

On Vassiliev Invariants

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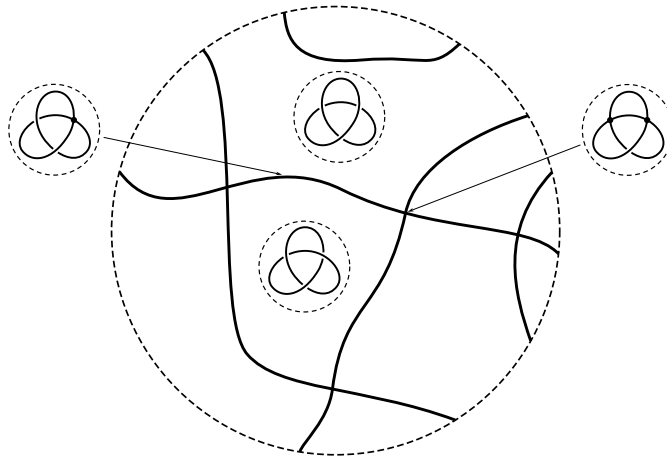
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Acknowledgements

Thanks to ...

Introduction

THE space of knots is the disconnected space of embeddings of \mathbb{S}^1 into \mathbb{R}^3 , in which the connected components, the “rooms”, are the knot types. Vassiliev studied the space of knots by looking at its “walls” of a specific type: those immersions of \mathbb{S}^1 into \mathbb{R}^3 which fail to be embeddings by having a single point of trasverse intersection. The addition of these walls makes the space of objects we study a connected space. Any two knots are connected by a path that passes through finitely many of the walls. The space of walls is also disconnected, but it can be connected by allowing paths to pass through finitely many “cornices” where two walls meet. These are immersions that fail to be embeddings by having two points of transverse intersection. The cornices are again disconnected but can be connected by “corners” and so on, with any immersions with m double points being connected by a finite number of immersions with $m + 1$. This produces the “stratification” of the space: a very schematic illustration is given below. Note that this picture doesn’t properly capture the infinite-dimensional nature of the stratification. Nor some other missing details which will appear in Chapter 1.



In [Vas90], Vassiliev makes a sequence of approximations of the cohomology ring of the space of knots, yielding a certain subring of the zeroth cohomology ring. Elements of this are locally constant functions on the space, so knot invariants. This subring of “Vassiliev” knot invariants can be computed on any knot by some procedure involving the homology group of the strata at a finite number of increasing depths.

Birman and Lin in [BL93] give an axiomatic definition of the Vassiliev invariants as those that respect the Vassiliev skein relation. It follows, as we will see in Chapter 1 that Vassiliev invariants can be described completely combinatorially by functions on chord diagrams obeying certain combinatorial rules.

By the work of Bar-Natan in [Bar95] the algebra of chord diagrams turns out to be equivalent to a different diagrammatic algebra, that of Jacobi diagrams, again up to a different set of combinatorial rules. This will be discussed in Chapter 2. This change of perspective introduces Lie theory in the following sense. A key relation in the algebra of Jacobi diagrams is a formal version of the relation in the universal enveloping algebra of a Lie algebra that the bracket is equal to the commutator. This is discussed in Chapter 3. A rigorous version of this statement is the work of Hinnich and Vaintrob [HV00] which constructs the algebra of Jacobi diagrams as the universal enveloping algebra object of some Lie algebra object in some tensor category.

A paragraph introducing welded knots: If knots have to do with the configuration space of some number of points, then welded knots have to do with the configuration space of some number of ‘flying rings’. Arrowed Jacobi diagrams will need to be introduced. Kashiwara-Vergne may need to be mentioned.

In Chapter 5, we generalise the result that Jacobi diagrams are a universal enveloping algebra to directed(/welded/arrowed) Jacobi diagrams.

Some paragraphs talking about the rest of the Chapters.

Vassiliev invariants and chord diagrams

VASSILIEV invariants are sophisticated to define in terms of the space of knots from the introduction, but the axiomatic definition of Birman-Lin [BL93] is much simpler. The definition also illustrates an analogy first made by Bar-Natan in [Bar95] in which Vassiliev invariants are “polynomial invariants”. This is not meant in the sense that Vassiliev invariants take values in a polynomial ring (like say, the Jones polynomial), but rather that Vassiliev invariants have special properties not shared by all invariants, just as polynomial functions have special properties not shared by all functions.

