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► **To cite this version:**

| Jamel Ghannouchi. A proof of Pillai conjecture. 2012. hal-00698687v15

**HAL Id: hal-00698687**

**<https://hal.science/hal-00698687v15>**

Preprint submitted on 1 Nov 2012 (v15), last revised 28 Mar 2013 (v22)

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# A proof of Pillai conjecture

## Jamel Ghanouchi

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### Abstract

(MSC=11D04) More than one century after its formulation by the Belgian mathematician Eugene Catalan, Preda Mihailescu has solved the open problem. But, is it all ? Mihailescu's solution utilizes computation on machines, we propose here not really a proof as it is entended classically, but a resolution of an equation like the resolution of the polynomial equations of third and fourth degrees. This solution is totally algebraic and does not utilize, of course, computers or any kind of calculation.

(Keywords : Diophantine equations, Catalan equation ; Algebraic resolution)

### Introduction

Catalan theorem has been proved in 2002 by Preda Mihailescu. In 2004, it became officially Catalan-Mihailescu theorem. This theorem stipulates that there are not consecutive pure powers. There do not exist integers stricly greater than 1,  $X > 1$  and  $Y > 1$ , for which with exponents strictly greater than 1,  $p > 1$  and  $q > 1$ ,

$$Y^p = X^q + 1$$

but for  $(X, Y, p, q) = (2, 3, 2, 3)$ . We can verify that

$$3^2 = 2^3 + 1$$

Euler has proved that the equation  $X^3 + 1 = Y^2$  has this only solution. We propose in this study a general solution. The particular cases already solved concern  $p = 2$ , solved by Ko Chao in 1965, and  $q = 3$  which has been solved in 2002. The case  $q = 2$  has been solved by Lebesgue in 1850. We solve here the equation for the general case.

### The resolution

Let Catalan equation

$$Y^p = X^q + 1$$

We pose

$$c = \frac{X^p - 1}{Y^{\frac{p}{2}}}; \quad c' = \frac{7 - X^p}{Y^{\frac{p}{2}}}$$

Thus

$$Y^{\frac{p}{2}} = \frac{6}{c+c'}$$

$$X^p = cY^{\frac{p}{2}} + 1 = \frac{6c}{c+c'} + 1 = \frac{7c+c'}{c+c'}$$

And

$$X^q = Y^p - 1 = \frac{36 - (c+c')^2}{(c+c')^2}$$

We have  $X^p > 7$  hence  $c' < 0$  and  $c > c'$  and  $Y^{\frac{p}{2}} \geq 3$  thus  $0 < c+c' \leq 3$  Two cases  $c^2 > 1$  and  $c^2 \leq 1$

$c^2 > 1$  We have

$$\begin{aligned} X^q - X^{2p} &= \frac{36 - (c+c')^2 - (7c+c')^2}{(c+c')^2} \\ &< \frac{36 - 36c^2}{(c+c')^2} < 0 \end{aligned}$$

We deduce

$$q+1 \leq 2p$$

But let

$$Z = \frac{c+7c'}{c+c'}$$

We have

$$Z + X^p = 8$$

Thus

$$2X^q - (Z + X^p)^2 = 2X^q - 64 \geq 0$$

And

$$2X^{q-2p} \geq (ZX^{-p} + 1)^2$$

Let

$$\begin{aligned} n = \frac{-6X^p}{6X^p - 48} < 0 &\Rightarrow n+1 = \frac{-48}{6X^p - 48} < 0 \\ &\Rightarrow \frac{n+1}{n} = \frac{8}{X^p} > 0 \\ m = \frac{6Z}{-6Z + 48} < 0 &\Rightarrow m+1 = \frac{48}{-6Z + 48} > 0 \\ &\Rightarrow \frac{m+1}{m} = \frac{8}{Z} < 0 \end{aligned}$$

