CONTEMPORARY MATHEMATICS

773

Commutative Algebra

150 Years with Roger and Sylvia Wiegand

Combined Proceedings:

Second International Meeting
Commutative Algebra and Related Areas (SIMCARA)
July 22–26, 2019
Universidade de São Paulo, São Carlos, Brazil

AMS Special Session
Commutative Algebra: In Celebration of the 150th Birthday
of Roger and Sylvia Wiegand
September 14–15, 2019
University of Wisconsin–Madison, Wisconsin

Nicholas R. Baeth
Thiago H. Freitas
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Contents

Two conferences

This volume contains the combined Proceedings of the Second International Meeting on Commutative Algebra and Related Areas (SIMCARA) in São Carlos, Brazil (July 2019), and the AMS Special Session on Commutative Algebra at the Fall Central Sectional Meeting of the AMS in Madison Wisconsin (September 2019). These two meetings celebrated the combined 150th birthday of Roger and Sylvia Wiegand. The Wiegands have been a fixture in the commutative algebra community, as well as the wider mathematical community, for over 40 years.

These Proceedings include 16 research articles from speakers or invited speakers at the conferences, in various areas of homological algebra, ideal theory, and representation theory. They include many areas to which the Wiegands themselves, or their students, have made contributions, such as homological rigidity, maximal Cohen-Macaulay modules, and the behavior of prime spectra under completion. They also touch upon the state of the art in related fields, such as local cohomology, Hilbert-Kunz functions, and magic squares.

The articles in this volume bear evidence that the area of commutative algebra is a vibrant one, and highlight the influence of the Wiegands on generations of researchers in the area.

The life and times of Roger and Sylvia Wiegand

This volume celebrates the mathematics and mathematical influence of Sylvia and Roger Wiegand, as well as their leadership in the mathematical community.

Roger and Sylvia on first ascent of Maparaju (17,474')
Cordillera Blanca, Peru, 1969.

From an early age, Sylvia was drawn to mathematics, desserts, and the outdoors. The daughter of analyst Laurence Chisholm Young and granddaughter of mathematicians Grace Chisholm and William Henry Young, who hobnobbed with the likes of Felix Klein and David Hilbert, she was introduced to mathematics at a young age. While in high school she completed coursework at the University of Wisconsin where her father taught. By that time she had earned renown for her still-famous "Sylvia brownies" which won her a blue ribbon at the Wisconsin State

Fair in 1956. Finishing her Bachelor's degree in mathematics in just three years at Bryn Mawr, she then earned a Master's from the University of Washington and her PhD in 1971 on *Galois Theory of Essential Extensions of Modules and Vanishing Tensor Powers* from the University of Wisconsin under the direction of Lawrence Levy. She has been a role model for women in mathematics for decades, fostering a supportive environment for faculty and students at the University of Nebraska and serving as president of the Association for Women in Mathematics 1997–1999. Sylvia is known for her brownies, her stylish bonnets, having run a marathon in each of the fifty states (most with multiplicity larger than one), her patient and supportive teaching, and a body of mathematical work that includes a forthcoming book (with Christel Rotthaus and William Heinzer) on power series over Noetherian rings.

Roger grew up outside of Chicago, surrounded by classical music — especially works for piano and organ, played by his father — and, as his father was one of its inventors, early versions of the electric guitar. When he wasn't learning to speak backwards by reversing the recordings made on early magnetic recording devices or building Tesla coils and disrupting the neighbors' television signals, he was rock climbing (from the age of 10), sometimes at night. After earning his Bachelor's in both mathematics and shenanigans at Princeton, Roger completed his doctoral work on *Sheaf Cohomology of Locally Compact Totally Disconnected Spaces* in 1967 from the University of Washington (taking the unusual path of writing a thesis and then choosing an advisor, Richard Pierce). A Willa Cather Emeritus Professor of Mathematics at Nebraska, Roger is known for his rock-climbing prowess (including first ascents in Colorado, Maine, Wisconsin, and Wyoming and multiple ascents of the Diamond on Long's Peak), his penchant for redefining words to match their 'true' definitions, teaching that inspires and stretches, and an impressive catalog of work including an AMS book (with Graham Leuschke) on maximal Cohen-Macaulay modules.

Sylvia and Roger met in 1964 when a busload of students from Bryn Mawr traveled to Princeton for a mixer. They hit it off right away, so much in fact that Sylvia was able to convince Roger to pause (only until the bus left Princeton, as it turned out) action on the herculean task of imbibing a case of beer in one day. They married in 1966, and Sylvia joined Roger in studies at the University of Washington. In 1967 the couple moved to Madison, where Roger joined the faculty and Sylvia began her PhD work at the University of Wisconsin. They started their careers together at Nebraska in 1972, and have helped transform the math department into a hub for commutative algebra. Their common affinity for all things math, mountains, food, wine, and travel have kept them globetrotting together, spreading commutative algebra across the world. The couple has a penchant for locating interesting parts of the world (nearly always with mountains nearby) and then finding future collaborators in these locales. They have organized numerous conferences on four continents, bringing together algebraists from across the globe. Together they helped to create an encouraging and nurturing environment for both new faculty and graduate students. In particular, they helped to make the Mathematics Department at the University of Nebraska the standard bearer for solving "two-body problems" and increasing the number of women graduate students and faculty. The cornerstone of social activities in both the NU math department and

