Power of Two as Sums of Three Pell Numbers

Joint work with J. J. Bravo, F. Luca

Bernadette Faye

Ph.d Student

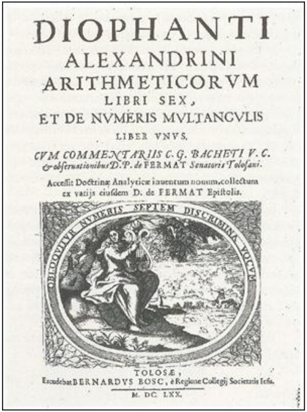
Journées Algophantiennes Bordelaises,

07-09 July 2017

Motivation

Diophantine equations obtained by asking that members of some fixed binary recurrence sequence be

- squares,
- factorials,
- triangular,
- belonging to some other interesting sequence of positive integers.


DIOPHANTI
ALEXANDRINI
ARITHMETICORVM
LIBRI SEX,
ET DE NVMERIS MVLTANGVLIS
LIBER VNVS.
CVM COMMENTARIIS C. G. BACHETI V. C.
& obseruationibus D. P. de FERMAT Senatoris Tolosani.
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Excudebat BERNARDVS BOSC, è Regione Collegij Societatis Iesu.
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Motivation

Problem: Find all solutions in positive integers m, n, ℓ, a of the equation

$$P_m + P_n + P_\ell = 2^a,$$

where

$$\begin{cases} P_0 = 0 \\ P_1 = 1 \\ P_{n+2} = 2P_{n+1} + P_n, \ \ for \ \ n \geq 0 \end{cases}$$

History

- Stewart(1980), "On the representation of integers in two different basis": the set

$$\{n : s_a(n) < K \text{ and } s_b(n) < K\}$$

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- Bravo, Goméz and Luca(2016): $F_n^{(k)} + F_m^{(k)} = 2^a$

Most Recent results...

- Meher and Rout(Preprint):

$$U_{n_1} + \cdots + U_{n_t} = b_1 p_1^{z_1} + \cdots + b_s p_s^{z_s}$$

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- Chim and Ziegler(Preprint):

$$F_{n_1} + F_{n_2} = 2^{a_1} + 2^{a_2} + 2^{a_3}.$$

$$F_{m_1} + F_{m_2} + F_{m_3} = 2^{t_1} + 2^{t_2}.$$

Theorem 1 (Bravo, F., Luca, 2017)

The only solutions (n, m, ℓ, a) *of the Diophantine equation*

$$P_n + P_m + P_\ell = 2^a \tag{1}$$

in integers $n \geq m \geq \ell \geq 0$ *are in*

$$(2,1,1,2), (3,2,1,3), (5,2,1,5), (6,5,5,7),$$

$$(1,1,0,1), (2,2,0,2), (2,0,0,1), (1,0,0,0).$$

Strategy of the Proof

Assume $n \geq 150$, $n \geq m \geq \ell$

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- The iterated application of linear forms in logarithms...

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- Baker-Devenport reduction algorithm
- Properties of the convergent of the continued fractions

Proof

- Recall that

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$$2^a < \alpha^{n-1} + \alpha^{m-1} + \alpha^{\ell-1} < 2^{2n-2}(1 + 2^{2(m-n)} + 2^{2(\ell-n)}) < 2^{2n+1}.$$

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$$\implies a \leq 2n.$$

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$$\left|1 - 2^{a+1} \cdot \alpha^{-n} \cdot \sqrt{2}\right| < \frac{8}{\alpha^{n-m}}.$$

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$$\left|1 - 2^{a+1} \cdot \alpha^{-n} \cdot \sqrt{2}\right| < \frac{8}{\alpha^{n-m}}.$$
- Bounding $n - m$ in terms of n

Linear forms in Logarithms à la Baker

Theorem 2 (Matveev 2000)

Let $\mathbb{K}$ *be a number field of degree* D *over* $\mathbb{Q}$, $\eta_1, \ldots, \eta_t$ *be positive real numbers of* $\mathbb{K}$, *and* $b_1, \ldots, b_t$ *rational integers. Put*

$$\Lambda = \eta_1^{b_1} \cdots \eta_t^{b_t} - 1 \qquad \textit{and} \qquad B \geq \max\{|b_1|, \ldots, |b_t|\}.$$

Let $A_i \geq \max\{Dh(\eta_i), |\log \eta_i|, 0.16\}$ *be real numbers, for* $i = 1, \ldots, t$.

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Let $A_i \geq \max\{Dh(\eta_i), |\log \eta_i|, 0.16\}$ be real numbers, for $i = 1, \ldots, t$. Then, assuming that $\Lambda \neq 0$, we have

$$|\Lambda| > \exp(-1.4 \times 30^{t+3} \times t^{4.5} \times D^2(1 + \log D)(1 + \log B)A_1 \cdots A_t).$$

First Linear Forms in Logarithms

From

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Then

$$|\Lambda| \geq \exp\left(-1.4 \times 30^6 \times 3^{4.5} \times 2^2 \times (1 + \log 2)(2\log n) \times 1.4 \times 0.9 \times 0.7\right.$$

$$\Longrightarrow (n - m)\log\alpha < 1.8 \times 10^{12} \log n.$$

Second Linear Forms in Logarithms

Rewriting the equation $P_n + P_m + P_\ell = 2^a$ in a different way, we get to

$$\left|1 - 2^{a+1} \cdot \alpha^{-n} \cdot \sqrt{2}(1 + \alpha^{m-n})^{-1}\right| < \frac{5}{\alpha^{n-\ell}}.$$

