Universes as Bigdata:

Superstrings, Calabi-Yau Manifolds and Machine-Learning

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KEK Theory workshop 2020

1984: $10 = 4 + 3 \times 2$

- First String Revolution [Green-Schwarz] anomaly cancellation;

  Heterotic string [Gross-Harvey-Martinec-Rohm]: $E_8 \times E_8$ or $SO(32)$, 1984 - 5
- String Phenomenology [Candelas-Horowitz-Strominger-Witten]: 1985
  - $SU(3) \times SU(2) \times U(1) \subset SU(5) \subset SO(10) \subset E_6 \subset E_8$
  - Standard Solution (MANY more since): $\mathbb{R}^{3,1} \times X$, X Ricci-flat, Kähler
- *mathematicians were independently thinking of the same problem*:
  - Riemann Uniformization Theorem in $\dim_{\mathbb{C}} = 1$: Trichotomy $R < 0, = 0, > 0$
  - Euler, Gauss, Riemann, Bourbaki, Atiyah-Singer ...

$$\chi(\Sigma) = 2 - 2g(\Sigma) = [c_1(\Sigma)] \cdot [\Sigma] = \frac{1}{2\pi}\int_\Sigma R = \sum_{i=0}^{2}(-1)^i h^i(\Sigma)$$

Calabi-Yau

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Calabi-Yau

An Early Physical Challenge to Algebraic Geometry

- CY3 X, tangent bundle $SU(3) \Rightarrow$
  1. E_6 GUT: commutant $E_8 \to SU(3) \times E_6$, then
  2. Wilson-line/discrete symmetry to break E_6-GUT to some SUSY version of Standard Model (generalize later)
  3. Particle Spectrum:

Particle Spectrum:	Generation	$n_{27} = h^1(X, TX) = h^{2,1}_{\bar{\partial}}(X)$
	Anti-Generation	$n_{\overline{27}} = h^1(X, TX^*) = h^{1,1}_{\bar{\partial}}(X)$

- Net-generation: $\chi = 2(h^{1,1} - h^{2,1}) =$ Euler Number
- 1980s Question: Are there Calabi-Yau threefolds with Euler number ± 6?
- None of obvious ones ☹

  e.g., Quintic Q in $\mathbb{P}^4$ is CY3 $Q_{\chi}^{h^{1,1}, h^{2,1}} = Q_{-200}^{1,101}$ so too may generations

  (even with quotient $-200 \notin 3\mathbb{Z}$)

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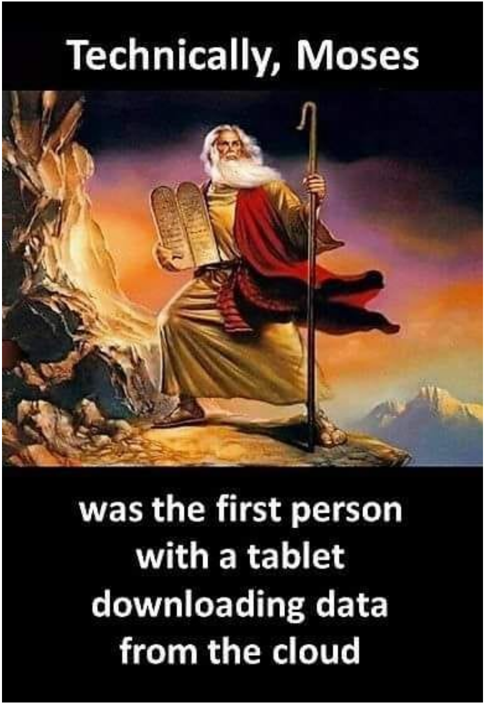
The First Data-sets in Mathematical Physics/Geometry