And

$$\begin{aligned} ZX^{-p} &= \frac{(n+1)m}{(m+1)n} = \frac{m(6Z-48)}{n(6X^p-48)} \\ nZ(6X^p-48) &= mX^p(6Z-48) \\ 6ZX^p(n-m) &= 48(nZ-mX^p) \\ 6ZX^{-p}(n-m) &= 48(nZX^{-p}-m)X^{-p} \end{aligned}$$

$$\begin{aligned}
& ((6 - 48X^{-p})n - 6m)ZX^{-p} = -48mX^{-p} \\
ZX^{-p} &= \frac{48mX^{-p}}{48nX^{-p} - 6n + 6m} = \frac{m(n+1)}{n(m+1)} = \frac{48mnX^{-p}}{48mnX^{-p} + 6n - 6m} \\
ZX^{-p} + 1 &= \frac{-36.96Z + 36X^p(6Z - 48) + 36Z(6X^p - 48)}{-36.48Z + 36X^p(6Z - 48) + 36Z(X^p - 48)} \\
&= \frac{-36.96Z + 36.12ZX^p - 48.36.8}{-36.48Z + 36.12ZX^p - 48.36.8} \\
(ZX^{-p} + 1)^2 &= \frac{(-36.96Z + 36.12ZX^p - 48.36.8)^2}{(-36.48Z + 36.12ZX^p - 48.36.8)^2} > \frac{1}{4}
\end{aligned}$$

Because

$$\begin{aligned}
& (-36.144Z + 36.12ZX^p - 48.36.8)(-36.240Z + 36^2ZX^p - 96.36.24) \\
&= (36.12Z(X^p - 12) - 48.36.8)(36.12Z(3X^p - 10) - 96.36.24) > 0
\end{aligned}$$

As  $Z < 0$ . Thus

$$X^{q+1} \geq 32X^q > X^{2p} \geq X^{q+1}$$

Or

$$q + 1 = 2p$$

And  $32 > X$  or  $X = 2$  then

$$Y^p = 2^{2p-1} + 1 \Rightarrow (Y, p) = (\pm 3, 2)$$

Thus

$$(X, q) = (2, 3) \Rightarrow p = 2 \Rightarrow Y = \pm 3$$

$$c^2 \leq 1$$

$$\begin{aligned}
2X^q - X^{2p} &= \frac{72 - 2(c + c')^2 - (7c + c')^2}{(c + c')^2} \\
&> \frac{64 - 49c^2}{(c + c')^2} > 0
\end{aligned}$$

Thus

$$X^q < X^{2p}$$

Or

$$q + 1 \leq 2p$$

But let

$$Z = 9 - Y^p = \frac{9(c + c')^2 - 36}{(c + c')^2}$$

We have

$$Z + X^q = 8$$

$$X^{2p} - (Z + X^q)^2 = 4X^{2p} - 64 \geq 0$$

And

$$X^{2p-q} \geq X^q(ZX^{-q} + 1)^2$$

Let

$$\begin{aligned}
n &= \frac{-6X^q}{6X^q - 48} < 0 \Rightarrow n + 1 = \frac{-48}{6X^q - 48} < 0 \\
&\Rightarrow \frac{n+1}{n} = \frac{8}{X^q} > 0 \\
m &= \frac{6Z}{-6Z + 48} < 0 \Rightarrow m + 1 = \frac{48}{-6Z + 48} > 0 \\
&\Rightarrow \frac{m+1}{m} = \frac{8}{Z} < 0
\end{aligned}$$

And

$$\begin{aligned}
ZX^{-q} &= \frac{(n+1)m}{(m+1)n} = \frac{m(6Z-48)}{n(6X^q-48)} \\
nZ(6X^q-48) &= mX^q(6Z-48) \\
6ZX^q(n-m) &= 48(nZ-mX^q) \\
6ZX^{-q}(n-m) &= 48(nZX^{-q}-m)X^{-q} \\
((6-48X^{-q})n-6m)ZX^{-q} &= -48mX^{-q} \\
ZX^{-q} &= \frac{48mX^{-q}}{48nX^{-q}-6n+6m} = \frac{m(n+1)}{n(m+1)} = \frac{48mnX^{-q}}{48mnX^{-q}+6n-6m} \\
ZX^{-q}+1 &= \frac{-36.96Z+36X^q(6Z-48)+36Z(6X^q-48)}{-36.48Z+36X^q(6Z-48)+36Z(X^q-48)} \\
&= \frac{-36.96Z+36.12ZX^q-48.36.8}{-36.48Z+36.12ZX^q-48.36.8} \\
(ZX^{-q}+1)^2 &= \frac{(-36.96Z+36.12ZX^q-48.36.8)^2}{(-36.48Z+36.12ZX^q-48.36.8)^2} > \frac{1}{4}
\end{aligned}$$

