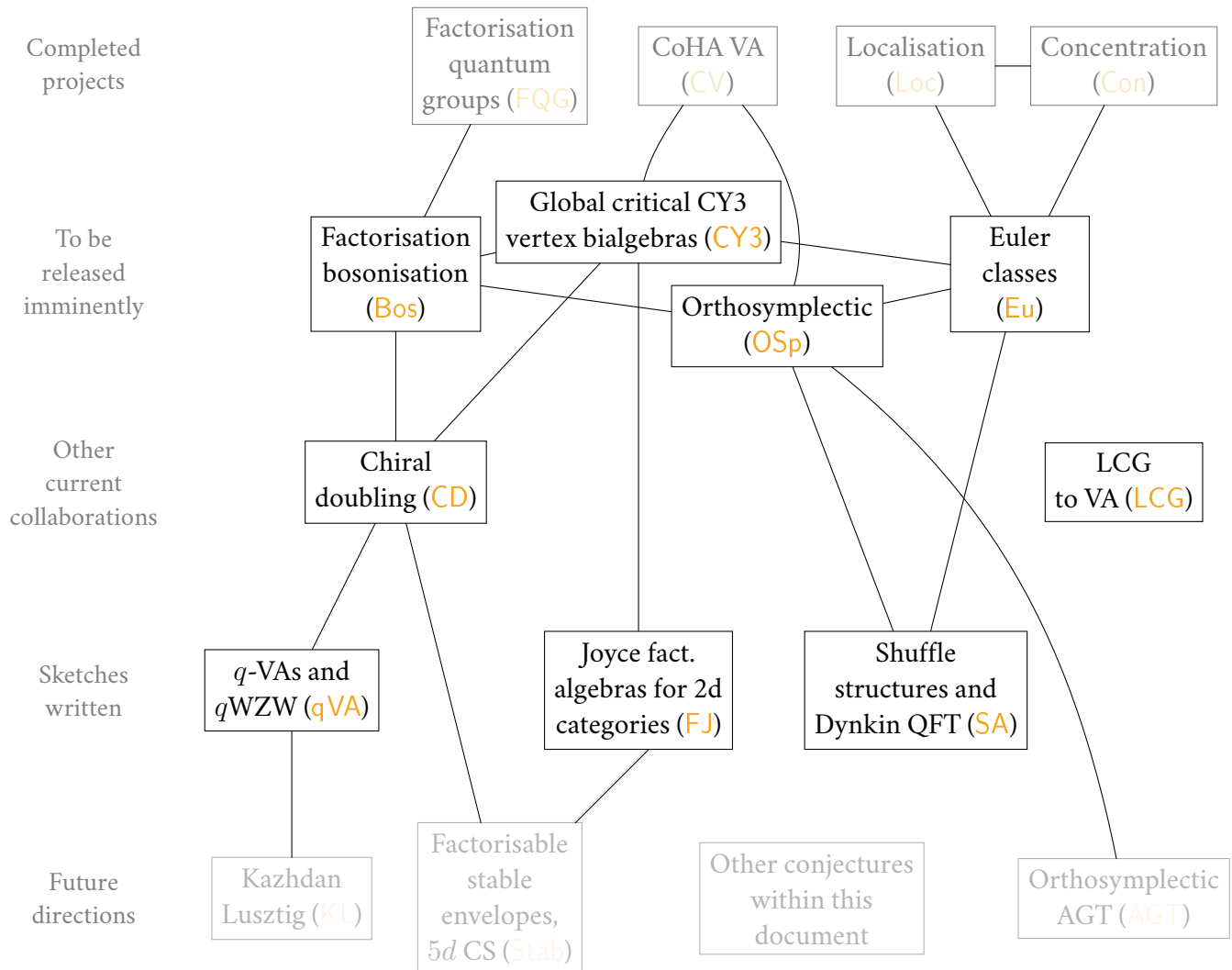


RESEARCH PLANS - ABRIDGED

ALEXEI LATYNTSEV

See <https://alyoshalatyntsev.github.io/plan/plan.pdf> for a more detailed research statement.



1. Research statement

I am a mathematician working in geometric representation theory.

1.1. Algebraic structures attached to CY3s (CV, CY3, FJ, Stab)

Cohomological Hall algebras are associative algebras attached to Calabi-Yau varieties or categories [Daa; KS; KPS]. They relate to DT theory [KS; Sz], algebraic structures previously appearing in representation theory [BD; RSYZ; YZ] (e.g. quantum groups [MO]), hence are a key object in geometric representation theory/enumerative invariants.