- [Candelas-A. He-Hübsch-Lutken-Schimmrigk-Berglund] (1986-1990)
  - CICYs (complete intersection CYs) multi-deg polys in products of $\mathbb{CP}^{n_i}$ CICYs
  - Problem: *classify all configuration matrices*; employed the best computers at the time (**CERN supercomputer**); q.v. magnetic tape and dot-matrix printout in Philip's office
  - 7890 matrices, 266 Hodge pairs $(h^{1,1}, h^{2,1})$, 70 Euler $\chi \in [-200, 0]$
- [Candelas-Lynker-Schimmrigk, 1990]
  - Hypersurfaces in Weighted P4
  - 7555 inequivalent 5-vectors w_i, 2780 Hodge pairs, $\chi \in [-960, 960]$
- [Kreuzer-Skarke, mid-1990s - 2000] Reflexive Polytopes
  - Hypersurfaces in (Reflexive, Gorenstein Fano) Toric 4-folds
  - 6-month running time on dual Pentium SGI machine
  - at least 473,800,776, with 30,108 distinct Hodge pairs, $\chi \in [-960, 960]$



The age of data science in mathematical physics/string theory not as recent as you might think

of course, experimental physics had been decades ahead in data-science/machine-learning

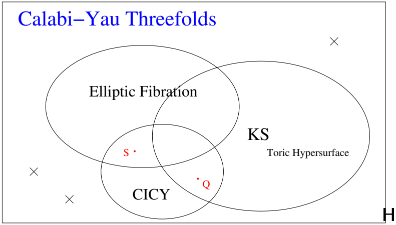
After 40 years of research by mathematicians and physicists

. . . . . .

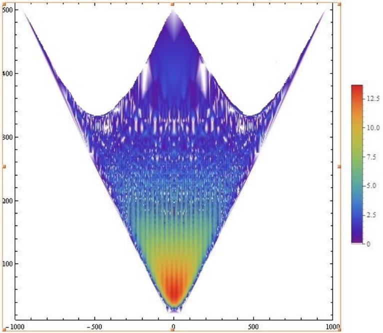
The Compact CY3 Landscape

cf. YHH, *The Calabi-Yau Landscape: from Geometry, to Physics, to Machine-Learning*, 1812.02893, [Springer, to appear]

Vienna (KS, Knapp,...), Penn (Ovrut, Cvetic, Donagi, Pantev ...), Oxford/London (Candelas, Constantin, Lukas, Mishra, YHH, ...), MIT (Taylor, Johnson, Wang, ...), Northeastern/Wits (Halverson, Long, Nelson, Jejjala, YHH), Virginia Tech (Anderson, Gray, SJ Lee, ...), Utrecht (Grimm ...), CERN (Weigand, ...), Cornell (MacAllister, Stillman), Munich (Luest, Vaudravange), Uppsala (Larfors, Seong) ...



Georgia O'Keefe on Kreuzer-Skarke



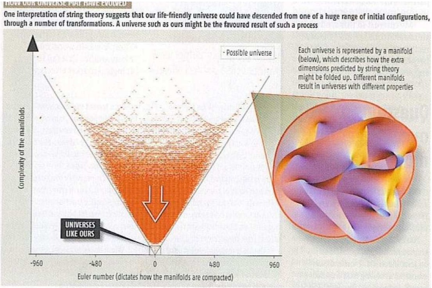
Horizontal $\chi = 2(h^{1,1} - h^{2,1})$ vs. Vertical $h^{1,1} + h^{2,1}$

Triadophilia

Exact (MS)SM Particle Content from String Compactification

- [Braun-YHH-Ovrut-Pantev, Bouchard-Cvetic-Donagi 2005] first exact MSSM
- [Anderson-Gray-YHH-Lukas, 2007-] use alg./comp. algebraic geo & sift
- Anderson-Gray-Lukas-Ovrut-Palti ~ 200 in 10^{10} MSSM Stable Sum of Line Bundles over CICYs (Oxford-Penn-Virginia 2012-)

Constantin-YHH-Lukas '19: 10^{23} exact MSSMs (by extrapolation on above set)?



A Special Corner

[New Scientist, Jan, 5, 2008 feature]

P. Candelas, X. de la Ossa, YHH, and B. Szendroi

"Triadophilia: A Special Corner of the Landscape" ATMP, 2008

The Landscape Explosion & Vacuum Degeneracy Problem

meanwhile ... LANDSCAPE grew rapidly with

- D-branes Polchinski 1995
- M-Theory/G_2 Witten, 1995
- F-Theory/4-folds Katz-Morrison-Vafa, 1996
- AdS/CFT Maldacena 1998 Alg Geo of AdS/CFT
- Flux-compactification Kachru-Kallosh-Linde-Trivedi, 2003, Denef-Douglas 2005-6: $10^{\gg 500}$ possibilities ...