In the introduction below we loosely follow [BS97] and [Hut98].

1.1 Vassiliev Invariants

Definition 1.1.1 A **singular knot** is an immersion of S^1 into \mathbb{R}^3 which fails to be an embedding at finitely many singularities, and where the singularities are double-points and transverse. When a singular knot has m such singularities, we call it **m -singular**.

Remark 1.1.2 Knots with triple-points are excluded from this definition, despite also being immersions with singularities.

Any knot invariant, V can be extended to an invariant $V^{(m)}$ of m -singular knots by the Vassiliev skein relation

$$V^{(0)} = V \tag{1.1}$$

and

$$V^{(m+1)} \left(\begin{array}{c} \nearrow \searrow \\ \times \\ \swarrow \nwarrow \end{array} \right) = V^{(m)} \left(\begin{array}{c} \nearrow \nwarrow \\ \times \\ \swarrow \searrow \end{array} \right) - V^{(m)} \left(\begin{array}{c} \nwarrow \searrow \\ \times \\ \swarrow \nearrow \end{array} \right). \tag{1.2}$$

Definitions 1.1.3 (a) A knot invariant is a **Vassiliev invariant** of order (or type) if there is an integer m such that

$$V^{(m+1)} \left(\underbrace{\begin{array}{c} \nearrow \searrow \quad \dots \quad \nwarrow \swarrow \\ \times \quad \dots \quad \times \end{array}}_{m+1} \right) = 0.$$

(b) The **order** of a Vassiliev invariant V is the highest m such that V is a Vassiliev invariant of order m .

The order of a Vassiliev invariant is the highest number of double points a knot K can have without $V(K)$ having to vanish.

The Vassiliev skein relation is more often seen as

$$V \left(\begin{array}{c} \nearrow \searrow \\ \bullet \\ \nwarrow \nearrow \end{array} \right) = V \left(\begin{array}{c} \nearrow \nearrow \\ \nwarrow \nwarrow \end{array} \right) - V \left(\begin{array}{c} \nwarrow \nwarrow \\ \nearrow \nearrow \end{array} \right),$$

however equations (1.1) and (1.2) are reminiscent of the notation of the $(m + 1)$ st derivative of a function V . This is reflected in the substance of (1.2) too: V evaluated at a double point is the difference between V evaluated at two very close points in the space of knots.

Remark 1.1.4 Vassiliev invariants of order m are those that vanish after $m + 1$ derivatives, just like degree m polynomials.

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1.3 Third subsection

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Lie theory and Jacobi diagrams

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Jacobi diagrams as a universal enveloping algebra

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Welded knots and arrow diagrams

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Arrowed Jacobi diagrams as a universal enveloping algebra

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Expansions and associators

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6.2 Second section

6.3 Third subsection

Emergent knotting

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7.2 Second section

7.3 Third subsection

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Emergent welded associators

8.1 First subsection

8.2 Second section

8.3 Third subsection

References

- [Bar95] Dror Bar-Natan. “On the Vassiliev knot invariants”. In: *Topology* 34.2 (1995), pp. 423–472.
- [BL93] Joan S. Birman and Xiao-Song Lin. “Knot polynomials and Vassiliev’s invariants”. In: *Inventiones Mathematicae* 111.2 (1993), pp. 225–270.
- [BS97] Dror Bar-Natan and Alexander Stoimenow. *The Fundamental Theorem of Vassiliev Invariants*. 1997. arXiv: [q-alg/9702009](https://arxiv.org/abs/q-alg/9702009).
- [Hut98] Michael Hutchings. “Integration of Singular Braid Invariants and Graph Cohomology”. In: *Transactions of the American Mathematical Society* 350.5 (1998), pp. 1791–1809.
- [HV00] Vladimir Hinich and Arkady Vaintrob. “Cyclic operads and algebra of chord diagrams”. In: *Selecta Mathematica, New Series* 8 (May 2000).
- [Vas90] V. A. Vassiliev. In: *Cohomology of knot spaces*. Dec. 1990, pp. 23–70.