Dogma handout on 170814

August 14, 2017 6:08 AM

Activate links!

Dror Bar-Natan: Talks: Sydney-1708:

The Dogma is Wrong

Follows Rozansky [Ro1, Ro2, Ro3] and Overbay [Ov], joint with van der Veen. More at ωεβ/talks.

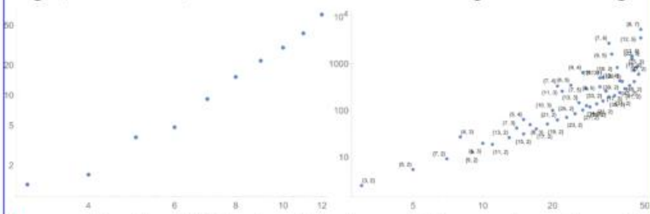
Thanks for the invitation!

ωεβ:=http://drorbn.net/Sydney-1708/

Abstract. It has long been known that there are knot invariants associated to semi-simple Lie algebras, and there has long been a dogma as for how to extract them: "quantize and use representation theory". We present an alternative and better procedure: "centrally extend, approximate by solvable, and learn how to re-order exponentials in a universal enveloping algebra". While equivalent to the old invariants via a complicated process, our invariants are in practice stronger, faster to compute (poly-time vs. exp-time), and clearly carry topological information.

KiW 43 Abstract (ωεβ/kiw). Whether or not you like the formulas on this page, they describe the strongest truly computable knot invariant we know.

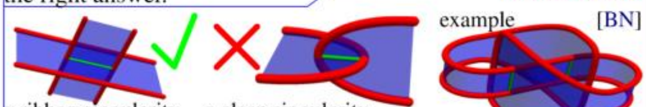
Experimental Analysis (ωεβ/Exp). Log-log plots of computation time (sec) vs. crossing number, for all knots with up to 12 crossings (mean times) and for all torus knots with up to 48 crossings:



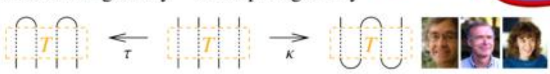
Power. On the 250 knots with at most 10 crossings, the pair (ω,ρ_1) attains 250 distinct values, while (Khovanov, HOMFLY-PT) attains only 249 distinct values. To 11 crossings the numbers are (802, 788, 772) and to 12 they are (2978, 2883, 2786).

Genus. Up to 12 xings, always ρ_1 is symmetric under $t \leftrightarrow t^{-1}$. With ρ_1^+ denoting the positive-degree part of ρ_1, always $\deg\rho_1^+ \leq 2g-1$, where g is the 3-genus of K (equality for 2530 knots). This gives a lower bound on g in terms of ρ_1 (conjectural, but undoubtedly true). This bound is often weaker than the Alexander bound, yet for 10 of the 12-xing Alexander failures it does give the right answer.

Ribbon Knots.

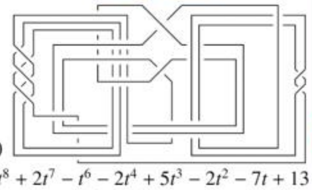


a ribbon singularity a clasp singularity example [BN]



Gompf, Scharlemann, Thompson [GST]

$$\begin{tikzcd} & U \in \mathcal{T}_n & & 1 \in \mathcal{A}_n \\ \mathcal{T}_{2n} \arrow[ur, "\tau"] \arrow[dr, "\kappa"'] \arrow[rr, "z"] & & \mathcal{A}_{2n} \arrow[ur, "\tau"] \arrow[dr, "\kappa"'] & \\ & \text{ribbon } K \in \mathcal{T}_1 & & z(K) \in \mathcal{R} \subseteq \mathcal{A}_1 \end{tikzcd}$$



[Vo]: Works for Alexander!  with $\mathcal{R} := \kappa(\tau^{-1}(1))$

$A^+ = -t^8 + 2t^7 - t^6 - 2t^4 + 5t^3 - 2t^2 - 7t + 13$

$\rho_1^+ = 5t^{15} - 18t^{14} + 33t^{13} - 32t^{12} + 2t^{11} + 42t^{10} - 62t^9 - 8t^8 + 166t^7 - 242t^6 + 108t^5 + 132t^4 - 226t^3 + 148t^2 - 11t - 36$

Faster is better, leaner is meaner!

dog·ma (dôg′mə, dŏg′-) The Free Dictionary, ωεβ/TFD

n. pl. **dog·mas** or **dog·ma·ta** (-mə-tə)

1. A doctrine or a corpus of doctrines relating to matters such as morality and faith, set forth in an authoritative manner by a religion.

