Table of contents of Bourbaki's

Elements of mathematics

assembled by Ulrich Thiel 1

Note. This table is incomplete in so far as it only contains the table of contents of a few books of the series. But all these tables are complete. Version from August 25, 2011.

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- [Bou72] Nicolas Bourbaki, *Commutative algebra. chapters 1 to 7.*, Elements of mathematics., Addison-Wesley Publishing Co., 1972, Translated from the French.
- [Bou73] _____, Algèbre. chapitre 8, Éléments de mathématique, Hermann, 1973, Réimpression inchangée de l'édition originale de 1958.
- [Bou89] _____, Algebra I. Chapters 1–3, Elements of mathematics, Springer, 1989, Translated from the 1970 French edition.
- [Bou90] _____, Algebra II. Chapters 4–7, Elements of mathematics, Springer, 1990, Translated from the 1981 French edition by P. M. Cohn and J. Howie.
- [Bou05] _____, Lie groups and Lie algebras. chapters 7-9, Elements of mathematics, Springer, 2005, English translation of Groupes et algèbre de Lie.
- [Bou07a] ______, Algèbre. chapitre 10, Éléments de mathématique, Springer, 2007, Réimpression inchangée de l'édition originale de 1980.
- [Bou07b] ______, Algèbre. chapitre 9, Éléments de mathématique, Springer, 2007, Réimpression inchangée de l'édition originale de 1959.