

Assignment

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Math 240: Homework #10

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Problem 10.1. Let C be a projective, non-singular curve, D a divisor on C with degree $d > 0$ such that $\mathcal{L}(D)$ is base point-free, of dimension r . Let $\phi : C \rightarrow \mathbb{P}^r$ be the morphism associated to D .

(a) Projecting from a point $P \notin C$ induces a morphism $\phi_P : C \rightarrow \mathbb{P}^{r-1}$. Show that this morphism is associated to subseries of $\mathcal{L}(D)$.

(b) Projecting from a point $P \in C$ induces a rational map $\phi_P : C \setminus \{P\} \rightarrow \mathbb{P}^{r-1}$. Show that it extends to a morphism $\bar{\phi}_P : C \rightarrow \mathbb{P}^{r-1}$. Identify a linear series that this morphism is associated to.

Solution.

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Problem 10.2. (a) Show that any two effective divisors of degree d in \mathbb{P}^1 are linearly equivalent.

(b) Let C be a projective non-singular curve, D a divisor on C of degree $d > 0$, and such that $l(D) = \dim \mathcal{L}(D) = d + 1$. Show that $C = \mathbb{P}^1$.

(c) Show that if C is a projective non-singular curve that is not isomorphic to \mathbb{P}^1 , then for any $d > 1$, there are effective divisors of degree d that are not linearly equivalent.

Solution. (a)

Fix a $d > 0$. Let $D = \sum_i^n c_i [P_i]$, $D' = \sum_j^m d_j [Q_j]$ be effective divisors of \mathbb{P}^1 . Consider $f = \prod_k^m (x - Q_k)^{d_k}$, $g = \prod_l^n (x - P_l)^{c_l}$, where, for my sanity, we take $(x - y)$ to mean $X_0 - y_0$ if $y_0 = 0$ and otherwise, to mean $X_1 - y_1$ if $y_0 \neq 0$ where X_0, X_1 are the formal variables for the 0th and 1st coordinates and y_0, y_1 are the coordinates of the point y . We notice that since D, D' have the same degree d , then f, g are homogenous polynomials of degree d . Then, we may look at g/f as a rational function. Since f has finitely many zeros, exactly $\{Q_1, \dots, Q_m\}$, we can look at this quotient on the open set $\mathbb{P}^1 \setminus \{Q_1, \dots, Q_m\}$, open because individual points are closed. Then, we notice that:

$$D(g/f) = \sum_l^n c_l [P_l] + \sum_k^m -d_k [Q_k] = D - D'$$

Thus, D, D' are linearly equivalent.

(b)

(c)

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Problem 10.3. Let C be the twisted cubic parametrized by (s^3, s^2t, st^2, t^3) .

(a) Show that the projection of the curve from the point $(1, 0, 0, 0)$ to the plane $X_0 = 0$ is a conic.

(b) Show that the projection from the point $(0, 1, 0, 0)$ onto the plane $X_1 = 0$ is a cuspidal cubic.

Solution. (a)

We consider first the image in the plane $X_0 = 0$. Let $A = (s^3, s^2t, st^2, t^3)$, $B = (1, 0, 0, 0)$. In a projective space, a line is exactly $xA + yB$ for $x, y \in k$, our base field. Then, to be in our plane $X_0 = 0$, we solve for x, y . In particular, we look at the first coordinate, and extract the condition:

$$xs^3 + y = 0$$

If $x = 0$, then we have $y = 0$, so our point is identically 0, which is not allowed. Then, suppose $y = 0$. Then, this is only reasonable if $s = 0$, so that we are coming from the point $(0, 0, 0, t^3) = (0, 0, 0, 1)$, which we notice is already in our plane, which is fine. Then, assume $x, y \neq 0$. Then, we look at $y = -xs^3$. Substituting into the equation of our line, we find the point in the plane as being:

$$x(s^3, s^2t, st^2, t^3) + (-xs^3)(1, 0, 0, 0) = (0, xs^2t, xst^2, xt^3) = (0, s^2t, st^2, t^3)$$

Since we know that from our original curve that s, t cannot be both 0, as that would not be a valid point in \mathbb{P}^3 , we are guaranteed that the last 3 coordinates never become identically 0. Then, we can project down into a \mathbb{P}^2 copy and retrieve the coordinates (s^2t, st^2, t^3) . Looking at the parametrization, we notice that we can realize this as the zero locus of the polynomial: $V(Y_1^2 - Y_0Y_2)$, where we name the coordinates Y_0, Y_1, Y_2 , which we identify as a conic, as it is the zero locus of a degree 2 homogeneous polynomial.

(b)

In the same vein, we do the same procedure, and look at the condition from the second coordinate: $xs^2t + y = 0$. First, we see if $s = 0$, we're looking at the point $(0, 0, 0, t^3) = (0, 0, 0, 1)$ which is already in the hyperplane. Similarly, if $t = 0$, we're looking at $(s^3, 0, 0, 0) = (1, 0, 0, 0)$, also in the hyperplane. And, we see that if $x = 0$, then $y = 0$, and vice versa, so we may not allow either of those, if we assume $s, t \neq 0$. Then, in that case, we take $y = -xs^2t$. Substituting, we find:

$$x(s^3, s^2t, st^2, t^3) + (-xs^2t)(0, 1, 0, 0) = (xs^3, 0, xst^2, xt^3) = (s^3, 0, st^2, t^3)$$

Again, since we know s, t cannot be identically 0, we may look at this as a point in a \mathbb{P}^2 , (s^3, st^2, t^3) , and, by the shape of the parametrization, we notice that we may realize this as the zero locus of the polynomial $Y_1^3 - Y_0Y_2^2$. Analyzing this polynomial for singular points, we compute the Jacobian as:

$$\mathcal{J} = [-Y_2^2, 3Y_1^2, -2Y_0Y_2]$$

Looking for actual points, we notice by the first two entries that that forces $Y_2 = 0, Y_1 = 0$, but Y_0 remains free, so we expect $(1, 0, 0)$ to be a singular point.

Now, analyzing the singular point, we look at the tangent cone here. In particular, we look at the affine version where we delete $Y_0 = 0$. Then, we can take $Y_0 = 1$, since we can always scale to achieve this, and then this implies in this affine plane, we are looking at the polynomial $Y_1^3 - Y_2^2$. Looking at the tangent cone, this has form $-Y_2^2$, which has multiplicity 2, which is a cusp. Thus, this is a cuspidal cubic.

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