Lightning Talks
Thursday July 13, 2023

Presenters -

Lewis Combes (University of Sheffield)
Pascal Molin (Université Paris Cité)
Eric Moss (Boston College)
Tung Nguyen (Western University)
Alexey Pozdnyakov (University of Connecticut)
Brandon Williams
Ajmain Yamin (CUNY Graduate Center)
Mingjie Chen (University of Birmingham)
Travis Morrison (Virginia Tech)
James Boyd (Wolfram Institute)
Daniel Gordon (IDA Center for Communications Research- La Jolla)
Maria Sabitova (CUNY Queens College)
Period polynomials of Bianchi modular forms
LuCANT

Lewis Combes

University of Sheffield
Let $\Delta \in S_{12}(\text{PSL}_2(\mathbb{Z}))$. 

\[ r \Delta(X, Y) = \int_0^{\infty} \Delta(z) \left( Xz + Y \right)^{10} \, dz = \omega + 36691X^{10} - X^8Y^2 + 3X^6Y^4 - 3X^4Y^6 + X^2Y^8 - 36691Y^{10} + \omega - 4X^9Y - 25X^7Y^3 + 42X^5Y^5 - 25X^3Y^7 + 4XY^9, \]

where $\omega + \approx 0.1437902$ and $\omega - \approx 0.00926927$.

Recall Ramanujan's famous congruence $\Delta \equiv E_{12} \pmod{691}$. 
Let $\Delta \in S_{12}(\text{PSL}_2(\mathbb{Z}))$.

\[
  r_\Delta(X, Y) = \int_0^\infty \Delta(z)(Xz + Y)^{10} dz
  = \omega_+ \left( \frac{36}{691} X^{10} - X^8 Y^2 + 3X^6 Y^4 - 3X^4 Y^6 + X^2 Y^8 - \frac{36}{691} Y^{10} \right)
  + \omega_- \left( 4X^9 Y - 25X^7 Y^3 + 42X^5 Y^5 - 25X^3 Y^7 + 4XY^9 \right),
\]

where $\omega_+ \approx 0.11437902$ and $\omega_- \approx 0.00926927$. 
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$$
\begin{align*}
    r_\Delta(X, Y) &= \int_0^\infty \Delta(z)(Xz + Y)^{10} \, dz \\
    &= \omega_+ \left( \frac{36}{691} X^{10} - X^8 Y^2 + 3X^6 Y^4 - 3X^4 Y^6 + X^2 Y^8 - \frac{36}{691} Y^{10} \right) \\
    &\quad + \omega_- \left( 4X^9 Y - 25X^7 Y^3 + 42X^5 Y^5 - 25X^3 Y^7 + 4XY^9 \right),
\end{align*}
$$

where $\omega_+ \approx 0.11437902$ and $\omega_- \approx 0.00926927$.

Recall Ramanujan’s famous congruence

$$
\Delta \equiv E_{12} \pmod{691}.
$$
Base-change $\Delta$ to $K = \mathbb{Q}(\sqrt{-11})$, and compute in Magma the space of period polynomials using cohomology.
Bianchi period polynomials

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Bianchi period polynomials

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$$r_\Delta(X, Y, \bar{X}, \bar{Y}) = \frac{31452624}{691} X^{10} \bar{X}^{10} + \text{(integral terms)} - \frac{31452624}{691} Y^{10} \bar{Y}^{10}$$

and $\Delta \equiv E_{12} \pmod{691}$ still holds.
Base-change $\Delta$ to $K = \mathbb{Q}(\sqrt{-11})$, and compute in Magma the space of period polynomials using cohomology. Bianchi period polynomials come in four variables, $X$, $Y$, $\overline{X}$ and $\overline{Y}$.

$$\quad r_\Delta(X, Y, \overline{X}, \overline{Y}) = \frac{31452624}{691} X^{10} \overline{X}^{10} + (\text{integral terms}) - \frac{31452624}{691} Y^{10} \overline{Y}^{10}$$

and $\Delta \equiv E_{12} \pmod{691}$ still holds. Two genuine cusp forms $F_1, F_2$ also in the space. This is rare for level 1 Bianchi forms.

