Claire Voisin on the question of rationality

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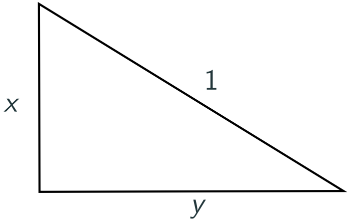
Warm-up

Can you recognise these numbers?

$\left(\frac{3}{5}, \frac{4}{5}\right), \left(\frac{5}{13}, \frac{12}{13}\right), \left(\frac{8}{17}, \frac{15}{17}\right), \left(\frac{7}{25}, \frac{24}{25}\right), \left(\frac{20}{29}, \frac{21}{29}\right), \ldots.$

These are solutions (x, y) of

$$x^2 + y^2 = 1.$$



All the solutions:

$$x = \frac{1 - t^2}{1 + t^2} \qquad y = \frac{2t}{1 + t^2}.$$

Warm-up

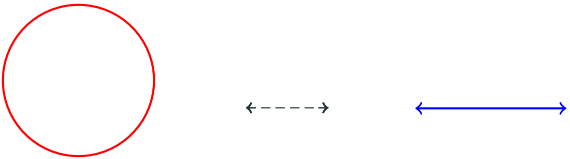
Two systems of equations ...

Variables: x, y	Variables: t
Equations: $x^2 + y^2 = 1.$	Equations: None.

... are equivalent by

$$x = \frac{1-t^2}{1+t^2}, \quad y = \frac{2t}{1+t^2} \quad \longleftarrow \quad t$$

$$x, y \quad \longrightarrow \quad \frac{y+1-x}{y+1+x}$$

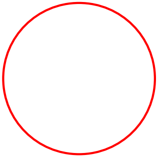


$x^2 + y^2 = 1$

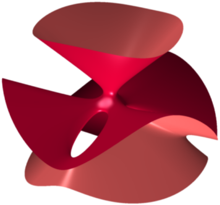
Algebraic varieties

An algebraic variety is the set of solutions of a system of polynomial equations.

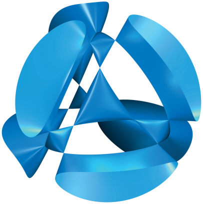
Examples



$x^2 + y^2 = 1$



$x^3 + y^3 + z^3 + 1 = (x + y + z + 1)^3$



A Kummer Surface

Algebraic varieties

An algebraic variety is the set of solutions of a system of polynomial equations.

Example (The best one)

$\mathbf{A}^n$ = The ambient space (no equations)!

Rational varieties

A variety X is rational if it is birational to $\mathbf{A}^n$.

System of equations ⇠ Coördinate change ⇢ No equations!

Rational varieties

Which varieties are rational?

1. The variety defined by $x^2 + y^2 = 1$ is rational.
2. Varieties defined by linear equations are rational.
3. Varieties defined by one quadratic equation are rational (over $\mathbf{C}$).
4. Varieties defined by one cubic ?
   4.1 Cubic curves: not rational (ancient)
   4.2 Cubic surfaces: rational (Castelnuovo, Enriques: Early 1900s)
   4.3 Cubic threefolds: not rational (Clemens–Griffiths: 1972)
   4.4 Cubic fourfolds and higher: ???

Invariants to detect non-rationality

Artin–Mumford (1971): If X is a rational smooth projective variety, then $H^3(X, \mathbf{Z})$ is torsion-free.

So we have the Artin–Mumford invariant

$$H^3(X, \mathbf{Z})_{\mathrm{tors}}$$

as a candidate to detect non-rationality.

But $H^3(X, \mathbf{Z})_{\mathrm{tors}} = 0$ for all interesting examples.

Photo credit: CNRS News Article "Claire Voisin, 2016 CNRS Gold Medal"

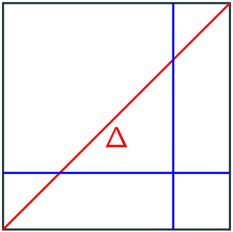
Decomposition of the diagonal

Definition (Voisin, 2015)

X admits a decomposition of the diagonal if in $\mathrm{Chow}(X \times X)$,

$$[\Delta] \sim \{x\} \times X + \alpha$$

for some α supported on $X \times Z$ for $Z \subsetneq X$.

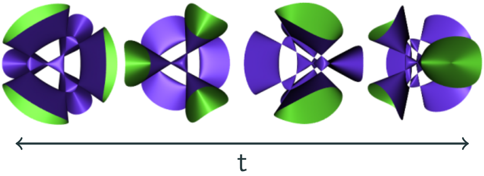


Decomposition of the diagonal

Theorem (Voisin, 2015)

1. *X rational $\implies$ X admits a decomp. of the diagonal.*
2. *X admits decomp. of the diagonal $\implies$ $H^3(X, \mathbf{Z})_{\mathrm{tors}} = 0$.*
3. *If X_t is a family of varieties such that some X_{t_0} does not admit a decomp. of the diagonal, then neither does X_t for almost all t.*

For example, $X_t = \{x^4 + y^4 + z^4 + w^4 - txyzw = 0\}$.



Decomposition of the diagonal

New technique for non-rationality theorems:

1. Consider a family X_t.
2. Find a t_0 such that X_{t_0} does not admit a decomposition of the diagonal (for example, show $H^3(X_{t_0}, \mathbf{Z})_{\mathrm{tors}} \neq 0$).
3. Theorem: Almost all X_t are not rational!

- Very general quartic double solids are not rational (Voisin, 2015).
- Rationality is not deformation invariant (Hassett–Pirutka–Tschinkel, 2016).
- Very general hypersurfaces in $\mathbf{P}^{n+1}$ of degree $d \geq \log_2 n + 2$ are not rational (Schreieder, 2018).

There's a lot more...

1. Kodaira problem,
2. Green's conjecture for canonical curves,
3. Chow rings of K3 surfaces,
4. Many questions related to the Hodge conjecture.

Thank you!