

Raynaud's proof III

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BUNTES

These slides are available online (in handout form) at

https://alexjbest.github.io/talks/raynaud2/slides_h.pdf

Goal: To explain the proof of case 3) of Raynaud's proof of Abhyankar.

Recall

A group is **rev- p** if it appears as an unramified cover of $\mathbf{A}_{\mathbf{F}_p}^1$.

We are proving Abhyankar's conjecture via the following:

Theorem

Let G be a quasi- p -group and S a p -Sylow subgroup of G then we let $G(S)$ be the subgroup of G generated by all strict quasi- p -subgroups of G which have a p -Sylow subgroup contained in S .

1. If H is a normal p -subgroup of G and G/H is rev- p then G is rev- p .
2. If the strict quasi- p subgroups of G are all rev- p then $G(S)$ is rev- p .
3. If $G(S) \neq G$ and if G does not contain a non-trivial normal p -subgroup, then G is rev- p . \Leftarrow

Example of case 3)

Pop-quiz: what is an example of case 3)?

If we consider simple groups that are not p -groups we rule out case 1).

To find a quasi- p -group whose strict quasi- p -subgroups do not generate it, we could take one with no strict quasi- p -subgroups.

What about A_4 of order 12, it's simple, quasi p for $p = 2, 3$, not a p -group. The only strict quasi-3 subgroup is the 3-Sylow (the 3-cycle), so it is not generated by strict quasi-3-subgroups.

1. Construct a curve Y'' over a DVR R (with residue field k) with an action of G on Y'' , such that Y''/G has special fibre a tree of \mathbf{P}^1 's.
2. Associate a graph with a group action to this situation, where irreducible components of $Y''_k \leftrightarrow$ vertices.
3. (The combinatorial step, next week) Show that a graph with a group action satisfying additional properties must contain a vertex on which the group acts in a specific way.
4. This vertex corresponds to a component C of Y''_k covering P in X''_k in such a way that the restriction of C to $P - \{\infty\}$ is etale and Galois of group G .

Semi-stable curves

Let R be a discrete valuation ring with fraction field K .

We will outline a general construction that takes G -covers between smooth proper R -curves $Y \rightarrow X$ and creates combinatorially simpler models that can be analysed explicitly.

Definition

Let Y be a smooth projective curve over K with $H^0(Y, \mathcal{O}_Y) = K$. Then Y is said to be semi-stable if there exists a proper model of Y which is at-worst-nodal of relative dimension 1 over R (i.e. all closed points of X_k are either in the smooth locus of the structure morphism $X \rightarrow \operatorname{Spec}(k)$ or are ordinary double points). We call this a semi-stable model.

Given a semistable model, the special fibre consists of a set of irreducible components linked by double points.

We can take the dual graph of this set-up, i.e. vertices for irreducible components, with edges connecting the vertices corresponding to a pair of components that meet (this could include self-loops).

If G acts on a semistable model then we get an action on the corresponding graph.

Theorem (Semi-stable reduction theorem)

Let X be a proper R -curve with geometrically connected generic fibre. Then there exists a finite extension R' of R , such that there exists a birational and proper R' -morphism $\pi: \tilde{X} \rightarrow X \times \operatorname{Spec} R'$ where \tilde{X} is semi-stable.

Example

Consider the nodal cubic

$$y^2 = x^3 + p/\mathbf{Z}_p$$

this does not have semi-stable reduction as on the special fibre the singularity is not an ordinary double point.

However upon base-extension to $\mathbf{Z}_p[\sqrt[6]{p}]$ we can change the model to get

$$y^2 = x^3 + 1/\mathbf{Z}_p$$

which in fact has good reduction (for $p \neq 2, 3$).

Let X be an R -curve and x a closed point of X such that X_k is reduced at x . Then let

$$\delta_x = \dim_k \tilde{\mathcal{O}}_x / \mathcal{O}_x$$

(the normalization of localization of the local ring at x inside its fraction ring).

Let m_x be the number of maximal ideals of \mathcal{O}_x .

Then we set

$$\mu_x = 2\delta_x - m_x + 1 \in \mathbf{Z}_{\geq 0}$$

which has the property that:

$$\mu_x = 0 \iff x \text{ smooth and}$$

$$\mu_x = 1 \iff x \text{ is an ordinary double point.}$$

Proposition

Let $f: Y \rightarrow X$ be a covering of R -curves with X_k, Y_k both reduced. Let y be a closed point of Y with $x = f(y)$. Then

$$\mu_y \geq \mu_x.$$

Proposition (Kato)

Let $f: Y \rightarrow X$ be a covering of R -curves X_k, Y_k both reduced. Let y be a closed point of Y with $x = f(y)$. And $(x_j)_{j \in J}$ the points of the normalization \tilde{X}_k over x . Likewise let $(y_{i,j})_{j \in J, i \in I_j}$ be the points of the normalization of Y_k .