$$\quad r_{F_1}(X, Y, \overline{X}, \overline{Y}) = \frac{40656}{173} X^{10} \overline{X}^{10} + (\text{integral terms}) - \frac{40656}{173} Y^{10} \overline{Y}^{10}.$$ 

and $F_1, F_2 \equiv E_{12} \pmod{173}$. 


congruences can be detected with period polynomials.
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$$r_{F_1}(X, Y, \bar{X}, \bar{Y}) = \frac{40656}{173}X^{10}\bar{X}^{10} + \text{(integral terms)} - \frac{40656}{173}Y^{10}\bar{Y}^{10}.$$ 

and $F_1, F_2 \equiv E_{12} \pmod{173}$.

\(\sim\) congruences can be detected with period polynomials.
Congruences between cusp forms

Haberland’s formula for $\mathbb{Q}$:

Period polynomials $\leadsto$ Petersson product

In https://arxiv.org/abs/2306.10877, we compute a (conjectural) analogue to find another congruence $\Delta \equiv F_1, F_2 \pmod{43}$. 

Lewis Combes (University of Sheffield)

Bianchi period polynomials
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Computing S5 modular forms with the « Abstract Groups » section

Pascal MOLIN - Université Paris-Cité

\[ \rho : G_0 \rightarrow \text{GL}_2(\mathbb{F}) \quad \text{odd, irred, cond } N, \det X \qquad \text{Serre, Deligne, Khare, Wintemberger} \]

\[ g \in S_1(N, X, \mathbb{F}) \quad \text{eigen newform} \]

\[ \rho(F_{\text{dr}, p}) \quad \text{today} \quad a_p \]
S5 forms?

\[ \text{Gal}(\mathbb{1}/\mathbb{Q}) = S_5 \xrightarrow{\sim} \text{PGL}_2(\mathbb{1}F_5) \] (Galois)

proj image too big, \( q \) does not come from char 0 (aka "ethereal form")
S5 forms?

\[ \hat{L} \xrightarrow{\text{Gal} (\hat{L}/Q)} \hat{L} \] 

\[ \text{Gal}(L/Q) = S_5 \xrightarrow{\sim} \mathbb{PGL}_2(\mathbb{F}_5) \] 

today \( F = \mathbb{F}_{25} \), \( X^2 = 1 \), \[ \hat{L} \text{ ker } X = L \text{ ker sign} \]
Lifting 1: group theory

\[ C \rightarrow \tilde{G} \rightarrow G \rightarrow \mathbb{F}_{25}^* \]

\[ \mathbb{F}_{25}^* \rightarrow \mathbb{PGL}_2(\mathbb{F}_5) \]

LMFDB: \[ \tilde{G} = C_2 \cdot S_5 = \langle \text{SL}_2(\mathbb{F}_5), (\alpha, 2\alpha) \rangle \]

Extension of \( S_5 \)
+ central
+ mon split
+ cyclic
+ \#C = 2 if \( X \) quadratic and \( \text{ker } X = \text{ker } \text{Sign} \)
Lifting 2: Galois theory

LMFDB : \[ \mathbb{C}_5 \dashrightarrow \mathbb{C}_5 : \mathbb{C}_4 \dashrightarrow \mathbb{C}_2 \cdot S_5 \]

Algo \[ S_5 \text{ field} \quad \rightarrow \quad L \quad \rightarrow \quad K_1 \quad \rightarrow \quad K_2 \quad \rightarrow \quad \tilde{L} \quad \rightarrow \quad \mathbb{Q} \]

\[ 1 \subset H_2 \subset H_1 \subset C_2 \cdot S_5 \]

\[ H_1/H_2 \text{ abelian} \]
Computing Bianchi-Maass Forms

Eric Moss

Boston College

2023 LuCaNT Lightning Talks

July 13, 2023
Bianchi groups $\Gamma_d$ act discretely on hyperbolic 3-space. Let $d > 0$ and let $\mathcal{O}_d = \mathcal{O}_{\mathbb{Q}(\sqrt{-d})}$.