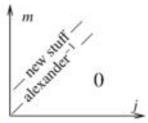
2. A principle or statement of ideas, or a group of such principles or statements, especially when considered to be authoritative or accepted uncritically: *"Much education consists in the instilling of unfounded dogmas in place of a spirit of inquiry" (Bertrand Russell).*

Theorem ([BNG], conjectured [MM], elucidated [Ro1]). Let $J_d(K)$ be the coloured Jones polynomial of K, in the d-dimensional representation of sl_2. Writing

Melvin, Morton, Garoufalidis

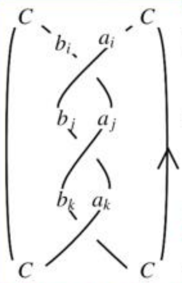
$$\left.\frac{(q^{1/2}-q^{-1/2})J_d(K)}{q^{d/2}-q^{-d/2}}\right|_{q=e^\hbar} = \sum_{j,m\geq 0} a_{jm}(K)d^j\hbar^m,$$

"below diagonal" coefficients vanish, $a_{jm}(K) = 0$ if $j > m$, and "on diagonal" coefficients give the inverse of the Alexander polynomial: $\left(\sum_{m=0}^\infty a_{mm}(K)\hbar^m\right)\cdot\omega(K)(e^\hbar) = 1$.



"Above diagonal" we have Rozansky's Theorem [Ro3, (1.2)]:

$$J_d(K)(q) = \frac{q^d - q^{-d}}{(q-q^{-1})\omega(K)(q^d)}\left(1 + \sum_{k=1}^\infty \frac{(q-1)^k\rho_k(K)(q^d)}{\omega^{2k}(K)(q^d)}\right).$$



The Yang-Baxter Technique. Given an algebra A (typically $\hat{\mathcal{U}}(\mathfrak{g})$ or $\hat{\mathcal{U}}_q(\mathfrak{g})$) and elements

$$R = \sum a_i \otimes b_i \in A \otimes A \quad\text{and}\quad C \in A,$$

form

$$Z = \sum_{i,j,k} Ca_ib_ja_kC^2b_ia_jb_kC.$$

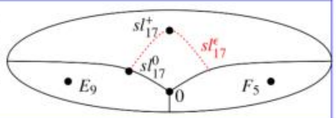
Problem. Extract information from Z.

The Dogma. Use representation theory. In principle finite, but *slow*.

The Loyal Opposition. For certain algebras, work in a homomorphic poly-dimensional "space of formulas".

$$m^{ij}_k \circlearrowright \{\mathcal{F}_S\} \xrightarrow{\mathbb{E}} \{A^{\otimes S}\} \circlearrowleft m^{ij}_k$$

The (fake) moduli of Lie algebras on V, a quadratic variety in $(V^*)^{\otimes 2}\otimes V$ is on the right. We care about $sl^k_{17} := sl^\epsilon_{17}/(\epsilon^{k+1}=0)$.



Why are "solvable algebras" any good? Contrary to common beliefs, computations in semi-simple Lie algebras are just awful:

```
In[1]:= MatrixExp[( a b ; c d )] // FullSimplify // MatrixForm     Enter
```

Yet in solvable algebras, exponentiation is fine and even BCH, $z = \log(e^xe^y)$, is bearable:

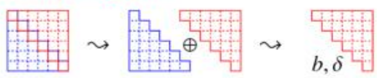
```
In[2]:= MatrixExp[( a b ; 0 c )] // MatrixForm
```

Out[2]//MatrixForm=

$$\begin{pmatrix} e^a & \frac{b(e^a-e^c)}{a-c} \\ 0 & e^c \end{pmatrix}$$

```
In[3]:= MatrixExp[( a1 b1 ; 0 c1 )].MatrixExp[( a2 b2 ; 0 c2 )] //
    MatrixLog // PowerExpand // Simplify //
  MatrixForm                                              Enter
```