Global critical CY3 vertex quantum groups. Let \mathcal{C} be the CY3 category $\text{Rep}(Q, W)$, the representations of a Jacobi algebra of a quiver with potential, or $\text{Coh}_0(K_{T^*C})$, zero dimensional coherent sheaves on a local curve [KK], or more generally a deformed CY3 completion.

Theorem. [CY3] *The critical cohomology¹ of the moduli stack of objects \mathcal{M} has a vertex coproduct*

$$H^\bullet(\mathcal{M}, \varphi) \rightarrow H^\bullet(\mathcal{M}, \varphi) \hat{\otimes} H^\bullet(\mathcal{M}, \varphi)((z^{-1}))$$

compatible with the CoHA: it forms a vertex quantum group (see FQG for a definition).

Theorem. [CY3] *There is a functor Φ from Q -localised bialgebras [Daa] to vertex bialgebras. The former is equivalent to the category of factorisation bialgebras on the coloured configuration space $\text{Conf}_{Q_0}\mathbf{A}^1$.*

Theorem. [CY3; CV for $W = 0$] *For any quiver Q , the vertex coproduct on the preprojective CoHA $H_{\mathbf{G}_m}^\bullet(\mathcal{M}_{Q(3)}, \varphi_{W(3)})^{\text{ext}} \stackrel{[\text{BD}]}{\simeq} Y_h(\mathfrak{b}_Q)$ is identified by Φ with the Davison/Yang-Zhao localised coproduct [Daa; YZ], and (when defined) Drinfeld's meromorphic coproduct [Dr; GLW].*

This generalises **Joyce-Liu's vertex coproduct** [Joa; Li], shows that all these well-known coproducts on the Yangian are **equal**, and gives a **geometric** definition using moduli stacks and configuration spaces. Finally, Theorem 1.1 points to a new Ran space definition of vertex-vertex bialgebras.

Lift to factorisation algebra and relation to stable envelopes. To move towards arbitrary CY3s, we first interpret the above in terms of factorisation algebras; second, we relate to the \mathcal{W} -algebras for surfaces of [MMSV], thus understanding the structure for K_S . Let Q be a quiver with torus $T = \prod T_d$.

Conjecture. [FJ] *Given $\mathcal{M}^f = \{(m, \lambda) : \lambda \in \mathfrak{t}, m \in \mathcal{M}^\lambda\} \xrightarrow{\pi} \text{colim}(\mathfrak{t}_d) = \text{Ran}_{Q_0}\mathbf{A}^1$, its relative BM-homology $\mathcal{A} = \pi_*\omega$ is a factorisation algebra over the coloured Ran space. Its restriction to the colour-diagonal recovers the vertex quantum group structure on the nilpotent CoHA [SV].*

Conjecture. [FJ] *For S a smooth algebraic surface, there is a braided factorisation category $\text{Rep}\mathcal{W}$ over $\text{Ran}_S K_S$ (c.f. FQG). Applying Bos/CD allows us to construct $\mathcal{W}(S)^{\geq 0}$ and $\mathcal{W}(S)$ from [MMSV]'s $\mathcal{W}(S)^{>0}$.*

The definition of \mathcal{M}^f is clearly reminiscent of [MO, §5.1.1]'s stable envelope construction, and suggests a resolution to their question: “we view this definition as provisional; perhaps a better set of axioms will emerge later”. Let \mathbf{w} be a multidimension vector of quiver Q and $M(\mathbf{w})$ the quiver variety.

Conjecture. [Stab] *There is a factorisation space $\pi_{\mathbf{w}} : M(\mathbf{w})^f \rightarrow \text{Ran}_Q\mathbf{A}^1$ and the factorisation category \mathcal{E} spanned by $\pi_{\mathbf{w},*}\omega$ is acted on by $\mathcal{A} = \pi_*\omega$. Applying chiral Tannakian reconstruction $\mathcal{E} \simeq \text{Rep}\mathbf{D}\mathcal{A}$ gives the double of \mathcal{A} with its (two) coproducts.*

The above is a Drinfeld-Kohno Theorem for [MO]'s Yangians $Y_h(\mathfrak{g}_Q)$ (see qVA for relations to $q\text{KZ}$).