$$\mathcal{H}^3 = \{x + jy \mid x \in \mathbb{C}, \ y > 0\}$$

$$\Gamma_d = \text{PSL}_2(\mathcal{O}_d) \subset \mathcal{H}^3$$

**Definition**

Bianchi-Maass form of weight 0 for $\Gamma_d$

- $f : \Gamma_d \mathcal{H}^3 \to \mathbb{C}$, smooth, $L^2$
- $\Delta f = \lambda f$

Our interest is in cusp forms. They have a Fourier expansion ($\lambda = 1 - (ir)^2)$,

$$f(x+jy) = \sum_{n \in \mathcal{O}_d} a_n y K_{ir} \left(\frac{2\pi}{A} |n| y\right) \exp \left(\frac{\pi i}{A} \langle in, x \rangle\right).$$
It is expected that level 1 Maass cusp forms are “transcendental”; coefficients and eigenvalues conjectured to be transcendental numbers.

We use **Hejhal’s algorithm**. Produces a well-conditioned linear system with the coefficients $a_n$ as the unknowns. Is heuristic, not rigorous.

Dennis Hejhal (1992) over $\mathbb{Q}$

Gunther Steil (1997) nonlinear methods for $d = 1, 2, 3, 7, 11$ ($h(\mathcal{O}_d) = 1$, euclidean)

Holger Then (2004) extended Hejhal to $\text{PSL}_2(\mathbb{Z}[i])$ (i.e. $d = 1$).

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**Maass form on $\Gamma_0(1)$ with $R = 9.53369526135$**

The Maass form on $SL(2,\mathbb{Z})$ with the smallest eigenvalue.

**Maass form invariants**

- **Level:** 1
- **Weight:** 0
- **Character:** 1.1
- **Symmetry:** odd
- **Fricke sign:** +1
- **Spectral parameter:** 9.53369526135

**Maass form coefficients**

- $a_1 = +1.000000000$
- $a_2 = -1.068333551$
- $a_3 = -0.456197355$
- $a_4 = +0.141336577$
- $a_5 = -0.29672555$
- $a_6 = +0.487491640$
- $a_7 = -0.744841612$
- $a_8 = +0.917338945$
- $a_9 = -0.791883974$
- $a_{10} = +0.310535243$
- $a_{11} = +0.166135597$
- $a_{12} = -0.064477372$
- $a_{13} = -0.586685528$
- $a_{14} = +0.765546118$
- $a_{15} = +0.132604051$
- $a_{16} = -1.121160549$
- $a_{17} = +0.57065802$
- $a_{18} = +0.845999218$
- $a_{19} = -0.981938587$
- $a_{20} = -0.041082664$
I have implemented an extension of Hejhal’s algorithm to the remaining Euclidean fields \((d = 1, 2, 3, 7, 11)\). In C++ using Arb.

Must search for eigenvalues and coefficients simultaneously.

Extending Hejhal to \(\mathcal{O}_d\) comes with an increase in computational complexity which increases as \(d\) increases.

Coming soon: Extending to noneuclidean \(\mathcal{O}_d\) with \(h(\mathcal{O}_d) = 1\). Key tool: reduction algorithm for points in \(\mathcal{H}^3\)
Fekete polynomials of principal Dirichlet characters

Shiva Chidambaram, Ján Mináč
Duy Tan Nguyen, Tung T. Nguyen (*)