Assume $f_k: Y_k \rightarrow X_k$ is generically etale. Then

$$\mu_y - 1 = n(\mu_x - 1) + d_K - d_k^w$$

where $n = \deg(\mathrm{Spec} \hat{\mathcal{O}}_{Y,y} \rightarrow \mathrm{Spec} \hat{\mathcal{O}}_{X,x})$, the value d_K the degree of the ramification divisor of

$$\mathrm{Spec} \left(\hat{\mathcal{O}}_{Y,y} \otimes_R K \right) \rightarrow \mathrm{Spec} \left(\hat{\mathcal{O}}_{X,x} \otimes_R K \right)$$

and $d_k^w := \sum d_{i,j}^w$, $d_{i,j}^w := v_{x_j}(\delta_{y_{i,j}, x_j}) - e_{i,j} + 1$

$$\mu_y - 1 = n(\mu_x - 1) + d_K - d_K^w$$

$$d_K^w := \sum d_{i,j}^w, \quad d_{i,j}^w := v_{x_j}(\delta_{y_{i,j}, x_j}) - e_{i,j} + 1$$

where $\delta_{y_{i,j}, x_j}$ is the discriminant ideal of the extension $\hat{\mathcal{O}}_{\tilde{X}_k, x_j} \rightarrow \hat{\mathcal{O}}_{\tilde{Y}_k, y_{i,j}}$ of complete DVRs, and $e_{i,j}$ its ramification index. The integer d_K^w equals 0 if and only if the morphism $\tilde{Y}_k \rightarrow \tilde{X}_k$ between the normalisations of X_k and Y_k is tamely ramified.

Proposition

Let Y be an R -curve. Let G be a finite group acting by automorphisms on Y . Then the quotient $X := Y/G$ of Y by G exists.

Proof.

A quotient exists if and only if every orbit of G is contained in an open affine of Y , but as G is finite and every finite set of points in a quasi-projective space (such as Y) is contained in an affine. □

Proposition

Let $f: Y \rightarrow X$ be a covering. If Y is semi-stable then X is semi-stable.

Proof.

Let y be a closed point of Y , and let x be its image in X . We have $\mu_y \geq \mu_x$ and $\mu_y \in \{0, 1\}$, hence $\mu_x \in \{0, 1\}$. Thus if y is a smooth point then x is smooth, and if y is an ordinary double point, x is either a double point or a smooth point depending on the number of branches passing through x . \square

Proposition

Let $X := \operatorname{Spec} \mathcal{O}_{X',x}$ be the localisation of an R -curve X' at a smooth closed point x , and let $s : S \rightarrow X$ be an S point of X . Let $f : Y \rightarrow X$ be a Galois covering, and let e be its ramification index above the point $\tilde{x} := s(\operatorname{Spec} K)$. Assume that f is étale outside $s(S)$, and that e is prime to $\operatorname{char}(K)$. Then Y is smooth, and the morphism $f_k : Y_k \rightarrow X_k$ is tamely ramified at x with ramification index e . In particular the inertia subgroup at a point y of Y above x is cyclic of order e .

Proof

Let y be a closed point of Y above the point x . After étale localisation at y and x we can assume that y is the unique closed point of Y which is above x . Use local Riemann-Hurwitz.

Proof

$$\mu_y - 1 = n(\mu_x - 1) + d_K - d_k^w$$

We have $\mu_x = 0$. We compute d_K . Let $\{\tilde{y}_i\}_{i=1}^r$ be the points of Y_K above \tilde{x} and let f be the residual degree at these points, then $d_K = r(e f - 1)$. Hence

$\mu_y = 1 - n + n - r - d_w = 1 - r - d_w$. The only possibility is that $r = 1$, $d_w = 0$ and $\mu_y = 0$ as claimed. The inertia subgroup at y is then the same as the inertia of the extension $\mathcal{O}_{X_k, x} \rightarrow \mathcal{O}_{Y_k, y}$ which is cyclic of order e .

Proposition

Assume $\text{char}(K) = 0$ now. Let \tilde{y} be a rational point of Y_K which specialises to a point y of Y_k , and let η be the generic point of the irreducible component of Y_k containing y . Let \tilde{x} be the image of \tilde{y} in X_K and assume that $f_K : Y_K \rightarrow X_K$ is étale outside \tilde{x} . Let $e'p^a$ be the ramification index at \tilde{y} , with e' prime to p . (Note that $I(\tilde{y})$ and $I(\eta)$ are subgroups of $I(y)$.) Then:

1. $I(\eta)$ is a p -group.
2. $I(\eta)$ is invariant in $I(y)$, and the quotient $I(y)/I(\eta)$ is cyclic of order e'

In particular if $e' = 1$, then $I(\tilde{y}) \subset I(\eta) = I(y)$, and moreover if $a \geq 1$ then $f : Y \rightarrow X$ is ramified along the irreducible component containing y .