1.2. The structure of factorisation quantum groups (FQG, Bos, CD)

Historically the definitions of (double) affine quantum groups $U_q(\hat{\mathfrak{g}})$, $Y_h(\mathfrak{g})$, $\mathcal{E}_{h,\tau}(\mathfrak{g})$, $Y_h(\hat{\mathfrak{g}})$, $\mathcal{W}_{1+\infty}(\mathfrak{g})$ were (ingeniously) made very explicitly [Dr; MO], and still much of the modern (e.g. CoHA) literature is based on explicit shuffle computations, e.g. [MMSV; SV; YZ]. This series of projects **axiomatises** (operadically) these structures, allowing us to

¹i.e. $\mathcal{M} = \text{Crit}(W)$ is a critical locus inside a smooth moduli stack; we take the vanishing cycle sheaf $\varphi = \varphi_W$.

import techniques from the theory of ordinary **quantum groups**,² to recover the above formulas as a **consequence** of these definition.

Factorisation quantum groups. In **FQG** we develop a theory of \mathbf{E}_n -factorisation categories over factorisation spaces X (including ordinary groups G , configuration spaces $\text{Conf}_{Q_0}\mathbf{A}^1$, and algebraic-topological Ran spaces $\text{Ran}(\mathbf{A}^n \times \mathbf{R}^m)$). We first give basic structure results for braided factorisation categories \mathcal{C} :

Theorem. [**FQG**] *Let \mathcal{A} be a factorisation algebra in \mathcal{C} over X , a (braided) factorisation structure on $\mathcal{A}\text{-FactMod}(\mathcal{C})$ induces a factorisation bialgebra structure on \mathcal{A} (and a factorisation R -matrix $R : \mathcal{A} \otimes_{\mathcal{C}, X} \mathcal{A} \xrightarrow{\sim} \mathcal{A} \otimes_{\mathcal{C}, X} \mathcal{A}$).*

Theorem. [**FQG**] *When $X = \text{Ran}\mathbf{A}^1$ (resp. $\text{Conf}\mathbf{A}^1$), Theorem 1.2 recovers classical notions [EK; FR] of **quantum vertex algebras** (resp. **localised algebras**) and their R -matrices $R(z)$ satisfying the spectral YBE.*

For instance, the structure [GLW] for **Yangians** (e.g. two (meromorphic) coproducts and R -matrices R^- , $R^{0,\epsilon}$, R^ϵ relating them) are equivalent to: $Y_h(\mathfrak{g})\text{-Mod}$ is a lax braided factorisation category. This makes rigorous the physics claim [CWY] that $Y_h(\mathfrak{g})\text{-Mod}$ from 4d Chern-Simons is a topological-holomorphic factorisation category over $\mathbf{R} \times \mathbf{C}$. The above may help understand **affine Yangians** (e.g. [GRZ]; **qVA** for relation to q -WZW) and the **new KL equivalences** [BCDN]. Finally, in principle we may get lots of examples from:

Theorem. [**FQG**] *A generalisation of Borchers' twist construction [Bo] to arbitrary decomposition algebra.*

Factorisation bosonisation. In the CoHA literature, a lot of algebraic effort needs to be expended each time [Daa; RSYZ; YZ], [**CY3**; **OSp**] to add in the Cartan piece $H^\bullet(\mathcal{M}, \varphi) \rightsquigarrow H^\bullet(\mathcal{M}, \varphi)^{\text{ext}}$, e.g. to obtain Yangians of Borels $Y_h(\mathfrak{b}_Q)$. In the finite groups case, a clean construction is Tannakian reconstruction

$$U_q(\mathfrak{n}) \rightsquigarrow U_q(\mathfrak{n}) \quad \text{via} \quad U_q(\mathfrak{b})\text{-Mod} \xrightarrow{\sim} U_q(\mathfrak{n})\text{-Mod}(\text{Rep}_q T),$$

c.f. [Ga; Maa; Mab]; in **Bos** we apply the same to vertex and factorisation bialgebras:

Theorem. [**Bos**, in preparation] *There is a Tannakian reconstruction functor from (braided) factorisation categories \mathcal{C} to (quasitriangular) factorisation quantum groups \mathcal{A} . In the preprojective case of Theorem 1.1,*

$$Y_h(\mathfrak{b}_Q)\text{-Mod} \simeq Y_h(\mathfrak{n}_Q)\text{-Mod}(Y_h(\mathfrak{t}_Q)\text{-Mod})$$

we Tannakian reconstruct $Y_h(\mathfrak{b}_Q) \simeq H^\bullet(\mathcal{M}, \varphi)^{\text{ext}}$ with its localised or vertex bialgebra structure.

Applying this to $H^\bullet(\mathcal{M}, \varphi)\text{-Mod}(H^\bullet(\mathcal{M})\text{-Mod}^\cup)$ **automates** the process of extending CoHAs.

