebraic surface X such that the canonical sheaf is trivial, $\omega_X \simeq \mathscr{O}_X$, and such that $H^1(X, \mathscr{O}_X) = 0$. These conditions completely determine the Hodge numbers of X.

2 Commutative algebra

2.1 Modules

2.1.1 Depth

Let R be a noetherian ring, and M a finitely-generated R-module and I an ideal of R such that $IM \neq M$. Then the I-depth of M is (see Ext):

$$\inf\{i \mid \operatorname{Ext}^i_R(R/I, M) \neq 0\}.$$

This is also the length of a maximal M-sequence in I.

2.2 Rings

2.2.1 Cohen-Macaulay ring

A local Cohen-Macaulay ring (CM-ring for short) is a commutative noetherian local ring with Krull dimension equal to its depth. A ring is Cohen-Macaulay if its localization at all prime ideals are Cohen-Macaulay.

2.2.2 Depth of a ring

The depth of a ring R is is its depth as a module over itself.

2.2.3 Gorenstein ring

A commutative ring R is Gorenstein if each localization at a prime ideal is a Gorenstein local ring. A Gorenstein local ring is a local ring with finite injective dimension as an R-module. This is equivalent to the following: $\operatorname{Ext}^i_R(k, R) = 0$ for $i \neq n$ and $\operatorname{Ext}^n_R(k, R) \simeq k$ (here $k = R/\mathfrak{m}$ and n is the Krull dimension of R).

2.2.4 Normal ring

An integral domain R is **normal** if all its localizations at prime ideals $\mathfrak{p} \in \operatorname{Spec} R$ are integrally closed domains.

3 Convex geometry

3.1 Cones

3.1.1 Gorenstein cone

A cone $C \subset M_{\mathbb{R}}$ is **Gorenstein** if there exists a point $n \in N$ in the dual lattice such that $\langle v, n \rangle = 1$ for all generators of the semigroup $C \cap M$.

3.1.2 Simplicial cone

A cone C generated by $\{v_1, \cdots, v_k\} \subseteq N_{\mathbb{R}}$ is **simplicial** if the v_i are linearly independent.

3.2 Polyhedra

3.2.1 Dual (polar) polyhedron

If Δ is a polyhedron, its dual Δ° is defined by

$$\Delta^\circ = \{x \in N_{\mathbb{R}} \mid \langle x, y \rangle \geq -1 \,\forall\, y \in \Delta\}\,.$$

3.2.2 Gorenstein polytope of index r

A lattice polytope $P \subset \mathbb{R}^{d+r-1}$ is called a **Gorenstein polytope of index** r if rP contains a single interior lattice point p and $rP - p$ is a reflexive polytope.

3.2.3 Reflexive polytope

A polytope Δ is reflexive if the following two conditions hold:

1. All facets Γ of Δ are supported by a□ne hyperplanes of the form $\{m \in M_{\mathbb{R}} \mid \langle m, v_\Gamma \rangle\}$ for some $v_\Gamma \in N$.
2. The only interior point of Δ is 0, that is: $\mathrm{Int}(\Delta) \cap M = \{0\}$.

4 Homological algebra

4.1 Derived functors

4.1.1 Ext

Let R be a ring and M, N be R-modules. Then $\mathrm{Ext}^i_R(M, N)$ is the right-derived functors of the $\mathrm{Hom}(M, -)$-functor. In particular, $\mathrm{Ext}^i_R(M, N)$ can be computed as follows: choose a projective resolution $C_\cdot$ of N over R. Then apply the left-exact functor $\mathrm{Hom}_R(M, -)$ to the resolution and take homology. Then $\mathrm{Ext}^i_R(M, N) = h^i(C_\cdot)$.

4.1.2 Tor

Let R be a ring and M, N be R-modules. Then $\mathrm{Tor}^i_R(M, N)$ is the right-derived functors of the $- \otimes_R N$-functor. In particular $\mathrm{Tor}^i_R(M, N)$ can be computed by taking a projective resolution of M, tensoring with N, and then taking homology.

References

[1] Robin Hartshorne. *Algebraic geometry*. Springer-Verlag, New York, 1977. Graduate Texts in Mathematics, No. 52.