String theory trades one hard-problem [quantization of gravity] by another [looking for the right compactification] (in many ways a richer and more interesting problem, especially for the string/maths community)

Where we stand . . .

The Good: Last 10-15 years: large collaborations of physicists, computational mathematicians (cf. SageMATH, GAP, Bertini, MAGMA, Macaulay2, Singular) have bitten the bullet computed many geometrical/physical quantities and compiled them into various databases **Landscape Data** ($10^{9\sim10}$ entries typically)

The Bad: Generic computation HARD: dual cone algorithm (exponential), triangulation (exponential), Gröbner basis (double-exponential) . . . e.g., how to construct stable bundles over the $\gg 473$ million KS CY3? Sifting through for SM computationally impossible . . .

The ???: **Borrow new techniques from "Big Data" revolution**

A Wild Question

- Typical Problem in String Theory/Algebraic Geometry:

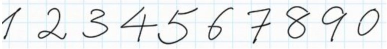
$$\underset{\textit{INPUT}}{\boxed{\text{integer tensor}}} \longrightarrow \underset{\textit{OUTPUT}}{\boxed{\text{integer}}}$$

- Q: Can (classes of problems in computational) Algebraic Geometry be "learned" by AI ? , i.e., can we "machine-learn the landscape?"
- [YHH 1706.02714] Deep-Learning the Landscape, *PLB 774, 2017* (*Science*, Aug, vol 365 issue 6452, 2019): Experimentally, it seems so for many situations in geometry and beyond.
- 2017

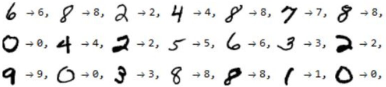
  YHH (1706.02714), Seong-Krefl (1706.03346), Ruehle (1706.07024), Carifio-Halverson-Krioukov-Nelson (1707.00655) Progress in String Theory

A Prototypical Question

- Hand-writing Recognition, e.g., my 0 to 9 is different from yours:



- How to set up a bijection that takes these to $\{1, 2, \ldots, 9, 0\}$? Find a clever Morse function? Compute persistent homology? Find topological invariants? <u>ALL are inefficient and too sensitive to variation.</u>
- What does your iPhone/tablet do? What does Google do? Machine-Learn
  - Take large sample, take a few hundred thousand (e.g. NIST database)



...

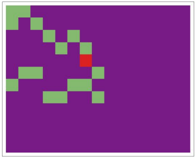
$28 \times 28 \times (RGB)$

Supervised ML in 1 min

NN Doesn't Care/Know about Alg. Geometry (1706.02714)

- Hodge Number of a Complete Intersection CY is the association rule, e.g.

$$X = \begin{pmatrix} 1&1&0&0&0&0&0&0 \\ 1&0&1&0&0&0&0&0 \\ 0&0&0&1&0&1&0&0 \\ 0&0&0&0&1&0&1&0 \\ 0&0&0&0&0&0&2&0 \\ 0&1&1&0&0&0&0&1 \\ 1&0&0&0&0&1&1&0 \\ 0&0&0&1&1&0&0&1 \end{pmatrix}, \qquad h^{1,1}(X) = 8 \quad \rightsquigarrow$$



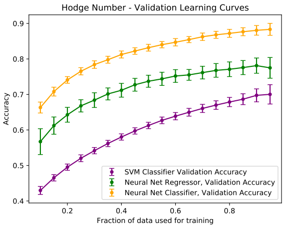
$\longrightarrow 8$

CICY is 12×15 integer matrix with entries $\in [0, 5]$ is simply represented as a 12×15 pixel image of 6 colours Proper Way ; ML in matter of seconds/minutes

- Cross-Validation:
  - Take samples of $X \to h^{1,1}$
  - train a NN, or SVM
  - Validation on *unseen* $X \to h^{1,1}$