Factorisation Drinfeld doubling. An active problem is how the structures in **CY3** relate to **wall crossing** and stability conditions, see [Br; Job]. As a first attempt, we use **FQG** to understand **doubling**, where the CoHA of heart \mathcal{A} and its opposite $\mathcal{A}[1]$ are glued, in a similar way to **Bos**:

Conjecture. [**CD**] *There is a Drinfeld centre construction $Z_{\mathbf{E}_1}(\mathcal{C})$ of a chiral factorisation category \mathcal{C} , which carries compatible chiral and ordinary monoidal structures, and Tannakian reconstruction gives*

$$Z_{\mathbf{E}_1}^{Y_h(\mathfrak{t}_Q)\text{-Mod}}(Y_h(\mathfrak{b}_Q)\text{-Mod}) \simeq Y_h(\mathfrak{g}_Q)\text{-Mod}$$

and likewise we recover the Takiff algebra double construction of [AN].

1.3. Orthosymplectic structures (**OSp**, **SA**, **AGT**)

Orthosymplectic CoHAs. We define *orthosymplectic moduli stacks* \mathcal{M}^{OSp} , including perverse-coherent sheaves with a symplectic/orthogonal bilinear form, and quivers and potential with involution.

Theorem. [**OSp**] *For \mathcal{M} as in \mathcal{C} the vertex quantum group $H^\bullet(\mathcal{M}, \varphi)$ acts on $H^\bullet(\mathcal{M}^\tau, \varphi^\tau)$, i.e.*

- (1) *there is a left module action a of the CoHA respecting the involution,³ compatible with*
- (2) *a **symplectic vertex algebra** structure (factorisation coalgebra over symplectic Ran space $\text{Ran}_{\text{Sp}}\mathbf{A}^1 = \text{colim}_{\text{Sp}_{2n}} \text{Ran}_{\text{Sp}}\mathbf{A}^1$, see **SA**). The defining R -/ K -matrices satisfy the **Cherednik reflection equation**.*

²Namely, when $X = \text{Ran}\mathbf{R}^2$ in the below, via Lurie [Lu].

³i.e. the left action a and the right action $a \cdot (\text{id} \otimes \tau)$ commute, where τ is the involution.

Theorem. [OSp] There is an action of $H_{\bullet}^{\text{BM}}(\mathcal{M})$ of the CoHA of zero-dimensional coherent sheaves on surface S on $H_{\bullet}^{\text{BM}}(\mathcal{M}_{\sigma\text{-ss}}^{\text{OSp}})$ the BM homology of a compactification of the stack of $G \in \{\text{Sp}, \text{O}\}$ -bundles.

This gives a rigorous definition of the objects coming from boundary 4d Chern-Simons theory [BS], should relate to work in **quantum groups** [LW] and Finkelberg-Hanany-Nakajima's ongoing work on **orthosymplectic Coulomb branches** (see also AGT). In the quiver with potential case, we have:

Theorem. [OSp] An explicit shuffle formula for the CoHA action and vertex coaction on $H^*(\mathcal{M}_{Q,W}^{\text{OSp}}, \varphi^{\text{OSp}})$.

Conjecture. When Q is type A_{2n+1} with the reflection involution, the preprojective orthosymplectic CoHA⁴ is isomorphic to the **twisted Yangian** $Y_h(\mathfrak{gl}_n)^{tw}$ of [BR].

Dynkin QFT and shuffle structures. The structures (2) in OSp are defined over the symplectic configuration space⁵ $\text{Conf}_{\text{Sp}}(\mathbf{A}^1) = \text{Spec } H^*(\text{BSp})$, with singularities over the root hyperplanes; alternatively over $\text{Ran}_{\text{Sp}} \mathbf{A}^1 = \text{colim } \mathfrak{t}_{\text{Sp}_{2n}}$.

Theorem. [OSp] To give examples, we construct an **invariants** functor involving restricting along $\mathfrak{t}_{\text{Sp}_{2n}} \hookrightarrow \mathfrak{t}_{\mathfrak{gl}_{2n}}$

$$\iota : \text{FactAlg}_{\text{GL}}(\mathbf{A}^2) \rightarrow \text{FactAlg}_{\text{Sp}}(\mathbf{A}^1), \quad (\mathcal{A}, \tau) \mapsto (\mathcal{A}, \mathcal{A}^\tau)$$

where \mathcal{A} is a factorisation algebra with involution τ

In SA, we **generalise** the above to systems of **arbitrary Kac-Moody groups** G_i [Ku, §V]; this forms a category K_{KM} with morphisms the parabolics. Write $K_{\text{GL}}, K_{\text{Sp}}, \dots$ for the appropriate subcategories.