Because

$$\begin{aligned}
&(-36.144Z+36.12ZX^q-48.36.8)(-36.240Z+36^2ZX^q-96.36.24) \\
&= (36.12Z(X^q-12)-48.36.8)(36.12Z(3X^q-10)-96.36.24) > 0
\end{aligned}$$

As  $Z < 0$  and  $X^q > 12$  (else  $X^q = 8$ ). Thus

$$X^{2p} > X^q$$

Or

$$2p \geq q + 1 \geq 2p$$

which means  $q + 1 = 2p$  and

$$0 > (c^2 - 1)Y^p = X^{2p} - 2X^p - X^q = X^{2p} - 2X^p - X^{2p-1} > 0$$

Thus

$$0 = (c^2 - 1)Y^p = X^{2p} - 2X^p - X^{2p-1}$$

It means

$$X^{p-1} - X^{p-2} = \frac{2}{X} \in \mathbb{N}$$

And  $X = 2$  and  $p = 2$  thus  $q = 2p - 1 = 3$  and  $Y = \pm 3$ . The only solution of Catalan equation is

$$(Y, X, p, q) = (\pm 3, 2, 2, 3)$$

### Generalization to Pillai equation

The Pillai equation is  $Y^p = X^q + a$  let us pose  $a = 1_a 1_a$  thus

$$Y^p = X^q + 1_a 1_a$$

We pose

$$c = \frac{X^p - 1_a}{Y^{\frac{p}{2}}}, \quad c' = \frac{7_a - X^p}{Y^{\frac{p}{2}}}$$

Thus

$$Y^{\frac{p}{2}} = \frac{6_a}{c + c'}$$

$$X^p = cY^{\frac{p}{2}} + 1_a = \frac{6_a c}{c + c'} + 1_a = \frac{7_a c + 1_a c'}{c + c'}$$

And

$$X^q = Y^p - 1_a 1_a = \frac{36_a 1_a - 1_a 1_a (c + c')^2}{(c + c')^2}$$

We have  $X^p > 7_a$  hence  $c' < 0$  and  $c > c'$  and  $Y^{\frac{p}{2}} \geq 3_a$  thus  $0 < c + c' \leq 3$  Two cases  $c^2 > 1$  and  $c^2 \leq 1$

$c^2 > 1$  We have

$$X^q - X^{2p} = \frac{36_a 1_a - 1_a 1_a (c + c')^2 - (7_a c + 1_a c')^2}{(c + c')^2}$$

$$< \frac{36_a 1_a - 36_a 1_a c^2}{(c + c')^2} < 0$$

We deduce

$$q + 1 \leq 2p$$

But let

$$Z = \frac{1_a c + 7_a c'}{c + c'}$$

We have

$$Z + X^p = 8_a$$

Thus

$$8_a X^q - (Z + X^p)^2 = 8_a X^q - 64_a 1_a \geq 0$$

And

$$8_a X^{q-2p} \geq (ZX^{-p} + 1)^2$$

Let

$$n = \frac{-6X^p}{6X^p - 48} < 0 \Rightarrow n + 1 = \frac{-48}{6X^p - 48} < 0$$

$$\begin{aligned} &\Rightarrow \frac{n+1}{n} = \frac{8}{X^p} > 0 \\ m = \frac{6Z}{-6Z+48} > 0 &\Rightarrow m+1 = \frac{48}{-6Z+48} > 0 \\ &\Rightarrow \frac{m+1}{m} = \frac{8}{Z} < 0 \end{aligned}$$

And And

$$\begin{aligned} ZX^{-p} &= \frac{(n+1)m}{(m+1)n} = \frac{m(6Z-48)}{n(6X^p-48)} \\ nZ(6X^p-48) &= mX^p(6Z-48) \\ 6ZX^p(n-m) &= 48(nZ-mX^p) \\ 6ZX^{-p}(n-m) &= 48(nZX^{-p}-m)X^{-p} \\ ((6-48X^{-p})n-6m)ZX^{-p} &= -48mX^{-p} \\ ZX^{-p} &= \frac{48mX^{-p}}{48nX^{-p}-6n+6m} = \frac{m(n+1)}{n(m+1)} = \frac{48mnX^{-p}}{48mnX^{-p}+6n-6m} \\ ZX^{-p}+1 &= \frac{-36.96Z+36X^p(6Z-48)+36Z(6X^p-48)}{-36.48Z+36X^p(6Z-48)+36Z(X^p-48)} \\ &= \frac{-36.96Z+36.12ZX^p-48.36.8}{-36.48Z+36.12ZX^p-48.36.8} \\ (ZX^{-p}+1)^2 &= \frac{(-36.96Z+36.12ZX^p-48.36.8)^2}{(-36.48Z+36.12ZX^p-48.36.8)^2} > \frac{1}{4} \end{aligned}$$