Deep-Learning Algebraic Geometry

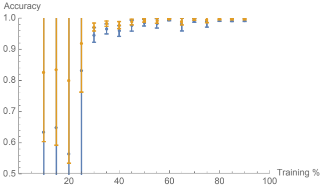
- YHH (1706.02714) Bull-YHH-Jejjala-Mishra (1806.03121, 1903.03113), Krippendorf-Syvaeri [2003.13679] Erbin-Finotello (2007.13379; Google Inception NN) YHH-Lukas [2009.02544]



Learning Hodge Number $h^{1,1} \in [0, 19]$ so can set up 20-channel NN classifer, regressor, as well as SVM,

bypass exact sequences

- YHH-SJ Lee (1904.08530): Distinguishing Elliptic Fibrations in CY3



bypass Oguiso-Kollar-Wilson Theorem/Conjecture

learning curves for precision and Matthews ϕ

More Success Stories in Algebraic Geometry/Strings

- Ruehle '17: genetic algorithm for bundle cohomology
- Halverson, Nelson, Long et al '17- programme of ML of KS data
- Brodie-Constantin-Lukas '19: EXACT formulae for line-bundle coho / complex surfaces Interpolation vs Extrapolation $\rightsquigarrow$ Conjecture Formulation
- Ashmore-YHH-Ovrut '19: ML Calabi-Yau metric: improves Donaldson alg. for numerical CY metric by 10-100 times
- Otsuka-Takemoto; Deen-YHH-Lee-Lukas '20: Distinguishing Heterotic SMs from the sum-line-bundle database and extrapolating beyond
- q.v. K. Hashimoto '18: AdS/CFT = Boltzmann Machine; Halverson-Anindita 2008.08601 NN=QFT; Vanchurin 2008.01540 NN=Spacetime; $2\times$ de Mello-Koch, Cheng 1906.05212 RL = RG

Representation/Group Theory

- ML Algebraic Structures (GAP DB) [YHH-MH. Kim 1905.02263]
  - When is a Latin Square (Sudoku) the Cayley (multiplication) table of a finite group? Bypass quadrangle thm (0.95, 0.9)
  - Can one look at the Cayley table and recognize a finite simple group?
    - bypass Sylow and Noether Thm; (0.97, 0.95) rmk: can do it via character-table T, but getting T not trivial
    - **SVM:** space of finite-groups (point-cloud of Cayley tables) seems to exist a hypersurface separating simple/non-simple
- ML Lie Structure Chen-YHH-Lal-Majumder [2011.00871] Weight vector → length of irrep decomp / tensor product: (0.97, 0.93); (train on small dim, predict high dim: (0.9, 0.8))
- [Chen-YHH-Lal-Zas 2006.16114]: even/odd/reflection sym (>0.99); distinguishing CFT 3pt functions (>0.99); Fourier coefficients / conformal block presence (>0.97) ...

  (q.v. [Krippendorf-Syvaeri 2003.13679])

Combinatorics, Graph/Quivers

- [YHH-ST. Yau 2006.16619] Wolfram Finite simple graphs DB
  - ML standard graph properties:

    ?acyclic (0.95, 0.96); ?planar (0.8, 0.6); ?genus $>, =, < 0$ (0.8, 0.7); ?∃ Hamilton cycles (0.8, 0.6); ?∃ Euler cycles (0.8, 0.6)

    (Rmk: NB. Only "solving" the likes of traveling salesman stochastically)
  - spectral bounds ($R^2 \sim 0.9$) ...
  - Recognition of Ricci-Flatness (0.9, 0.9) (todo: find new Ricci-flat graphs);
- [Bao-Franco-YHH-Hirst-Musiker-Xiao 2006.10783]: categorizing different quiver mutation (Seiberg-dual) classes (0.9 - 1.0, 0.9)

Number Theory: A Reprobate?