Fact. [SA] A shuffle algebra [KS; Gr] is equivalent to a monoidal functor $K_{\text{GL}} \xrightarrow{A} \text{Vect}$.

There are KM analogues of *vertex algebra* and *localised bialgebra*, *quiver representation* with moduli stack $\mathcal{M}_Q = \sqcup \mathfrak{u}_e/G_i$, *quiver varieties*, and (factorisation) *braided monoidal categories* (generalising the G_2 -**reflection equation** [Ku]). In the finite type cases K_G ,

Conjecture. [SA] There is a KM affine vertex algebra, giving the **boundary KZ equations**. (also elliptic) For another example, considering the groups $\hat{\mathfrak{gl}}_n$ of affine type A gives $\text{Ran}_{\widehat{\text{GL}}} \mathbf{A}^1$, \mathcal{D} -modules on which are related to \mathcal{D} -modules on \mathbf{A}^1/\mathbf{Z} , so we expect this should relate to trigonometric KZ equations. The **boundary KZ equations** may be derived by applying ι to the BD Grassmannian, taking distributions supported at the identity, and taking conformal blocks over $\text{Ran}_{\text{Sp}} \mathbf{A}^1$.

Using $\Delta^n \rightsquigarrow \Delta_G = T_G/\mathfrak{W}_G$ we generalise **Chen's Theorem** [Ch]: a K_{KM} shuffle structure on cochains $C^\bullet(LX)$ of a loop space.

Question. [SA] Can we recover Dynkin/ q -analogues of **multiple zeta values** [KMT; Mi] using this?

Question. [SA] Can we recover Dynkin/ q -analogues of **stable envelopes** (see [MO], Stab) using this?

Conjecture. [SA] Just as in OSp we used that C_n is obtained by folding A_{2n} ,⁶ we expect to be able to produce G_2 structures by taking $\mathbf{Z}/3$ -invariants of type D structures.

A twisted AGT correspondence. After OSp, one natural next step (project AGT) is to construct a boundary version [AGT; BFN]:

Conjecture. [AGT] The equivariant intersection homology of the invariant locus $\mathcal{U}_{\mathbf{P}^2, \text{GL}_n}^{\mathbf{Z}/2}$ in the Uhlenbeck space is a Verma module for an orthosymplectic analogue of the vertex W -algebra $\mathcal{W}^k(\mathfrak{gl}_n)$.

Likewise, we expect a version for an arbitrary smooth projective surface S . We expect the proof of the above should proceed in much the same way as in [BFN], but with the parabolic induction data replaced by

$$\begin{array}{ccc} & \text{BP} & \\ \swarrow & & \searrow \\ \text{BGL}_n \times \text{BSp}_{2m} & & \text{BSp}_{2n+2m} \end{array}$$

⁴i.e. the image of the CoHA in $\text{End}(H_{\bullet}^{\text{BM}}(\mathcal{M}^{\text{OSp}}))$.

⁵As opposed to the ordinary configuration space $\text{Conf} \mathbf{A}^1 = \sqcup \mathbf{A}^n // \mathfrak{S}_n = \text{Spec } H^*(\text{BGL})$.

⁶i.e. the invariants construction discussed in OSp.

as in **OSp**; i.e. we expect a **SA**-type analogue of free field realisations. Likewise, we expect a generalisation of [RSYZ] for instantons on \mathbf{A}^3 :

Conjecture. [AGT] *There is vertex algebra structure on the the orthosymplectic CoHA of the Jordan quiver, which acts on $\mathrm{IH}_T^\bullet(M^{\mathbb{Z}/2})$, the equivariant intersection cohomology of the invariant locus in the quiver variety.*

Just as the CoHA $\mathcal{W}_{1+\infty}^+$ of the Jordan quiver is by [Dab] the universal enveloping algebra of positive half of differential operators on \mathbf{C}^\times and admits the W-algebras of [BFN] as quotients, we expect the above to be a universal enveloping on differential operators on \mathbf{C}^\times/\pm , and admit the above W-algebras $\mathcal{W}^{k_n}(\mathfrak{gl}_n)^{\mathrm{OSp}}$ as quotients.

1.4. q -vertex algebras (**qVA**, **KL**)

q -vertex algebras. The main goal of project **qVA** is to develop the machinery of q -vertex algebras and define q -affine vertex algebras. In **KL** we hope to use it to produce the q KZ equations and relate to Kazhdan-Lusztig equivalences.

