Hopf Module Algebras

Brandon Mather

UNT Master's

History

- (1939) Heinz Hopf works on homology of sphere groups
- (1969) Moss Sweedler writes seminal book "Hopf Algebras"
- (1986) Vladimir Drinfeld gives ICM address on quantum groups
- (1992) Susan Montogomery writes "Hopf Algebras and Their Actions on Rings"

Goal

To understand the actions of Hopf algebras on other algebras

Quantum Plane

Notation: $\mathbb{C}[v_1,\ldots,v_n]=\mathbb{C}\langle v_1,\ldots,v_n\mid v_jv_i-v_iv_j\rangle$

Quantum Polynomial Ring

Let $Q = (q_{ij})$ be an $n \times n$ matrix of roots of unity where

$$q_{ii}=1=q_{ji}q_{ij}.$$

A quantum polynomial ring is

$$\mathbb{C}_{Q}[v_{1},\ldots,v_{n}] = \mathbb{C}\left\langle v_{1},\ldots,v_{n} \mid v_{j}v_{i} - q_{ij}v_{i}v_{j}\right\rangle.$$

Example: $\mathbb{C}_{-1}[v_1, v_2] = \mathbb{C} \langle v_1, v_2 | v_1 v_2 + v_2 v_1 \rangle$

Motivation

• When a grp G acts on a space V over $\mathbb C$ linearly, the action can be extended to $V\otimes V$ by $g\in G$ acting as

$$g \otimes g = \triangle(g)$$
.

Then \triangle defines a coproduct map

$$\triangle: \mathbb{C}G \to \mathbb{C}G \otimes \mathbb{C}G.$$

For arbitrary coproducts, $\triangle: A \to A \otimes A$, we call $g \in A$ **grouplike** if $\triangle(g) = g \otimes g$.

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• When a Lie alg $\mathfrak g$ acts on a space V over $\mathbb C$, the action can be extended to $V\otimes V$ by $x\in\mathfrak g$ acting as

$$x \otimes 1 + 1 \otimes x = \triangle(x)$$
.

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$$\triangle: \mathfrak{g} \to \mathfrak{g} \otimes \mathfrak{g}.$$

For arbitrary coproducts, $\triangle: A \rightarrow A \otimes A$, we call $x \in A$ **primitive** if $\triangle(x) = x \otimes 1 + 1 \otimes x$.

Hopf algebras combine the notions of Algebras and Coalgebras that have coproducts. We are looking for actions of Hopf algebras. In particular on non-commutative algebras like Quantum Polynomial Rings.

The unique 4-dim'l non-commutative, non-cocommutative Hopf alg given by M. Sweedler (1969):

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Let τ be the 'flip' over the tensor product, so $\tau(u \otimes v) = v \otimes u$. Note that $\tau \circ \triangle(x) \neq \triangle(x)$, so H is non-cocommutative.

Actions of Sweedler's Algebra

$${\it H}_{4}$$
 acts on $\mathbb{C}_{-1}[{\it v}_{1},{\it v}_{2}]$ by

$$g \cdot v_1 = v_1, \ g \cdot v_2 = -v_2, \ x \cdot v_1 = 0, \ x \cdot v_2 = v_1.$$

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We can express this action on the generators as

$$g \mapsto \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}, \ x \mapsto \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}.$$

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$$H_8 =$$

$$\langle x, y, z \mid x^2 = y^2 = 1, xy = yx, zx = yz, zy = xz, z^2 = \frac{1}{2}(1+x+y-xy) \rangle$$

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Actions of Kac-Paljutkin Algebra

 H_8 acts on $\mathbb{C}_q[v_1,v_2]$ where $q^2=-1$ via the representation

$$x \mapsto \begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix} \quad y \mapsto \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \quad z \mapsto \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}.$$

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And on $\mathbb{C}_Q[v_1, v_2, v_3, v_4]$ for

$$q_{12}=q_{34}^{-1}, \;\; q_{13}=q_{24}^{-1}, \;\; q_{14}^2=1, \;\; q_{23}^2=-1$$
 via the rep

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with operations:

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Note: You can recover $\mathcal{U}(\mathfrak{sl}_2)$ by limiting $q \to 1$.

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so that the following commute:

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id \otimes \nabla \downarrow & & \downarrow \nabla \\
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\end{array}$$

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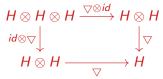
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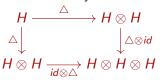
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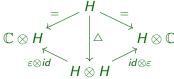
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Hopf Algebra Diagrams

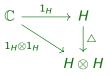
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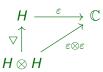
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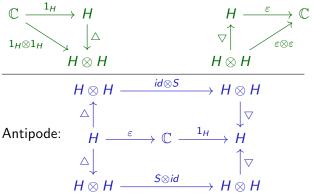


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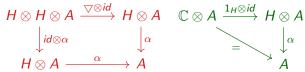
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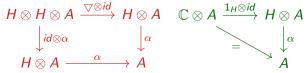


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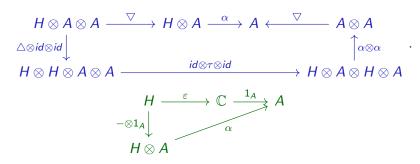
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In words, H acts on A iff you can multiply in H and then act on A or act on A consecutively, $\forall h, h' \in H, \forall a \in A$

$$(hh')(a) = h(h'(a)), \quad 1_H(a) = a.$$

And A is an H-module alg iff H acts on A and $\forall h \in H, \forall a, a' \in A$

$$h(aa') = \sum h_i(a) \cdot h_j(a), \quad h(1_A) = \varepsilon(h)1_A$$

where $\triangle(h) = \sum h_i \otimes h_j$.

Semidirect Product

Let G and G' be groups where G' acts on G by automorphisms, giving the semidirect product group, $G \rtimes G'$. The action can be extended to the group algebras:

$$\mathbb{C}(G \rtimes G') = \mathbb{C}G\#\mathbb{C}G'$$

with product g'g = g'(g)g'.

Smash Product Algebra

If H is a Hopf algebra and A an H-module algebra, then A#H is defined as $A\otimes H$ as a vector space and with product

$$(a'\otimes h)(a\otimes h')=\sum_i a'h_{i_1}(a)\otimes h_{i_2}h'$$

where $a \in A$, $h \in H$ and $\triangle(h) = \sum_i h_{i_1} \otimes h_{i_2}$.

Smash Product Algebra

"Group-like" and "Lie-like"

For Hopf alg H, define

$$G(H) = \{h \in H \mid \triangle(h) = h \otimes h\} = \text{grouplike elements}$$

which forms a group, and define

$$P(H) = \{h \in H \mid \triangle(h) = h \otimes 1 + 1 \otimes h\} = \text{primitive elements}$$

which forms a Lie alg.

Cartier-Kostant-Milnor-Moore Theorem

Let H be a cocommutative Hopf algebra over \mathbb{C} , then as Hopf algebras,

$$H \cong \mathcal{U}(P(H)) \# \mathbb{C}G(H)$$

Cor: Any cocomm, finite-dimn'l Hopf alg over $\mathbb C$ is iso to a grp alg.

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- Which Hopf Algebras act on AS-regular algebras?
- When are the invariant subrings from Hopf actions AS-Gorenstein?
- If H is semisimple and finite-dimensional, and A is semiprime, is A#H semiprime?
- If B is a Koszul algebra, are there nontrivial PBW deformations of $B\#\mathcal{U}_q(\mathfrak{sl}_2)$?