- Arithmetic (PRIMES are HARD)
  - [YHH 1706.02714, 1812.02893:] Predicting primes tried supervised ML on $2 \to 3,\ 2,3 \to 5,\ 2,3,5 \to 7$; fixed window of (yes/no)$_{1,2,\ldots,k}$ to (yes/no)$_{k+1}$, no breaking banks yet (expect same for Riemann zeroes)
  - [Alessandretti-Baronchelli-YHH 1911.02008] (LMFdb/Cremona Database) ML/TDA@Birch-Swinnerton-Dyer *New Scientist* feature Dec 9 $Ш$ and Ω ok with regression & decision trees: RMS < 0.1; Weierstrass $\to$ rank: random
- Arithmetic Geometry (Surprisingly)
  - [Hirst-YHH-Peterken 2004.05218]: adjacency of dessin d'enfants (Grothendieck's Esquisse for Abs. Galois) $\to$ transcendental degree (>0.9)
  - YHH-KH Lee-Oliver, 2010.01213: ML Sato-Tate (>0.99) 2011.08958: ML Number Fields (>0.97) 2012.04084: BSD from Euler coeffs (>0.99)

Meta-mathematics/physics?

[YHH-Jejjala-Nelson] "hep-th" 1807.00735

- Word2Vec: [Mikolov et al., '13] NN which maps words in sentences to a vector space **by context** (much better than word-frequency, quickly adopted by Google); maximize (partition function) over all words with sliding window ($W_{1,2}$ weights of 2 layers, C_α window size, D # windows)

$$Z(W_1, W_2) := \frac{1}{|D|} \sum_{\alpha=1}^{|D|} \log \prod_{c=1}^{C_\alpha} \frac{\exp([\vec{x}_c]^T \cdot W_1 \cdot W_2)}{\sum_{j=1}^{V} \exp([\vec{x}_c]^T \cdot W_1 \cdot W_2)}$$

- We downloaded all $\sim 10^6$ titles of hep-th, hep-ph, gr-qc, math-ph, hep-lat from ArXiv since the beginning (1989) till end of 2017 Word Cloud

  (rmk: Ginzparg has been doing a version of linguistic ML on ArXiv)

  (rmk: abs and full texts in future)

Subfields on ArXiv has own linguistic particulars

- Linear Syntactical Identities

  bosonic + string-theory = open-string

  holography + quantum + string + ads = extremal-black-hole

  string-theory + calabi-yau = m-theory + g2

  space + black-hole = geometry + gravity . . .

- binary classification (Word2Vec + SVM) of formal (hep-th, math-ph, gr-qc) vs phenomenological (hep-ph, hep-lat) : 87.1% accuracy (5-fold classification 65.1% accuracy). ArXiv classifications

- Cf. **Tshitoyan et al.**, "Unsupervised word embeddings capture latent knowledge from materials science literature", **Nature** July, 2019: 3.3. million materials-science abstracts; uncovers structure of periodic table, predicts discoveries of new thermoelectric materials years in advance, and suggests as-yet unknown materials

Summary and Outlook

PHYSICS

- Use AI (Neural Networks, SVMs, Regressor . . .) as
  1. Classifier deep-learn and categorize landscape data
  2. Predictor estimate results beyond computational power

MATHS

- how is AI doing maths w/o knowing any maths? (Alg Geo/$\mathbb{C}$, combinatorics, RT = integer matrices, NT ??)
  1. Predictor form new conjectures/formulae
  2. Classifier stochastically do NP-hard problems
- Hierarchy of Difficulty ML struggles with:

  numerical $<$ **algebraic geometry over** $\mathbb{C}$ $<$ **combinatorics/algebra** $<$ **number theory**

Thank you!

Syntax		Semantics
Alpha Go	$\rightarrow$	Alpha Zero
ML Patterns	$\rightarrow$	Auto Thm Pf&Chk
- Renner et al., PRL/Nature News, 2019: ML (*SciNet*, *autoencoder*)
- Lample-Charton, 2019: ML Symolic manipulations in mathematics
- Tegmark et al., 2019 AI Feynman, symb regressor
- Raayoni et al. 2020 Ramanujan-Machine
- Barbaresco-Nielson 2021 Infor Geom/ML

Sophia (Hanson Robotics, HK)

1st non-human citizen (2017, Saudi)

1st non-human with UN title (2017)