A natural first guess at a definition is to take the usual definition of vertex algebra but using \mathcal{D}_q -modules in place of \mathcal{D} -modules. The first observation is that a q -difference operator ∂_x on \mathbf{A}^1 induces a derivation $y\partial_x$ on the noncommutative plane⁷ \mathbf{A}_q^2 , and indeed the physics heuristic below points towards \mathcal{D} -modules on \mathbf{A}_q^2 (e.g. via [MS]) as the correct setting for q -vertex algebras:

Conjecture. [qVA] *There is a factorisation category over the noncommutative space \mathbf{A}_q^2 , such that any $\mathcal{A} \in \mathrm{FactAlg}^{st}(\mathcal{D}\text{-Mod}_{\mathrm{Ran}\mathbf{A}_q^2})$ defines a q -vertex algebra (generalising e.g. [FR]).*

To construct this category precisely, one needs to develop the theory of \mathcal{D} -modules (e.g. functoriality) over noncommutative spaces. We propose using work [FMW; MS] on jet spaces of noncommutative schemes to give a “ q -crystal/de Rham” definition.

Physics heuristic. Our guiding heuristic from physics is the following: much as $V^k(\mathfrak{g})$ and $U_h(\mathfrak{g})$ have module categories giving line operators for “3d Chern-Simons with boundary” on

$$\mathbf{C} \times \mathbf{R}_{\geq 0}$$

or more cleanly, on the suspension $S(\mathbf{CP}^1)$, so then module categories for $V_h^k(\mathfrak{g})$ and $Y_h(\hat{\mathfrak{g}})$ should define line operators for “5d Chern-Simons theory with boundary” on

$$(\mathbf{C} \times \mathbf{C})_{nc} \times \mathbf{R}_{\geq 0}$$

where $\mathbf{A}_q^2 = (\mathbf{C} \times \mathbf{C})_{nc}$ is the noncommutative plane with ring of functions $\mathbf{C}[x, y]/(xy - qyx)$, see [GRZ] or particularly Costello’s [Co] work.

Examples. The above definition will have been correct if we may answer

Question. *Is there an analogue of the Beilinson-Drinfeld Grassmannian $\mathrm{Gr}_{G,q} \rightarrow \mathrm{Ran}\mathbf{A}_q^2$?*

Such a factorisation space would for free by Conjecture 1.4 define for us a q -vertex algebra $V_q^k(\mathfrak{g})$, by the same construction as for the affine WZW vertex algebra: taking distributions supported at the identity. We expect that $V_q^k(\mathfrak{g})$ should be a q -deformation of the affine vertex algebra and should agree with Etingof-Kazhdan’s RTT construction in [EK] when $\mathfrak{g} = \mathfrak{sl}_n$.

Kazhdan-Lusztig. Conditional on having defined a factorisation algebra $V_q^k(\mathfrak{g})$ as in Question 1.4, many interesting questions follow. To begin with, for formal reasons just as for ordinary vertex algebras, given $V_q^k(\mathfrak{g})$ -modules M_1, \dots, M_n we expect to obtain a \mathcal{D}_q -module of *conformal blocks* $\mathbf{C}^\bullet(M_1, \dots, M_n)$ on $(\mathbf{A}_q^2)^n$.

Question. [KL] *Is its restriction to $(\mathbf{A}^1)_\circ^n$ equal to the q KZ connection?*

⁷Its with ring of functions $\mathbf{C}\langle x, y, q \rangle/(yx - xyq)$ with q central.

It has been long expected that one may define an affine analogue of the Kazhdan-Lusztig equivalence, and answering the above question would be a first step in understanding whether the geometric proof [CF] might be generalised to the affine setting.⁸

Orthogonally to this, we can try to understand ordinary Kazhdan-Lusztig better. First, we ask whether there is a lift of the *Zhu algebra* functor to the q -setting, fitting into a commuting square

$$\begin{array}{ccc} V_q^k(\mathfrak{g}) & \xrightarrow{q \rightarrow 1} & V^k(\mathfrak{g}) \\ \Downarrow \text{Zhu} & & \Downarrow \text{Zhu} \\ U_q(\mathfrak{g}) & \xrightarrow{q \rightarrow 1} & U(\mathfrak{g}) \end{array}$$

Noting the appearance of both objects $U_q(\mathfrak{g})$ and $V^k(\mathfrak{g})$ appearing in the Kazhdan-Lusztig equivalence, having done this we then ask whether these are the special and general fibres of a structure on $\mathbf{C} \times \mathbf{R}_{\geq 0}$:

Question. [KL] Does $V_q^k(\mathfrak{g})$ induce a topological-holomorphic factorisation algebra \mathcal{A} on $\mathbf{C} \times \mathbf{R}_{\geq 0}$, whose restriction to \mathbf{C} is $V^k(\mathfrak{g})$ and whose restriction to $\mathbf{C} \times \mathbf{R}_{> 0}$ is $U_q(\mathfrak{g})$?

