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VOLKER KESSLER

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On the minimum of the unit lattice.

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1. Introduction.

Computations in lattices often require a lower bound for the minimum of the lattice, both for practical purposes and for a theoretical analysis of the algorithms, e.g. [1] and [2].

In this paper we recall two results of Dobrowolski [3] and Smyth [5] in order to get such a bound for the unit lattice.

2. Lower bound.

Let K be a finite extension of $\mathbb{Q}$ of degree n with maximal order R. For $1 \leq i \leq n$ we denote by

$$K \to K^{(i)} \subset \mathbb{C}, \quad \alpha \to \alpha^{(i)}$$

the n different embeddings of K into the field $\mathbb{C}$ of complex numbers. The first r_1 of those embeddings are real, the last $2r_2$ embeddings are non-real and numbered such that the $(r_1 + r_2 + i)$th embedding is the complex-conjugation of the $(r_1 + i)$th embedding. Then the logarithmic map is given by

$$\mathrm{Log} : K^* \to \mathbb{R}^r, \quad \mathrm{Log}(\alpha) := (c_1 \log|\alpha^{(1)}|, \cdots, c_r \log|\alpha^{(r)}|)$$

with the unit rank $r = r_1 + r_2 - 1$ and

$$c_i = \begin{cases} 1 & \text{for } 1 \leq i \leq r_1 \\ 2 & \text{for } r_1 + 1 \leq i \leq r + 1. \end{cases}$$

The kernel of Log consists exactly of the roots of the unity lying in K. We define the *minimum* $\lambda(L)$ of the *unit lattice* $L := Log(R^*)$ by

$$\lambda(L) = \min\{ \|v\| \mid v \in L \backslash \{0\}\}$$

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where $|| \ ||$ denotes the Euclidean norm.

THEOREM : *A lower bound for the minimum $\lambda(L)$ is given by*

(1)
$$\lambda(L) > \mu(K) := \sqrt{\frac{2}{r+1}} \left(\frac{1}{1200} (\frac{\log \log n}{\log n})^3 - \frac{1}{2880000} (\frac{\log \log n}{\log n})^6 \right)$$

which is "a bit" larger than

$$\frac{1}{\sqrt{r+1}} \frac{1}{1000} (\frac{\log \log n}{\log n})^3.$$

Thus the inverse $1/\lambda(L)$ is of the magnitude $0(n^{1/2+\epsilon})$ for every $\epsilon > 0$.

PROOF. Let $\epsilon \in R^*$ be a unit of degree m over $\mathbb{Q}$, which is no root of unity. Without loss of generality we can assume that $m = n$, because if $||\text{Log } \epsilon||$ is larger than $\mu(K')$ for a subfield K' of K it is also larger than $\mu(K)$.

We are interested in two subsets of the conjugates $\epsilon^{(1)}, \cdots, \epsilon^{(n)}$

$$S := \{1 \le i \le r+1 \mid |\epsilon^{(i)}| > 1\}$$
$$T := \{1 \le i \le r+1 \mid |\epsilon^{(i)}| < 1\}.$$

Since ϵ is no root of unity S is non-empty and therefore T cannot be empty because of $N(\epsilon) = 1$.

We call ϵ *reciprocal* if ϵ is conjugate to ϵ^{-1}, i.e. its minimal polynomial $f(X) = X^n + a_{n-1}X^{n-1} + \cdots + a_0$ satisfies

$$f(X) = X^n f(\frac{1}{X}) = a_0 X^n + a_1 X^{n-1} + \cdots + a_{n-1} X + 1.$$

If ϵ is non-reciprocal we know from the theorem of [5] that

$$\prod_{i \in S} |\epsilon^{(i)}|^{c_i} \ge \theta$$

where θ is the real root of $X^3 - X - 1$, i.e. $\theta \approx 1.3247$. Thus

(2)
$$\sum_{i \in S} c_i \log |\epsilon^{(i)}| \ge \log \theta \approx 0.281$$

But from $N(\epsilon) = 1$ it follows

$$\sum_{i \in S} c_i \log |\epsilon^{(i)}| = - \sum_{i \in T} c_i \log |\epsilon^{(i)}|. \tag{3}$$

The value $c_{r+1} \log |\epsilon^{(r+1)}|$ does not occur in the norm of $\mathrm{Log}(\epsilon)$. But as a consequence of (3) it does not matter if $r+1$ lies in S or in T and so we can assume without restriction that $r+1 \notin S$. Thus

$$\begin{aligned} ||\mathrm{Log}(\epsilon)|| &\geq \sqrt{\sum_{i \in S} (c_i \ \log |\epsilon^{(i)}|)^2} \\ &\geq r^{-1/2} \sum_{i \in S} (c_i \ \log |\epsilon^{(i)}|) \geq r^{-1/2} \log \ \theta > \mu(K). \end{aligned}$$

(The second inequality follows from the well known norm equivalence between 1-norm and Euclidean norm.)

For <u>reciprocal</u> ϵ we know by Theorem 1 of [3] :

$$\prod_{i \in S} |\epsilon^{(i)}|^{c_i} > 1 + \frac{1}{1200} \left(\frac{\log \ \log \ n}{\log \ n}\right)^3. \tag{4}$$

We now use the Taylor series of the logarithm ($|y| < 1$) :

$$\log(1+y) = y - \frac{y^2}{2} + \frac{y^3}{3} \mp \cdots > y - \frac{y^2}{2}. \tag{5}$$

The inequality follows directly from Lagrange's representation of the residue. Applying (5) to (4) yields

$$\sum_{i \in S} c_i \ \log |\epsilon^{(i)}| > \frac{1}{1200} \left(\frac{\log \log n}{\log n}\right)^3 - \frac{1}{2880000} \left(\frac{\log \log n}{\log n}\right)^6.$$

Since ϵ is reciprocal the inverses of the conjugates of ϵ are also conjugate to ϵ. This implies that the numbers of conjugates outside the unit circle equals the number of conjugates inside the unit circle, i.e

$$\#S = \#T \leq \frac{r+1}{2} \leq \frac{n}{2}.$$

Again by (3) we can assume that $r+1 \notin S$

$$||\mathrm{Log}(\epsilon)|| \geq \sqrt{\sum_{i\in S}(c_i \log|\epsilon^{(i)}|)^2} \geq \sqrt{\frac{2}{r+1}} \sum_{i\in S} c_i \log|\epsilon^{(i)}|$$
$$> \sqrt{\frac{2}{r+1}} \left(\frac{1}{1200}(\frac{\log\log n}{\log n})^3 - \frac{1}{2880000}(\frac{\log\log n}{\log n})^6\right) = \mu(K)$$

which is larger than

$$\sqrt{\frac{2}{r+1}}(\frac{1}{1200} - \frac{1}{2880000})(\frac{\log\log n}{\log n})^3.$$

Because of $\sqrt{2}(\frac{1}{1200} - \frac{1}{2880000}) \approx 0.001178$ we thus proved the lower bound.

REMARK. If the conjecture of Schinzel and Zassenhaus [5] is correct the term $(\frac{\log\log n}{\log n})^3$ can be substituted by a constant independent of n. This bound would be provable the best one (up to constants).

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Volker Kessler
Siemens AG
ZFE ST SN 5
Otto-Hahn-Ring 6
D-8000 München 83.