1st String Data Conference (2017)

Digressions

$\chi(\Sigma)=2$	$\chi(\Sigma)=0$	$\chi(\Sigma)<0$
Spherical	Ricci-Flat	Hyperbolic
$+$ curvature	0 curvature	$-$ curvature
Fano	Calabi-Yau	General Type

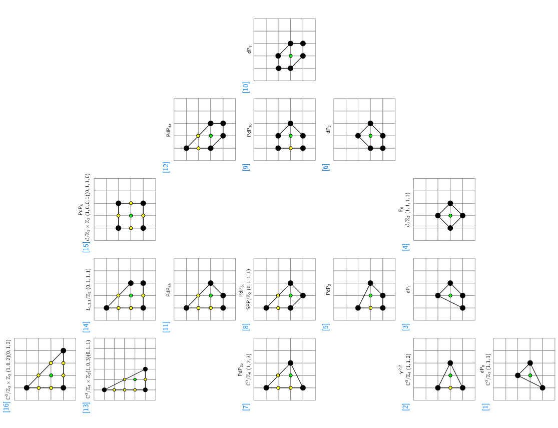
- Euler, Gauss, Riemann, Bourbaki, Atiyah-Singer ... $\rightsquigarrow$ generalize

$$\chi(\Sigma) = 2 - 2g(\Sigma) = [c_1(\Sigma)] \cdot [\Sigma] = \frac{1}{2\pi}\int_\Sigma R = \sum_{i=0}^{2}(-1)^i h^i(\Sigma)$$

- CONJECTURE [E. Calabi, 1954, 1957] / Thm [ST. Yau, 1977-8] M compact Kähler manifold (g,ω) and $([R] = [c_1(M)])_{H^{1,1}(M)}$. Then $\exists!(\tilde{g},\tilde{\omega})$ such that $([\omega]=[\tilde{\omega}])_{H^2(M;\mathbb{R})}$ and $Ricci(\tilde{\omega}) = R$.
- Strominger & Yau were neighbours at IAS in 1985: CHSW named Ricci-Flat Kähler as Calabi-Yau Back

16 Reflexive Polygons

Back to Reflexives



classify convex lattice polytopes with single interior point and all faces are distance 1 therefrom (up to $SL(n;\mathbb{Z})$)

Kreuzer-Skarke: 4319 reflexive polyhedra, 473,800,776 reflexive 4-polytopes,

Skarke: next number is at least 185,269,499,015.

Heterotic Comp: Recent Development

- E_6 GUTs a toy, $SU(5)$ and $SO(10)$ GUTs and SM: general embedding
  - Instead of TX, use (poly-)stable holomorphic vector bundle V
  - Gauge group$(V) = G = SU(n)$, $n = 3, 4, 5$, gives $H = \text{Commutant}(G, E_8)$:

$E_8 \to G \times H$	Breaking Pattern
$SU(3) \times E_6$	$248 \quad \to \quad (1,78) \oplus (3,27) \oplus (\bar{3},\overline{27}) \oplus (8,1)$
$SU(4) \times SO(10)$	$248 \quad \to \quad (1,45) \oplus (4,16) \oplus (\bar{4},\overline{16}) \oplus (6,10) \oplus (15,1)$
$SU(5) \times SU(5)$	$248 \quad \to \quad (1,24) \oplus (5,\overline{10}) \oplus (\bar{5},10) \oplus (10,5) \oplus (\overline{10},\bar{5}) \oplus (24,1)$

- MSSM: $H \xrightarrow{\text{Wilson Line}} SU(3) \times SU(2) \times U(1)$
- Issues in low-energy physics $\sim$ Precise questions in Alg Geo of (X, V)
  - Particle Content $\sim$ (tensor powers) V Bundle Cohomology on X
  - LE SUSY $\sim$ Hermitian Yang-Mills connection $\sim$ Bundle Stability
  - Yukawa $\sim$ Trilinear (Yoneda) composition
  - Doublet-Triplet splitting $\sim$ representation of fundamental group of X