Proof

Omitted

Proposition

Let $f : Y \rightarrow X$ be a Galois covering of group G where Y and X are semi-stable. Assume that $f_K : Y_K \rightarrow X_K$ is étale. Let y be an ordinary double point of Y , whose image in X is a double point x . Let C_1 and C_2 be the two irreducible components of Y_k passing through y (which may be equal), and let η_1 and η_2 be the corresponding generic points of Y_k . Then:

1. $I(\eta_1)$ and $I(\eta_2)$ are normal p -subgroups of $I(y)$, and they generate the (normal) p -syllow subgroup of $I(y)$
2. the quotient $I(y) / \langle I(\eta_1), I(\eta_2) \rangle$ is a cyclic group of order prime to p

Proof

1. Etale localize to assume y is the unique point of Y above x so that $G = I(y)$ and $C_1 \neq C_2$. Then $D(\eta_1) = D(\eta_2) = G$, and $I(\eta_1), I(\eta_2)$ are p -groups.
2. We can pass to the quotient curve $Y' = Y / \langle I(\eta_1), I(\eta_2) \rangle$ to trivialise this subgroup, then use local Riemann-Hurwitz. If y' is the image of y we have

$$\mu_{y'} - 1 = n(\mu_x - 1) + d_K - d_k^w$$

with $\mu_x = 1$ and $d_K = 0$ so $\mu_{y'} = 0$. So the only possibility is $\mu_{y'} = 0$ and $d_k^w = 0$ so the cover $Y'_k \rightarrow X'_k$ is tamely ramified. So the original quotient $I(y) / \langle I(\eta_1), I(\eta_2) \rangle$ is cyclic.

A nicer cover

Let X be a smooth proper R -curve with geom. conn. X_K and $\{a_i : \operatorname{Spec} R \rightarrow X\}_{i=1, \dots, r}$ all R -points of X s.t. they have disjoint support (distinct on the special fibre).

Let $f: Y \rightarrow X$ be a galois cover with group G s.t. $f_K: Y_K \rightarrow X_K$ is etale away from the points x_i , Y not necessarily smooth.

After extending R we can find $Y' \rightarrow Y$ proper birational with Y' semi-stable and in such a way that the G -action extends (this follows from choosing a minimal one).

We can quotient to get $X' = Y'/G$.

A nicer cover

The points x_i induce points x'_i on X' , which remain disjoint but may have support on a double point, to fix this blow up X' and Y' to get a semi-stable model Y'' with a G -action and hence $X'' = Y''/G$ in such a way that

- The irreducible components of the special fibre of Y'' are smooth.
- The integral points $\{x_i\}_{i=1}^r$ extend to points $\{x''_i\}_{i=1}^r$ of $X''(R)$ which have disjoint support and are contained in the smooth locus of X''

as X was smooth originally and X'' is a semi-stable model of X_K the special fibre of X'' is a tree with a bunch of \mathbf{P}^1 's added to the original special fibre at double points.

If G is a quasi- p -group then it is generated by a family $(\alpha_1, \dots, \alpha_m)$ of elements of p -power order, by adding new generators if needed we can assume $\alpha_1 \cdots \alpha_m = 1$.

Consider a complete DVR R with algebraically closed residue field k of characteristic p and fraction field K of characteristic 0, π a uniformizer.

Choose m distinct R -points x_1, \dots, x_m of the projective line \mathbf{P}_R , which have disjoint support (i.e. do not reduce to the same point on the special fibre). Write

$$U = \mathbf{P}_R \setminus \{x_1, \dots, x_m\}.$$

We consider the fundamental group of $U_{\overline{K}}$, the geometric generic fibre, as K was assumed to be of characteristic 0 the Lefschetz principle tells us that the answer agrees with the usual topological one (after profinite completion).

The fundamental group is a free profinite group where we have m topological generators $(\sigma_1, \dots, \sigma_m)$ satisfying $\sigma_1 \cdots \sigma_m = 1$, so that G is a quotient of π_1 . And we have a connected Galois cover $Y_{\overline{K}} \rightarrow \mathbf{P}_{\overline{K}}^1$ with group G etale away from $\{x_i\}_i$.

The inertia subgroups above these points are cyclic p -groups. We can choose σ_i to generate inertia above x_i .

Enlarging K everything is defined over K and we can take integral versions of everything.

We can now apply the theory we developed to obtain semi-stable models Y'' and X'' for this setup where

- The irreducible components of the special fibre of Y'' are smooth.
- The rational points $\{x_i\}_{i=1}^m$ extend to integral points $\{x''_i\}_{i=1}^m$ of $X''(R)$ which have disjoint support and are contained in the smooth locus of X''

and where the special fibre of X'' is a tree of projective lines.

Proving 3)

Assume we are in the case of 3); $G(S) \neq G$ and G does not contain a non-trivial normal p -subgroup, we will apply the theory of semi-stable curves to prove that G is rev- p .

Combinatorial step shows that: the graph of the special fibre of Y'' with action of G is a **graph with inertia** (satisfies 8 conditions see next week).

It then says that there is a vertex s of the graph of Y''_k for which the decomposition group for that component is all of G , and whose image in the quotient tree is a leaf. As we have no non-trivial normal p -subgroup by assumption we have $I_s = 1$.

Restricting to this component covering a single \mathbf{P}^1 in the tree below as the vertex is a leaf it meets the rest of the special fibre only once, giving us only one double point in that component, which when removed gives us an étale G -galois cover.