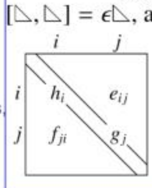
Recomposing gl_n. Half is enough! $gl_n \oplus \mathfrak{a}_n = \mathcal{D}(\nabla, b, \delta)$:



$b(\nabla) = b: \nabla\otimes\nabla \to \nabla$

$b(\triangle) \rightsquigarrow \delta: \nabla \to \nabla\otimes\nabla$

Now define $gl_n^\epsilon := \mathcal{D}(\nabla, b, \epsilon\delta)$. Schematically, this is $[\nabla,\nabla] = \nabla$, $[\triangle,\triangle] = \epsilon\triangle$, and $[\nabla,\triangle] = \triangle + \epsilon\nabla$. In detail, it is



$$[e_{ij}, e_{kl}] = \delta_{jk}e_{il} - \delta_{li}e_{kj} \qquad [f_{ij}, f_{kl}] = \epsilon\delta_{jk}f_{il} - \epsilon\delta_{li}f_{kj}$$

$$[e_{ij}, f_{kl}] = \delta_{jk}(\epsilon\delta_{j<k}e_{il} + \delta_{il}(h_i+\epsilon g_i)/2 + \delta_{i>l}f_{il}) - \delta_{li}(\epsilon\delta_{k<j}e_{kj} + \delta_{kj}(h_j+\epsilon g_j)/2 + \delta_{k>j}f_{kj})$$

$$[g_i, e_{jk}] = (\delta_{ij}-\delta_{ik})e_{jk} \qquad [h_i, e_{jk}] = \epsilon(\delta_{ij}-\delta_{ik})e_{jk}$$

$$[g_i, f_{jk}] = (\delta_{ij}-\delta_{ik})f_{jk} \qquad [h_i, f_{jk}] = \epsilon(\delta_{ij}-\delta_{ik})f_{jk}$$

The sl_2 Example. Let $\mathfrak{g}^\epsilon = \langle h,e,l,f\rangle/([h,\cdot]=0,\ [e,l]=-e,\ [f,l]=f,\ [e,f]=h-2\epsilon l)$ and let $\mathfrak{g}_k=\mathfrak{g}^\epsilon/(\epsilon^{k+1}=0)$.

The Main $\mathfrak{g}_k$ Theorem. The $\mathfrak{g}_k$-invariant of any S-component tangle T can be written in the form

$$Z(T)=\mathbb{O}\left(\omega\mathbb{e}^{L+Q+P}\colon \bigotimes_{i\in S} e_i l_i f_i\right),$$

where ω is a scalar (meaning, a rational function in the variables h_i and their exponentials $t_i:=\mathbb{e}^{h_i}$), where $L=\sum a_{ij}h_i l_j$ is a balanced quadratic in the variables h_i and l_j with integer coefficients, where $Q=\sum b_{ij}e_i f_j$ is a balanced quadratic in the variables e_i and f_j with scalar coefficients b_{ij}, and where P is a polynomial in $\{\epsilon,e_i,l_i,f_i\}$ (with scalar coefficients) whose ϵ^d-term is of degree at most $2d+2$ in $\{e_i,\sqrt{l_i},f_i\}$. Furthermore, after setting $h_i=h$ and $t_i=t$ for all i, the invariant $Z(T)$ is poly-time computable.

The Main $\mathfrak{g}_k$ Lemma. The following "re-ordering relations" hold:

$$\mathbb{O}\left(\mathbb{e}^{\gamma l+\beta e}\colon le\right)=\mathbb{O}\left(\mathbb{e}^{\gamma l+\mathbb{e}^\gamma\beta e}\colon el\right)\quad\text{(and similarly for } fl\to lf\text{)},$$

$$\mathbb{O}\left(\mathbb{e}^{\beta e+\alpha f+\delta ef}\colon fe\right)=\mathbb{O}\left(\nu\mathbb{e}^{\nu(-\alpha\beta h+\beta e+\alpha f+\delta ef)+\lambda_k(\epsilon,e,l,f,\alpha,\beta,\delta)}\colon elf\right),$$

with $\nu=(1+h\delta)^{-1}$ and where $\lambda_k(\epsilon,e,l,f,\alpha,\beta,\delta)$ is some fixed polynomial of degree at most $2k+2$ in $\epsilon,e,\sqrt{l},f,\alpha,\beta,\delta$, with scalar coefficients.