Back to Landscape

Various Databases

- Kreuzer-Skarke: `http://hep.itp.tuwien.ac.at/~kreuzer/CY/`
  - new PALP: Braun-Walliser: ArXiv 1106.4529
  - Triang: Altmann-YHH-Jejjala-Nelson: `http://www.rossealtman.com/`
- CICYs: resurrected Anderson-Gray-YHH-Lukas, `http://www-thphys.physics.ox.ac.uk/projects/CalabiYau/cicylist/index.html`
- q.v. other databases of interesting to the math/physics community:

  Graded Rings/Varieties: Brown, Kasprzyk, et al. `http://www.grdb.co.uk/`

  Finite Groups/Rings: GAP `https://www.gap-system.org/`

  Modular Forms: Sutherland, Cremona et al. `https://www.lmfdb.org/`

  Knots & Invariants: KnotAtlas `http://katlas.org/` Return

  . . .

Progress in String Theory
Back to ML/Maths

Major International Annual Conference Series

- 1986- First "Strings" Conference
- 2002- First "StringPheno" Conference
- 2006 - 2010 String Vacuum Project (NSF)
- 2011- First "String-Math" Conference
- 2014- First String/Theoretical Physics Session in SIAM Conference
- 2017- First "String-Data" Conference

A Single Neuron: The Perceptron

- began in 1957 (!!) in early AI experiments (using CdS photo-cells)
- DEF: Imitates a neuron: activates upon certain inputs, so define
  - Activation Function $f(z_i)$ for input tensor z_i for some multi-index i;
  - consider: $f(w_i z_i + b)$ with w_i weights and b bias/off-set;
  - typically, $f(z)$ is sigmoid, Tanh, etc.
- Given training data: $D = \{(x_i^{(j)}, d^{(j)}\}$ with input x_i and **known output** $d^{(j)}$, minimize

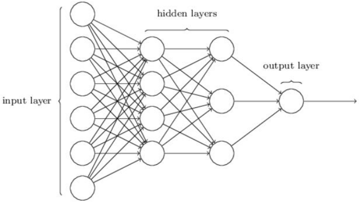
$$SD = \sum_j \left(f(\sum_i w_i x_i^{(j)} + b) - d^{(j)} \right)^2$$

to find optimal w_i and $b \rightsquigarrow$ "learning", then check against Validation Data

- Essentially (non-linear) regression

The Neural Network: network of neurons $\rightsquigarrow$ the "brain"

- DEF: a connected graph, each node is a perceptron (*Implemented on Mathematica* $\geq$ *11.1 / TensorFlow-Keras on Python*)
  1. adjustable weights/bias;
  2. distinguished nodes: 1 set for input and 1 for output;
  3. iterated training rounds.



Simple case: forward directed only,

called multilayer perceptron

Many Layers : DEEP Learning

Connectivity $\rightsquigarrow$ Emergence of Complexity

- Essentially how brain learns complex tasks; **apply to our Landscape Data**

Back to Landscape

CICYs

$$M = \begin{bmatrix} n_1 & q_1^1 & q_1^2 & \dots & q_1^K \\ n_2 & q_2^1 & q_2^2 & \dots & q_2^K \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ n_m & q_m^1 & q_m^2 & \dots & q_m^K \end{bmatrix}_{m \times K}$$

- Complete Intersection Calabi-Yau (CICY) 3-folds
- K eqns of multi-degree $q_j^i \in \mathbb{Z}_{\geq 0}$ embedded in $\mathbb{P}^{n_1} \times \ldots \times \mathbb{P}^{n_m}$
- $c_1(X) = 0 \rightsquigarrow \sum\limits_{j=1}^{K} q_r^j = n_r + 1$
- M^T also CICY

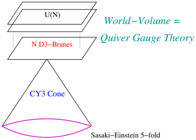
- The Quintic $Q = [4|5]^{1,101}_{-200}$ (or simply $[5]$);
- CICYs Central to string pheno in the 1st decade [Distler, Greene, Ross, et al.]

