

A quantitative Hilbert's basis theorem and the constructive Krull dimension

Ryota Kuroki

Graduate School of Mathematical Sciences, The University of Tokyo
kuroki-ryota128@g.ecc.u-tokyo.ac.jp

Hilbert's basis theorem (HBT) is an important topic in constructive algebra. In exploring constructive versions of HBT, several definitions of Noetherian rings have been considered, including Richman–Seidenberg Noetherian rings [Ric74, Sei74, MRR88]. Among them, Jacobsson and Löfwall's one [JL91] and Coquand and Persson's one [CP99] are (generalized) inductive definitions.

In this talk, we quantify the inductive definition and define α -Noetherian rings as follows, where α is an ordinal (as a Cantor Normal Form):

1. A list $[x_0, \dots, x_{n-1}] \in \mathbf{List} A$ is called (-1) -good (or simply *good*) if $n \geq 1$ and $x_{n-1} \in \langle x_0, \dots, x_{n-2} \rangle$.
2. A list $[x_0, \dots, x_{n-1}] \in \mathbf{List} A$ is called α -good if for every $x \in A$, there exists $\beta \in [-1, \alpha)$ such that $[x_0, \dots, x_{n-1}, x]$ is β -good.
3. A ring A is called α -Noetherian if the empty list $[] \in \mathbf{List} A$ is α -good.

Discrete fields are 1-Noetherian and $\mathbb{Z}$ is ω -Noetherian. We obtain the following constructive and quantitative version of HBT: if A is α -Noetherian, $A[X]$ is $(\omega \otimes \alpha)$ -Noetherian, where $\otimes$ denotes the Hessenberg natural product.

Another important topic in constructive algebra is the Krull dimension. Lombardi [Lom02, Théorème 5] has obtained the following elementary characterization of the Krull dimension: $\mathbf{Kdim} A < n$ if and only if for all $x_0, \dots, x_{n-1} \in A$, there exist $e_0, \dots, e_{n-1} \geq 0$ such that

$$x_0^{e_0} \cdots x_{n-1}^{e_{n-1}} \in \langle x_0^{e_0+1}, x_0^{e_0} x_1^{e_1+1}, \dots, x_0^{e_0} \cdots x_{n-2}^{e_{n-2}} x_{n-1}^{e_{n-1}+1} \rangle.$$

This characterization can be used as a definition of the Krull dimension in constructive algebra [LQ15, Proposition XIII-2.8].

If a ring A is α -Noetherian for some $\alpha < \omega^n$, then $\mathbf{Kdim} A < n$ holds. Hence, the quantitative HBT gives an alternative constructive proof of $\mathbf{Kdim} K[X_0, \dots, X_{n-1}] < 1 + n$ and $\mathbf{Kdim} \mathbb{Z}[X_0, \dots, X_{n-1}] < 2 + n$, where K is a discrete field.

Our results have already been proved in classical mathematics [Gul73, Bro03]. Classically, a ring A is α -Noetherian for some $\alpha < \omega^n$ if and only if A is Noetherian and $\mathbf{Kdim} A < n$. We hope that the notion of α -Noetherian rings is useful for developing the constructive dimension theory of Noetherian rings.

References

- [Bro03] G. Brookfield. The length of Noetherian polynomial rings. *Comm. Algebra* 31(11):5591–5607, 2003.
- [CP99] T. Coquand, H. Persson. Gröbner bases in type theory. In: T. Altenkirch, B. Reus, W. Naraschewski, eds., *TYPES 1998: Types for Proofs and Programs*. Lecture Notes in Comput. Sci., 1657:33–46. Springer, 1999.
- [Gul73] T. H. Gulliksen. A theory of length for Noetherian modules. *J. Pure Appl. Algebra* 3(2):159–170, 1973.
- [JL91] C. Jacobsson, C. Löfwall. Standard bases for general coefficient rings and a new constructive proof of Hilbert’s basis theorem. *J. Symbolic Comput.* 12(3):337–371, 1991.
- [Lom02] H. Lombardi. Dimension de Krull, Nullstellensätze et évaluation dynamique. *Math. Z.* 242(1):23–46, 2002.
- [LQ15] H. Lombardi, C. Quitté. *Commutative Algebra: Constructive Methods*. (T. K. Roblot, trans.) Algebra and Applications, Vol. 20. Dordrecht, The Netherlands: Springer, 2015.
- [MRR88] R. Mines, F. Richman, W. Ruitenburg. *A course in constructive algebra*. Universitext. Springer-Verlag, New York, 1988.
- [Ric74] F. Richman. Constructive aspects of Noetherian rings. *Proc. Amer. Mat. Soc.* 44(2):436–441, 1974.
- [Sei74] A. Seidenberg. What is Noetherian? *Seminario Mat. e. Fis. di Milano* 44(1):55–61, 1974.