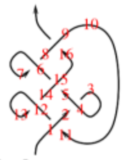
Also Fix in GWU

Demo Programs. ωεβ/Demo

Formatting
```
CF[ℰ_] := Module[{vars = Union@Cases[ℰ, e_ | l_ | f_, ∞]},
   If[vars === {}, Factor[ℰ],
    Total[CoefficientRules[ℰ, vars] /.
      (p_ → c_) ↦ Factor[c] Times @@ (vars^p)] ]];
CF[ℰ_𝔼] := CF /@ ℰ;
```

Preparation
```
𝔼[i_, j_, s_] := 𝔼[1, (-1)^s l_j, (-t)^s e_i f_j,
   t^s e_i l_(1+s) i-s j f_j + (-1)^s l_i l_j + (-t^2)^s e_i^2 f_j^2/4];
𝔼[i_, s_] := 𝔼[1, 0, 0, s l_i];
𝔼 /: 𝔼[1, L1_, Q1_, P1_] 𝔼[1, L2_, Q2_, P2_] :=
  𝔼[1, L1 + L2, Q1 + Q2, P1 + P2];
```

Preparing the Trefoil
```
z1 = (𝔼[1, 11, 0] 𝔼[4, 2, -1] 𝔼[15, 5, 0] ×
   𝔼[6, 8, -1] 𝔼[9, 16, 0] 𝔼[12, 14, -1] ×
   𝔼[3, -1] 𝔼[7, +1] 𝔼[10, -1] 𝔼[13, +1])
```



$$\mathbb{E}\Big[1,\ -l_2+l_5-l_8+l_{11}-l_{14}+l_{16},$$
$$-\frac{e_4 f_2}{t}+e_{15}f_5-\frac{e_6 f_8}{t}+e_1 f_{11}-\frac{e_{12}f_{14}}{t}+e_9 f_{16},$$
$$-\frac{e_4^2 f_2^2}{4t^2}+\frac14 e_{15}^2 f_5^2-\frac{e_6^2 f_8^2}{4t^2}+\frac14 e_1^2 f_{11}^2-\frac{e_{12}^2 f_{14}^2}{4t^2}+\frac14 e_9^2 f_{16}^2+e_1 f_{11} l_1+$$
$$\frac{e_4 f_2 l_2}{t}-l_3-l_2 l_4+l_7+\frac{e_6 f_8 l_8}{t}-l_6 l_8+e_9 f_{16} l_9-l_{10}+$$
$$l_1 l_{11}+l_{13}+\frac{e_{12}f_{14}l_{14}}{t}-l_{12}l_{14}+e_{15}f_5 l_{15}+l_5 l_{15}+l_9 l_{16}\Big]$$

Differential Polynomials

(Implementing $P(\partial_\alpha,\partial_\beta)(f)$)
```
DP_{x_→D_α_, y_→D_β_}[P_][f_] :=
 Total[CoefficientRules[P, {x, y}] /.
   ({m_, n_} → c_) ↦ c D[f, {α, m}, {β, n}]]
```

le and *fl* Sorts
```
S_{l_j_ (x:e|f)_i_ → k_}[𝔼[ω_, L_, Q_, P_]] :=
 With[{λ = ∂_{l_j} L, α = ∂_{x_i} Q, q = e^γ β x_k + γ l_k}, CF[
   𝔼[ω, L /. l_j → l_k, t^λ α x_k + (Q /. x_i → 0),
    e^-q DP_{l_j→D_γ, x_i→D_β}[P][e^q] /. {β → α / ω, γ → λ Log[t]}] ]];
```