Because

$$(-36.144Z+36.12ZX^p-48.36.8)(-36.240Z+36^2ZX^p-96.36.24) > 0$$

Thus

$$X^{q+1} \geq 32_a X^q > X^{2p} \geq X^{q+1}$$

Or

$$q+1 = 2p$$

And  $32_a > X$  then there is a finite number of solutions !

$c^2 \leq 1$

$$\begin{aligned} 2X^q - X^{2p} &= \frac{72_a 1_a - 2_a 1_a (c+c')^2 - (7_a c + 1_a c')^2}{(c+c')^2} \\ &> 1_a 1_a \frac{64-49c^2}{(c+c')^2} > 0 \end{aligned}$$

Thus

$$X^q < X^{2p}$$

Or

$$q+1 \leq 2p$$

But let

$$Z' = 9_a 1_a - Y^p = \frac{9_a 1_a (c + c')^2 - 36_a 1_a}{(c + c')^2}$$

We have

$$\begin{aligned} Z' + X^q &= 8 \\ X^{2p} - (Z' + X^q)^2 &= 4X^{2p} - 64 \geq 0 \end{aligned}$$

And

$$X^{2p-q} \geq X^q (Z' X^{-q} + 1)^2$$

Let

$$\begin{aligned} n &= \frac{-6X^q}{6X^q - 48} < 0 \Rightarrow n + 1 = \frac{-48}{6X^q - 48} < 0 \\ &\Rightarrow \frac{n+1}{n} = \frac{8}{X^q} > 0 \\ m &= \frac{6Z}{-6Z + 48} < 0 \Rightarrow m + 1 = \frac{48}{-6Z + 48} > 0 \\ &\Rightarrow \frac{m+1}{m} = \frac{8}{Z} < 0 \end{aligned}$$

And

$$\begin{aligned} ZX^{-q} &= \frac{(n+1)m}{(m+1)n} = \frac{m(6Z-48)}{n(6X^q-48)} \\ nZ(6X^q-48) &= mX^q(6Z-48) \\ 6ZX^q(n-m) &= 48(nZ-mX^q) \\ 6ZX^{-q}(n-m) &= 48(nZX^{-q}-m)X^{-q} \\ ((6-48X^{-q})n-6m)ZX^{-q} &= -48mX^{-q} \\ ZX^{-q} &= \frac{48mX^{-q}}{48nX^{-q}-6n+6m} = \frac{m(n+1)}{n(m+1)} = \frac{48mnX^{-q}}{48mnX^{-q}+6n-6m} \\ ZX^{-q} + 1 &= \frac{-36.96Z + 36X^q(6Z-48) + 36Z(6X^q-48)}{-36.48Z + 36X^q(6Z-48) + 36Z(X^q-48)} \\ &= \frac{-36.96Z + 36.12ZX^q - 48.36.8}{-36.48Z + 36.12ZX^q - 48.36.8} \\ (ZX^{-q} + 1)^2 &= \frac{(-36.96Z + 36.12ZX^q - 48.36.8)^2}{(-36.48Z + 36.12ZX^q - 48.36.8)^2} > \frac{1}{4} \end{aligned}$$

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Or

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which means  $q + 1 = 2p$  and

$$0 > (c^2 - 1)Y^p = X^{2p} - 2_a X^p - X^q = X^{2p} - 2_a X^p - X^{2p-1} > 0$$

Thus

$$0 = (c^2 - 1)Y^p = X^{2p} - 2_a X^p - X^{2p-1}$$

It means

$$X^{p-1} - X^{p-2} = \frac{2_a}{X} \in \mathbb{N}$$

And

$$X \leq 2_a$$

And there is a finite number of solutions !

### Conclusion

Catalan equation implies a second one, and an original solution of Catalan equation exists. We have the generalized the approach to illai equation and proved that it has a finite number of solutions !

## Références

- [1] P. MIHAILESCU A class number free criterion for catalan's conjecture, *Journal of Number theory* , **99** (2003).