Western University

LMFDB, Computation, and Number Theory
ICERM, July 2023
Let $\chi$ be a Dirichlet character of modulus $n$. The $L$-function of $\chi$ is defined as

$$L(\chi, s) = \sum_{m=1}^{\infty} \frac{\chi(m)}{m^s}.$$ 

$L(\chi, s)$ has the following integral representation

$$\Gamma(s)L(\chi, s) = \int_{0}^{1} \frac{(-\log(t))^{s-1}}{t} \frac{F_\chi(t)}{1 - t^n} dt$$

where $\Gamma(s)$ is the Gamma function and

$$F_\chi(x) = \sum_{a=0}^{n-1} \chi(a)x^a.$$ 

Fekete observed that if $\chi$ is a quadratic character such that $F_\chi(x)$ has no real roots on $(0, 1)$, then $L(\chi, s)$ has no real zeros near 1.
• Let $\chi_n$ be the principal Dirichlet character of modulus $n$

$$\chi_n(a) = \begin{cases} 0 & \text{if } \gcd(a, n) > 1 \\ 1 & \text{if } \gcd(a, n) = 1. \end{cases}$$

• Let

$$F_n(x) = F_{\chi_n}(x) = \sum_{\substack{0 \leq a \leq n-1 \\ \gcd(a, n) = 1}} x^a.$$

• Our numerical data suggests that $F_n$ has exactly one irreducible non-cyclotomic factor, which we denote by $f_n$. Furthermore, the Galois group of $f_n$ is as large as possible.

• For example

$$F_{15}(x) = x \Phi_2 \Phi_4 \Phi_8 f_{15}(x),$$

where $f_{15}(x) = x^6 - x^4 + x^3 - x^2 + 1$. 
- If \( d \mid n \), then by the theory of Ramanujan sums

\[
F_n(\zeta_d) = \frac{\mu(d)\varphi(n)}{\varphi(d)}.
\]

- Let \( p \) be a prime number such that \( \gcd(p, n) = 1 \). Then we have the following recursive formula

\[
F_{np}(x) = \frac{1 - x^{np}}{1 - x^n} F_n(x) - F_n(x^p).
\]

- If \( d \nmid np \) and \( d \mid p - 1 \) then \( \Phi_d \) is a factor of \( F_{np} \).

- By induction

\[
F_n(x) = (1 - x^n) \sum_{m \mid n} \mu(m) \frac{x^m}{1 - x^m}.
\]

- Using this formula, we can derive various combinatorial conditions on \( d \) such that \( \Phi_d \) is a factor of \( F_n \). We can also determine precisely the multiplicity of \( \Phi_d \).
Thank you!
Murmurations in Arithmetic
Alexey Pozdnyakov
University of Connecticut

A Murmuration of Dirichlet Characters.

Paper: arXiv.2307.00256
Murmurations of $L$-functions

Much more at math.mit.edu/~drew/murmurations
Theorem for Dirichlet Characters

Theorem

For \( c \in \mathbb{R}_{>1} \) and \( y \in \mathbb{R}_{>0} \) we have,

\[
\lim_{X \to \infty} \frac{\log X}{X} \sum_{N \in [X,cX]} \sum_{\chi \in \mathcal{D}_\pm(N)} \frac{\chi([yX]^p)}{G(\chi)} = \begin{cases} 
\int_1^c \cos \left( \frac{2\pi y}{x} \right) dx, & \text{if } +, \\
-i \int_1^c \sin \left( \frac{2\pi y}{x} \right) dx, & \text{if } -,
\end{cases}
\]

where \( \mathcal{D}_\pm(N) = \{ \chi \mod N : \chi \text{ primitive}, \chi(-1) = \pm 1 \} \).

- Similar results for weight 2, 4, 6 modular newforms (Nina Zubrilina).
- Universal density function for any suitable family of \( L \)-functions.
- Connections to \( L \)-function zeros and one-level density.
- See Murmurations in Arithmetic on ICERM website for related talks.
Computation of vector-valued modular forms

Brandon Williams

RWTH Aachen University

July 13, 2023
**Weil representation** $\rho_L$ of $\text{Mp}_2(\mathbb{Z})$ attached to an even lattice $L$. Applications: Jacobi forms (lattice index); Saito–Kurokawa lift / Gritsenko lift; Borcherds products.

“Computation” of modular forms $M_*(\rho_L)$:
(1) Each space $M_k(\rho_L)$ is finite dim’l and defined over $\mathbb{Q}$ ⇒ compute coefficients of a $\mathbb{Q}$-basis;
(2) $M_*(\rho_L)$ is a free $\mathbb{Q}[E_4, E_6]$-module of rank $\det(L)$ ⇒ compute coefficients of a basis.