The Λόγος
```
Λ[k_] := ((t - 1) (2 (α β + δ μ)^2 - α^2 β^2) - 4 e_k l_k f_k δ^2 μ^2 -
    δ (1 + μ) (f_k^2 α^2 + e_k^2 β^2) - e_k^2 f_k^2 δ^3 (1 + 3 μ) -
    2 (α β + 2 δ μ + e_k f_k δ^2 (1 + 2 μ) + 2 l_k δ μ^2) (f_k α + e_k β) -
    4 (l_k μ^2 + e_k f_k δ (1 + μ)) (α β + δ μ)) (1 + t) / 4;
```

fe Sorts
```
S_{f_i_ e_j_ → k_}[𝔼[ω_, L_, Q_, P_]] :=
 With[{q = ((1 - t) α β + β e_k + α f_k + δ e_k f_k) / μ}, CF[
   𝔼[μ ω, L, μ ω q + μ (Q /. f_i | e_j → 0),
     μ^4 e^-q DP_{f_i→D_α, e_j→D_β}[P][e^q] + ω^4 Λ[k]] /. μ → 1 + (t - 1) δ /.
   {α → ω^-1 (∂_{f_i} Q /. e_j → 0), β → ω^-1 (∂_{e_j} Q /. f_i → 0),
    δ → ω^-1 ∂_{f_i,e_j} Q}]];
```

Elf Merges
```
m_{i_,j_→k_}[Z_𝔼] := Module[{x, z},
  CF[(Z // S_{f_i e_j→x} // S_{l_i e_x→x} // S_{f_x l_j→x}) /. z_i|j|x → z_k]]
```

Rewriting the Trefoil

(by merging 16 elves)
```
(Do[z1 = z1 // m_{1,k→1}, {k, 2, 16}]; z1)
```

$$\mathbb{E}\Big[\frac{1-t+t^2}{t},\ 0,\ 0,\ \frac{(-1+t)\left(1-t+t^2\right)^2\left(1-t+2t^2\right)}{t^3}-\frac{2(-1+t)\left(1-t+t^2\right)^3 e_1 f_1}{t^4}-\frac{2(-1+t)(1+t)\left(1-t+t^2\right)^3 l_1}{t^4}\Big]$$

GWU

Readout
```
ρ1[𝔼[ω_, _, _, P_]] := CF[ t ((P /. e_ | l_ | f_ → 0) - t ω^3 (∂_t ω)) / ((t - 1)^2 ω^2) ]
```

$\rho_1(3_1)$
```
ρ1[z1] // Expand
```
$\frac{1}{t}+t$

References.

[BN] D. Bar-Natan, *Polynomial Time Knot Polynomial,* research proposal for the 2017 Killam Fellowship, ωεβ/K17.

[BNG] D. Bar-Natan and S. Garoufalidis, *On the Melvin-Morton-Rozansky conjecture,* Invent. Math. **125** (1996) 103–133.

[GST] R. E. Gompf, M. Scharlemann, and A. Thompson, *Fibered Knots and Potential Counterexamples to the Property 2R and Slice-Ribbon Conjectures,* Geom. and Top. **14** (2010) 2305–2347, arXiv:1103.1601.

[MM] P. M. Melvin and H. R. Morton, *The coloured Jones function,* Commun. Math. Phys. **169** (1995) 501–520.

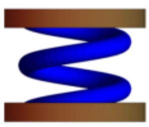
[Ov] A. Overbay, *Perturbative Expansion of the Colored Jones Polynomial,* University of North Carolina PhD thesis, ωεβ/Ov.

[Ro1] L. Rozansky, *A contribution of the trivial flat connection to the Jones polynomial and Witten's invariant of 3d manifolds, I,* Comm. Math. Phys. **175-2** (1996) 275–296, arXiv:hep-th/9401061.

[Ro2] L. Rozansky, *The Universal R-Matrix, Burau Representation and the Melvin-Morton Expansion of the Colored Jones Polynomial,* Adv. Math. **134-1** (1998) 1–31, arXiv:q-alg/9604005.

[Ro3] L. Rozansky, *A Universal U(1)-RCC Invariant of Links and Rationality Conjecture,* arXiv:math/0201139.

[Vo] H. Vo, University of Toronto Ph.D. thesis, in preparation.