One would then hope to interpret the fact that [CF]’s RH functor sends $V^k(\mathfrak{g})$ -FactMod to $\text{KD}(U_q(\mathfrak{g}))$ -FactMod as some sort of flatness statement for \mathcal{A} -FactMod over $\mathbf{R}_{\geq 0}$.⁹ This may give a new way to understand the recent Kazhdan-Lusztig equivalences [BCDN] coming from 3d mirror symmetry.

1.5. Sheaf methods (Con, Loc, Eu)

Localisation methods. Torus localisation is one of the main methods in enumerative geometry, and projects Con and Loc were concerned with extending these techniques to the Artin moduli stacks appearing in enumerative geometry. Given a closed Artin substack

$$\mathcal{Z} \hookrightarrow \mathcal{X}$$

not necessarily quasicompact,

Theorem. [Conc] If \mathcal{L}_i are a collection of line bundles such that at least one of them vanishes on each geometric point $x \in \mathcal{X} \setminus \mathcal{Z}$, then

$$C_{\bullet}^{\text{BM}}(\mathcal{X} \setminus \mathcal{Z})_{\text{loc}} = 0,$$

so then the cohomology of \mathcal{X} is “concentrated” on \mathcal{Z} : we have $i_* : C_{\bullet}^{\text{BM}}(\mathcal{Z}) \xrightarrow{\sim} C_{\bullet}^{\text{BM}}(\mathcal{X})$.

Here we have localised with respect to $c_1(\mathcal{L}_i)$, for instance we show the condition holds if $\mathcal{Z}_0/T \hookrightarrow \mathcal{X}_0/T$ is an inclusion of quotient stacks with $\dim \text{Stab}_x(T)$ non-maximal for all $x \in \mathcal{X}_0 \setminus \mathcal{Z}_0$, and we take for $\bigoplus \mathcal{L}_i$ the tautological T -bundle.

Theorem. [Loc] If $i : \mathcal{X}^T \hookrightarrow \mathcal{X}$ is the inclusion of the homotopy fixed points of a torus action on quasismooth dg scheme \mathcal{X} , there is a **Gysin pullback** map $i^! : C_{T, \bullet}^{\text{BM}}(\mathcal{X})_{\text{loc}} \rightarrow C_{T, \bullet}^{\text{BM}}(\mathcal{X}^T)_{\text{loc}}$ satisfying Atiyah-Bott and Graber-Pandharipande formulas:

$$\text{id} = i_* \frac{i^!(-)}{e(N_{\text{vir}})}, \quad [\mathcal{X}]^{\text{vir}} = i_* \frac{[\mathcal{X}^T]^{\text{vir}}}{e(N_{\text{vir}})}, \quad (1)$$

relating to pushforward and fundamental classes.

This recovers the usual torus localisation results when $\mathcal{Z} = X^T/T$ and $\mathcal{X} = X/T$ are quotients of smooth finite-type schemes by tori.

⁸Specifically, one wants a Riemann-Hilbert type functor “RH : $\text{FactCat}(\mathbf{A}_q^2) \rightarrow \text{FactCat}^{\text{QCoh}}(\mathbf{C}_q^2)$ ”, which sends the category $V_q^k(\mathfrak{g})$ -Mod to $Y_{\hbar}(\mathfrak{g})$ -Mod ^{f^d} .

⁹By means of extra evidence, it seems plausible that ordinary Riemann-Hilbert \mathcal{D} -Mod ^{rh} $\xrightarrow{\sim}$ Perv may be interpreted this way, where we consider \mathcal{A} a sheaf of algebras generated by $\mathcal{O}_{\Sigma \times \mathbf{R}_{\geq 0}}$ and the Lie algebra $\mathcal{T}_{\Sigma \times \mathbf{R}_{\geq 0}}$ of infinitesimal automorphisms of $\Sigma \times \mathbf{R}_{\geq 0}$ whose restriction to the boundary is antiholomorphic.

Virtual Euler classes and shuffle structures. In [Eu](#), we strengthen the above results in [Con](#) and [Loc](#) until:

- they give a general geometric method to output *shuffle products* for CoHAs,
- and show CoHAs are compatible with Davison/Yang-Zhao localised/Joyce vertex coproducts.