Elements of $M_*(\rho_L)$:
(1) Theta series (if $L$ is positive definite)
(2) Eisenstein series (easy Fourier coefficients)
Algorithm. Certain lattice embeddings $i : L \to M$ lead to “pullback” morphisms $i^* : M_*(\rho_M) \to M_*(\rho_L)$. Here $\det(M)$ can be smaller than $\det(L)$.

1. Find $\dim S_k$ using Riemann–Roch formula.
2. Compute a lattice embedding $i : L \to M$ with $\text{rk}(M) = \text{rk}(L) + 1$ and $\det(M)$ small.
3. Pull back Eisenstein series $E_{k-1/2}$ and related forms (Serre derivative, multiples by $\mathbb{Q}[E_4, E_6]$) along $i^*$.

Lemma. If $k \geq 3$ then as $i$ runs through all (appropriate) embeddings $E_k - i^*(E_{k-1/2})$ spans $S_k$! So repeat (1)-(3) to get a basis.

4. If $k$ is small then use

$$S_k(\rho) = \{ F/E_4 : F \in S_{k+4}(\rho) \text{ such that } \vartheta \vartheta(F/E_k) \in S_{k+4}(\rho) \}$$

where $\vartheta$ is the Serre derivative $\vartheta(f) = \eta^{2k}(f/\eta^{2k})'$. 

Implementation in Sage.

Brandon Williams  Computation of vector-valued modular forms
Belyi Pairs of Complete Regular Dessins

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LuCaNT Ⓞ
July 13, 2023
Problem Statement + Definitions


Theorem (Biggs (1985) + James & Jones (1971))

Classification of CRMs: Cayley maps associated to $\mathbb{F}_n$.

Theorem (Jones, Streit & Wolfart (2009))

Min. field of def. of $K_n$-dessin: spl. field of $p$ in $\mathbb{Q}(\zeta_{n-1})$, $n = p^f$.

Theorem (Hidalgo (2015))

Explicit affine models of $K_8$-dessins defined over $\mathbb{Q}(\sqrt{-7})$. 
Theorem (Y. (2023))

*Explicit affine models of $K_5$ & $K_7$-dessins def. $\mathbb{Q}(i)$ & $\mathbb{Q}(\omega)$ resp.*

Method: Cyclotomic construction + manipulate $\wp$-functions.

Future work: Generalize cycl. constr. + higher genus arithmetic.
Hidden Stabilizers, the Isogeny To Endomorphism Ring Problem and the Cryptanalysis of pSIDH

joint with Muhammad Imran, Gábor Ivanyos, Péter Kutas, Antonin Leroux, Christophe Petit

LuCaNT 2023

Mingjie Chen
University of Birmingham
July 2023
Isogeny-based Cryptography

After the death of SIDH in July 2022 ......

Endomorphism Ring Problem
Given a supersingular elliptic curve $E$, compute its endomorphism ring $\text{End}(E)$.

Path-finding Problem
Given a supersingular elliptic curve $E$, find a path on the supersingular $\ell$-isogeny graph from $E$ to a fixed curve $E_0$.

Can we find $\text{End}(E)$ if we know an isogeny from $E_0$ of arbitrary degree $D$?

SQISign
SQISignHD
Scallop
pSIDH ......

IsERP
Resolution of the IsERP

\[ \text{Given } \text{End}(E_0), \text{a representation of } \varphi: E_0 \rightarrow E, \text{compute End}(E). \]

\[ \text{Given } g \in \text{GL}_2(\mathbb{Z}/N\mathbb{Z}), \text{End}(E_0) \text{ and a representation of } \varphi: E_0 \rightarrow E \text{ with } \varphi \text{ of degree } N, \text{compute a representation of } g \ast \varphi. \]

\[ \mathcal{O} \text{ is a maximal order in } \mathcal{B}_{p,\infty}. \text{Given } N \text{ and } \sigma_0 \in \mathcal{O}, \text{find } \sigma = \lambda \sigma_0 \pmod{N} \text{ of powersmooth norm.} \]

Reducing IsERP to GAEP, we have a polynomial time quantum algorithm that solves the Borel Hidden Subgroup Problem.