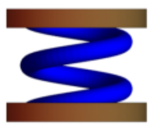
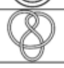
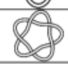


diagram	n_k^t / Today's / Rozansky's ρ_1^+	Alexander's ω^+	genus / ribbon unknotting number / amphicheiral	diagram	n_k^t / Today's / Rozansky's ρ_1^+	Alexander's ω^+	genus / ribbon unknotting number / amphicheiral
	0_1^a 0	1	0 / ✔ 0 / ✔		3_1^a t	$t-1$	1 / ✘ 1 / ✘
	4_1^a 0	$3-t$	1 / ✘ 1 / ✔		5_1^a $2t^3+3t$	t^2-t+1	2 / ✘ 2 / ✘

Partition handout!

[or maybe just partition the "implementation" part]

 Poly-Poly Extras

Warning. Conventions on this page change randomly from line to line.

The Algebra. $\mathcal{U}_{\hbar;\alpha\beta}$ conventions: $q = \mathbb{e}^{\hbar\alpha\beta}$, $H = \langle a, x\rangle/([a,x] = \alpha x)$ with

$$A = \mathbb{e}^{-\hbar\beta a}, \quad xA = qAx, \quad S(a,A,x) = (-a, A^{-1}, -A^{-1}x),$$
$$\Delta(a,A,x) = (a_1 + a_2, A_1A_2, x_1 + A_1x_2)$$

and dual $H^* = \langle b, y\rangle/([b,y] = -\beta y)$ with

$$B = \mathbb{e}^{-\hbar\alpha b}, \quad By = qyB, \quad S(b,B,y) = (-b, B^{-1}, -yB^{-1}),$$
$$\Delta(b,B,y) = (b_1 + b_2, B_1B_2, y_1B_2 + y_2).$$

Pairing by $(a,x)^* = \hbar(b,y)$ making $\langle y^l b^j, a^j x^k\rangle = \delta_{ij}\delta_{kl} i![k]_q!$. Then $\mathcal{U} = H^{*cop} \otimes H$ with $(\phi f)(\psi g) = \langle \psi_1 S^{-1} f_3\rangle\langle \psi_3, f_1\rangle(\phi\psi_2)(f_2 g)$. With the central $t := \beta a - \alpha b$, $T := e^{\hbar t} = A^{-1}B$ get

$$[a,y] = -\alpha y, \quad xy - qyx = (1 - TA^2)/\hbar.$$

Benkart-Witherspoon, 2017-06/BW.nb: At $\alpha\beta\hbar = \sigma - \rho$, represented by $y \to \begin{pmatrix} 0 & 0 \\ -\mathbb{e}^{\rho} & 0 \end{pmatrix}$, $a \to \frac{\alpha}{\rho-\sigma}\begin{pmatrix} \rho & 0 \\ 0 & \sigma \end{pmatrix}$, $A \to \begin{pmatrix} \mathbb{e}^{\rho} & 0 \\ 0 & \mathbb{e}^{\sigma} \end{pmatrix}$, $x \to \frac{\mathbb{e}^{\rho} - \mathbb{e}^{\sigma}}{\hbar\mathbb{e}^{\rho+\sigma}}\begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}$, $t \to \frac{\rho+\sigma}{\hbar}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, $T \to \frac{1}{\mathbb{e}^{\rho+\sigma}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, $b \to \frac{\beta}{\sigma-\rho}\begin{pmatrix} \sigma & 0 \\ 0 & \rho \end{pmatrix}$, $B \to \begin{pmatrix} \mathbb{e}^{-\sigma} & 0 \\ 0 & \mathbb{e}^{-\rho} \end{pmatrix}$.

The R-Matrix. With $[n]_q := (q^n - 1)/(q-1)$, $[n]_q! := [1]q \cdot \ldots \cdot [n]_q$ and $\mathbb{e}_q^x := \sum_{n\geq 0} \frac{x^n}{[n]_q!}$, we have the mysterious Quesne formula of arXiv:math-ph/0305003: $\mathbb{e}_q^x = \mathbb{e}^x \exp\left(\sum_{k\geq 2} \frac{(1-q)^k x^k}{k(1-q^k)}\right)$. Then $R_{ij} := \mathbb{O}\left(yb \otimes ax : \mathbb{e}^{\hbar ba}\mathbb{e}_q^{\hbar yx}\right)$.

xa Swaps.

ay Swaps.

xy Swaps.

The Drinfel'd Element.

Putting Everything Together.