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Matveev's Theorem

$$\Longrightarrow (n - \ell) \log \alpha < 5 \times 10^{24} \log^2 n.$$

Third Linear Forms in Logarithms

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$$\Longrightarrow n < 1.7 \times 10^{43}.$$

Summary of the above finding

Lemma 3

If (n, m, ℓ, a) *is a solution in positive integers of equation* $P_n + P_m + P_\ell = 2^a$ *, with* $n \geq m \geq \ell$*, then*

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If (n, m, ℓ, a) is a solution in positive integers of equation $P_n + P_m + P_\ell = 2^a$, with $n \geq m \geq \ell$, then

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- $(n - m) \log \alpha < 1.8 \times 10^{12} \log n$.
- $(n - \ell) \log \alpha < 5 \times 10^{24} \log^2 n$.
- $n < 1.7 \times 10^{43}$.
- $a < 2n + 1 < 4 \times 10^{43}$.

Reducing the bound on n

Lemma 4 (Baker-Devenport reduction Algorithm)

Let M be a positive integer, let p/q be a convergent of the continued fraction of the irrational γ such that $q > 6M$, and let A, B, μ be some real numbers with $A > 0$ and $B > 1$. Let $\epsilon := ||\mu q|| - M||\gamma q||$. If $\epsilon > 0$, then there is no solution to the inequality

$$0 < |u\gamma - v + \mu| < AB^{-w},$$

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$$u \leq M \quad \text{and} \quad w \geq \frac{\log(Aq/\epsilon)}{\log B}.$$

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Dividing across by $\log\alpha$ we get

$$0 < (2a+3)\left(\frac{\log 2}{\log\alpha}\right) - 2n < \frac{20}{\alpha^{n-m}}.$$

The inequality

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has the shape

$$|x\gamma - y| < 20/\alpha^{n-m}.$$

Find a lower bound for

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We use properties of the convergents of the continued fraction to $\gamma := [a_0, a_1, a_2, \ldots] = [0, 1, 3, 1, 2, \ldots]$.

Since $2a + 3 < 9 \times 10^{43}$, with a quick computation with Mathematica

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Furthermore $a_M := \max\{a_i : i = 1\ldots, 88\} = 100$. Then, from the properties of the continued fractions,

$$\frac{1}{(a_M+2)(2a+3)} < (2a+3)\gamma - 2n < \frac{20}{\alpha^{n-m}}$$

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$\Longrightarrow n - m < 124.$

The same argument as before gives

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- $n - \ell < 122$.

Finally, in order to obtain a better upper bound on n, we use consider the relation

$$\Lambda_3 := (a+1)\log 2 - n\log\alpha + \log\phi(n-m, n-\ell),$$

with $\phi(x_1, x_2) := \sqrt{2}(1+\alpha^{-x_1}+\alpha^{-x_2})^{-1}$.

Last Computations...

Hence, we use the inequality

$$0 < \left| (a+1)\left(\frac{\log 2}{\log \alpha}\right) - n + \left(\frac{\log \phi(n-m, n-\ell)}{\log \alpha}\right) \right| < \frac{5}{\alpha^n},$$

with $\phi(x_1, x_2) := \sqrt{2}(1 + \alpha^{-x_1} + \alpha^{-x_2})^{-1}$.

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$$0 < \left|(a+1)\left(\frac{\log 2}{\log \alpha}\right) - n + \left(\frac{\log \phi(n-m, n-\ell)}{\log \alpha}\right)\right| < \frac{5}{\alpha^n},$$

with $\phi(x_1, x_2) := \sqrt{2}(1 + \alpha^{-x_1} + \alpha^{-x_2})^{-1}$.

- For all possible choices of $n - m \in [0, 124]$ and $n - \ell \in [0, 140]$, use the reduction algorithm

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- For all possible choices of $n - m \in [0, 124]$ and $n - \ell \in [0, 140]$, use the reduction algorithm
- Find if (n, m, ℓ, a) is a possible solution of the equation $P_n + P_m + P_\ell = 2^a$,

Last Computations...

Hence, we use the inequality

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- For all possible choices of $n - m \in [0, 124]$ and $n - \ell \in [0, 140]$, use the reduction algorithm
- Find if (n, m, ℓ, a) is a possible solution of the equation $P_n + P_m + P_\ell = 2^a$,
- One gets that $n < 150$, contradiction.

Theorem 5 (Bravo, F., Luca, 2017)

The only solutions (n, m, ℓ, a) *of the Diophantine equation*

$$P_n + P_m + P_\ell = 2^a \tag{2}$$

in integers $n \geq m \geq \ell \geq 0$ *are in*

$$(2, 1, 1, 2), (3, 2, 1, 3), (5, 2, 1, 5), (6, 5, 5, 7),$$

$$(1, 1, 0, 1), (2, 2, 0, 2), (2, 0, 0, 1), (1, 0, 0, 0).$$

"I love mathematics for its own sake, because it allows for no hypocrisy and no vagueness." Stendhal

THANKS FOR YOUR ATTENTION !

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