We design a polynomial time algorithm that resolves it.
Beyond the SEA (algorithm):
Computing the trace of a supersingular endomorphism

Travis Morrison

Virginia Tech

joint work with: Lorenz Panny, Jana Sotáková, Michael Wills
Problem: given an elliptic curve $E/F_q$ and $\alpha \in \text{End}(E)$, compute $\text{Tr} \alpha \in \mathbb{Z}$.

Why?
Computing $\text{Tr} \pi_E$ reveals the ring structure of $\mathbb{Z}[\pi_E]$, i.e. a multiplication table for the basis $1, \pi_E$.
If $E$ is supersingular: computing traces lets us determine a multiplication table for basis elements of $\text{End}(E)$ (or a suborder).

How? Schoof’s algorithm
For small primes $\ell$, compute the characteristic polynomial of $\pi_E |_{E[\ell]} \in \text{End}(E[\ell])$ to get $t_\ell \equiv \text{Tr} \pi_E \pmod{\ell}$. Recover $\text{Tr} \pi_E$ from the $t_\ell$’s with CRT.

Elkies’ method for computing $t_\ell$
If $E$ admits a rational $\ell$-isogeny $\phi$, compute characteristic polynomial of $\pi_E |_{\ker \phi} \in \text{End}(\ker \phi)$ to get $t_\ell$. 
When $E/\mathbb{F}_{p^2}$ is supersingular: $E/\mathbb{F}_{p^2}$ has all of its $\ell$-isogenies defined over $\mathbb{F}_{p^2}$ (every prime is an Elkies prime!)

**Theorem (M.-Panny-Sotáková-Wills)**

There is an algorithm for computing the trace of an endomorphism $\alpha$ of a supersingular $E/\mathbb{F}_{p^2}$. Assuming GRH and that $\deg \alpha = d^e$ with $e = O(\log p)$ and $d = O(1)$, the algorithm terminates in expected $\tilde{O}((\log p)^4)$ bit operations.

**Beyond the SEA (algorithm)**

1. Compute $a \in \mathbb{F}_{p^2}$ such that $\alpha^* \omega_E = a \omega_E$, we get $\text{Tr} \alpha \equiv \text{Tr}_{\mathbb{F}_{p^2}/\mathbb{F}_p} a \pmod{p}$
2. Since $E$ is supersingular we know $\#E(\mathbb{F}_{p^2})$. If $\ell | \#E(\mathbb{F}_{p^2})$ then find $P$ of order $\ell$ and solve $(\alpha + \hat{\alpha})(P) = t_\ell P$. 
Online Math Databases on the Cheap

Dan Gordon

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July 13, 2023
A quick history

- Started in 1996 as a database of covering designs, one per HTML page
- Grew, rewrote as a MySQL database
- Hundreds of contributors of covering designs from all over
- Over the years added difference sets, circulant weighing matrices, Steiner systems

Issues

- I had to learn HTML, PHP, SQL, and AWS system administration
- How to make sure the data will always be available?
Many mathematicians face this issue

October 2021 Email from Robert Craigen

- Sent to 10 researchers interested in “Hadamardish” material
- Led to a zoom discussion of how to make data available online
- Wanted systematic, permanent, comprehensive databases
- No consensus about how to achieve that
For a paper published in DCC this year:

- github repo with data, basic code to use it
- jupyter notebook to run the code in
- zenodo.org gave it a permanent home with a DOI
- mybinder.org lets you run it without installing anything

Issues

- binder is slow
- can this scale up to larger (several GB) databases?
- Are there better solutions?
The La Jolla Combinatorics Repository
Signed Difference Sets
  https://doi.org/10.5281/zenodo.7473882
  github repo
A number theoretic classification of toroidal solenoids

Maria Sabitova
CUNY