Specifically, we prove analogues of Theorems 1.5 and 1.5 for the *vanishing cycle* (or any sheaf) cohomology of arbitrary closed embeddings $\mathcal{Z} \hookrightarrow \mathcal{X}$ which is quasismooth other a common base, and concentrated with respect to a multiplicative subset $\mathcal{S} \subseteq H^\bullet(\mathcal{X})$. As a result,

For \mathcal{M} of the form we consider in [CY3](#), we have the following:

Theorem. [\[Eu\]](#) For any “split locus” map $\pi : \mathcal{M}^s \rightarrow \mathcal{M}$, we have $\text{CoHA} = \text{CoHA}^s / e(N_{i,\text{vir}})$.

Taking \mathcal{M}^s a *shuffle space*¹⁰, this gives a **universal, geometric** way of producing/interpreting shuffle products for CoHAs [Daa; SV; YZ]. Taking $\mathcal{M}^s = \mathcal{M} \times \mathcal{M} \xrightarrow{\oplus} \mathcal{M}$ proves **compatibility** [[CV](#), [CY3](#), [Li](#)] between **coproducts** and the CoHA (c.f. [CY3](#)). This easily **generalises** to the [OSp](#)/Dynkin [SA](#) cases.

1.6. Liouville quantum gravity to vertex algebras ([LCG](#))

History. In recent years, probabilists have increasingly understood quantum field theory, giving rigorous definitions of Feynman measures for $2d$ CFTs, e.g. [CRV; DS; Sh] whose “holomorphic part” are expected to be W-algebras, Virasoro, and Heisenberg vertex algebras.

This approach is very different to the factorisation/vertex algebra/functorial QFT approach in the above projects, e.g. it can directly study level sets of fields as SLE curves [MS; SS], there is a rigorous connection to combinatorial toy models like the discrete Gaussian Free Field [BPR], and it is able to access the *full* CFT, not just the chiral part as we are in geometric representation theory, e.g. [KRV] proves the DOZZ formula for full OPEs in the Liouville CFT.

However, there is currently not much interaction between the two approaches, and this project aims to build a bridge between the two so that techniques/results/heuristics can move between subjects more easily (then give a simple example of this).

Conjecture. *There is a functor from Segal-style $2d$ conformal field theories to vertex algebras*

$$\text{CFT} \xrightarrow{(-)^{ch}} \text{CFT}^{hol} \xrightarrow{\text{Res}} \text{FactAlg}(\mathbf{C})_{\mathbf{C} \times \mathbf{C}^\times}^{hol} \xrightarrow{[\text{CG}]} \text{VertexAlg}, \quad (2)$$

then show that the Gaussian Free Field and Liouville Quantum Gravity Segal CFTs are sent to the Heisenberg and Virasoro vertex algebras, respectively.

Details. We will need to upgrade $\mathcal{Z} \in \text{CFT}$ to a definition that remembers the geometric structure on the category Cob_2 of conformal cobordisms. Namely, consider a complex vector bundle \mathcal{V} with connection over the Teichmuller space $\mathcal{T}_{g,n}$ satisfying a factorisation condition, and with a section ψ . The fibre of this data over Σ is the vector space $\mathcal{Z}(\partial\Sigma)$ and $\mathcal{Z}(\Sigma) : \mathbf{C} \rightarrow \mathcal{Z}(\partial\Sigma)$.

The induced factorisation algebra over \mathbf{C} is automatically smoothly translation and rotation equivariant, so if it is *holomorphic* (i.e. $\partial_{\bar{z}}\psi = 0$) then it is by [CG] a vertex algebra; these are the last two maps in (2). The equivariance comes from a G -action on $\mathcal{T}_{0,n}$, since then the Lie algebra \mathfrak{g} acts on \mathcal{V} by the connection, e.g. the vertex algebras in the image of (2) will automatically have an action by vector fields on \mathbf{P}^1 , so we expect they are VOAs.

The main task is to define a chiralisation functor $(-)^{ch}$ to holomorphic CFTs, and prove that [GKRV]’s LQG Segal CFT (upgraded appropriately in the above sense) is sent by (2) to the Virasoro vertex algebra, and relate the DOZZ formula [KRV, (1.12)] to the Virasoro OPE. Having done this, we plan to do the same for the GFF, and finally to give a new example of these methods, construct a probability measure in the domain of (2) recovering the affine vertex algebra, e.g. by using the free field embedding [FB, §11] to a direct sum of Heisenberg algebras.

¹⁰i.e. shuffle algebra in the category of spaces, see [SA](#).

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