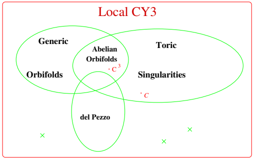
  E_6 GUTS unfavoured; Many exotics: e.g. 6 entire anti-generations

Back to CICYs

AdS/CFT as a Quiver Rep/Moduli Variety Corr.

a 20-year prog. joint with **A. Hanany**, S. Franco, B. Feng, et al.



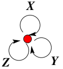


D-Brane Gauge Theory

(SCFT encoded as quiver)

$\longleftrightarrow$

Vacuum Space as affine Variety

- $(\mathcal{N}=4$ SYM$)$ ( $, W = \text{Tr}([x,y],z)$) $\longleftrightarrow \mathbb{C}^3 = \text{Cone}(S^5)$ [Maldacena]
- THM [(P) Feng, Franco, Hanany, YHH, Kennaway, Martelli, Mekareeya, Seong, Sparks, Vafa, Vegh, Yamazaki, Zaffaroni ... (M) R. Böckland, N. Broomhead, A. Craw, A. King, G. Musiker, K. Ueda ...] (coherent component of) representation variety of a quiver is toric CY3 iff quiver + superpotential graph dual to a bipartite graph on T^2 Back to Landscape

combinatorial data/lattice polytopes $\longleftrightarrow$ gauge thy data as quivers/graphs

Computing Hodge Numbers $\mathcal{O}(e^{e^d})$

- Recall Hodge decomposition $H^{p,q}(X) \simeq H^q(X, \wedge^p T^\star X) \rightsquigarrow$

$$H^{1,1}(X) = H^1(X, T_X^\star), \qquad H^{2,1}(X) \simeq H^{1,2} = H^2(X, T_X^\star) \simeq H^1(X, T_X)$$

- Euler Sequence for subvariety $X \subset A$ is short exact:

$$0 \to T_X \to T_M|_X \to N_X \to 0$$

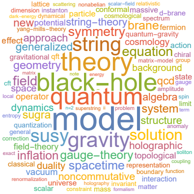
- Induces long exact sequence in cohomology:

$$\begin{array}{cccccccc}
0 & \to & H^0(X, T_X) \xrightarrow{\ 0\ } & \to & H^0(X, T_A|_X) & \to & H^0(X, N_X) & \to \\
 & \to & \boxed{H^1(X, T_X)} & \xrightarrow{d} & H^1(X, T_A|_X) & \to & H^1(X, N_X) & \to \\
 & \to & H^2(X, T_X) & \to & \ldots & & &
\end{array}$$

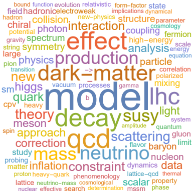
- Need to compute Rk(d), cohomology and $H^i(X, T_A|_X)$ (Cf. Hübsch)

Back to ML

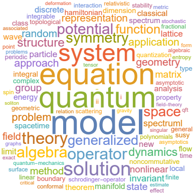
ArXiv Word-Clouds



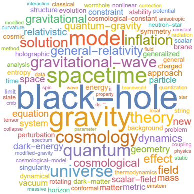
hep-th



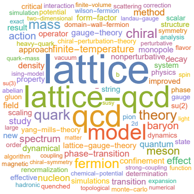
hep-ph



math-ph



gr-qc



hep-lat

Back to Word2Vec

Classifying Titles

Compare, + non-physics sections, non-science (Times), pseudo-science (viXra)

Actual \ Word2Vec + SVM	1	2	3	4	5
1	40.2	6.5	8.7	24.0	20.6
2	7.8	65.8	12.9	9.1	4.4
3	7.5	11.3	72.4	1.5	7.4
4	12.4	4.4	1.0	72.1	10.2
5	10.9	2.2	4.0	7.8	75.1

1 : hep-th
2 : hep-ph
3 : hep-lat
4 : gr-qc
5 : math-ph

Actual \ NN	1	2	3	4	5	6	7	8	9	10
viXra-hep	11.5	47.4	6.8	13.	11.	4.5	0.2	0.3	2.2	3.1
viXra-qgst	13.3	14.5	1.5	54.	8.4	1.8	0.1	1.1	2.8	3.

6: cond-mat, 7: q-fin, 8: stat, 9: q-bio, 10: Times of India Back to Main