the commutative algebra community, they have opened their home (commonly referred to as the 'party house') to literally thousands over the past several decades, including prospective graduate students who were encouraged to scale their stone chimney. The annual (since 1996) 'Bottle Smashing' event at their 'cabin' in Glen Haven, CO, is another example of their community building, bringing together anyone who (1) likes beer, (2) likes mountains, (3) knows the definition of a Gorenstein ring, or (4) knows someone who does, for a week of hiking, rock climbing, good food, and lively conversation, with a little bit of mathematics sprinkled throughout. Between them, the Wiegands have nearly 150 publications, 11 of them joint with each other. In addition to their 25 mathematical children and more than 10 grandstudents, Roger and Sylvia have two biological children, David and Andrea, and three grandchildren, Sam, Melanie, and Freya. For their significant contributions to mathematics research, they are well-deserving members of the inaugural class of AMS Fellows (2013). However, their legacy will be just as much about creating a sense of belonging among commutative algebraists, and in the mathematical community at large.

The mathematics of Sylvia and Roger Wiegand

Much of Sylvia's and Roger's early mathematical work, both collaborative and independent, was directly inspired by two problems raised by Irving Kaplansky in the 1950s:

(1) Characterize those partially ordered sets that are order-isomorphic to the prime spectrum of some Noetherian commutative ring.
(2) Characterize those (not necessarily Noetherian) commutative rings for which every finitely generated module is a direct sum of cyclic modules.

The first problem is still open (even when restricted to two-dimensional Noetherian domains), despite the best efforts of Mel Hochster, Louis Ratliff, Steve McAdam, the Wiegands, and others. In 1969 Hochster characterized, as a topological space, the poset structure of an arbitrary (not necessarily Noetherian) commutative ring. Roger and Sylvia made many contributions to partial solutions to the prime spectra of Noetherian commutative rings. Early on in her career, Sylvia showed in [**Wie75**] that every rooted tree is order isomorphic to the prime spectrum $\operatorname{Spec}(R)$ for some Bézout domain R with the localization $R_{\mathfrak{m}}$ a DVR for each maximal ideal $\mathfrak{m}$. Roger characterized the prime spectra of two-dimensional domains finitely generated over a finite field (or over the algebraic closure of a finite field) [**Wie78**] and showed that these spectra are all isomorphic (independent of the field). In [**Wie86**] he characterized the spectra of $\mathbb{Z}[X]$ and $D[X]$, where D is an order in an algebraic number field. Among other things, it follows from these results that, for a field k, $\operatorname{Spec}(k[X,Y])$ is order-isomorphic to $\operatorname{Spec}(\mathbb{Z}[X])$ if and only if k is contained in the algebraic closure of a finite field. Later, in [**HW89**], Sylvia, working with William Heinzer, gave a characterization of the prime spectrum of a polynomial ring $R[x]$ over a one-dimensional countable semilocal Noetherian domain R. Years later, in a mostly expository paper, [**WW10**], Roger and Sylvia summarized the state of affairs and motivated future research in the area, especially in terms of the open problems posed in [**Wie86**]. In addition, based on the work of Chandni Shah, they extended the main result of [**HW89**], allowing R to be a one-dimensional semilocal Noetherian domain of any cardinality.

Kaplansky's second problem, known as the FGC problem, was completely solved by 1976 through work of the Wiegands, their Nebraska colleagues Tom Shores and Jim Lewis, Willy Brandal, Peter Vamos and his student David Gill, and others (including Roger's PhD advisor Richard Pierce). The final characterization is given in a joint expository article by Roger and Sylvia [**WW77**]. The crux move of the solution was to show, in [**BW78**], that an FGC ring has only finitely many minimal primes, the proof of which uses "some heavy-duty point-set topology" [**WW10**]. This interplay between the module theory of the ring and the

topology (or poset structure) of its prime spectrum has been a unifying thread in Wiegand mathematics ever since.

The FGC problem naturally led the Wiegands to related questions about decompositions of modules, such as *bounded module type*: for which rings is there a global upper bound on the number of generators (or ranks) of indecomposables for some distinguished class of finitely generated modules? Together, separately, with their PhD students, and with others, Roger and Sylvia have worked on problems related to bounded module type. A case of central interest is that of torsion-free modules over a "ring-order", that is, a one-dimensional reduced Noetherian ring whose integral closure is a module-finite extension. In [**Wie89**, **Wie94**, **CWW95**] they gave the first complete proof that for local rings, certain conditions proposed by Drozd and Roiter in 1966 are necessary and sufficient for bounded torsion-free type. Indeed, bounded type is equivalent in this situation to *finite* type, that is, only finitely many indecomposable torsion-free modules up to isomorphism. Moreover, in a series of papers [**Wie88**, **CW91**, **WW94**] and subsequent joint work by their students, Roger and Sylvia gave a complete classification, in terms of their ranks, of the indecomposable finitely generated torsion-free modules over these rings. Students of Roger have also extended these results to include ring-orders with infinite representation type. Studying the interplay between matrices and finitely presented modules, Sylvia and Vamos [**VW11**] extended the work of Levy to show that matrices over certain Prüfer domains are equivalent to matrices with blocks of bounded size along the diagonal.

Studying the representation theory of one-dimensional rings naturally led Roger to study direct-sum decompositions of modules. His first forays into this area were to use the natural map from the Picard group of a ring to the Picard group of its integral closure to show that direct-sum cancellation rarely holds, even in well-behaved one- and two-dimensional domains that are finitely generated over a field, [**Wie84**]. Even when cancellation holds, say for finitely generated modules over local rings, direct-sum decompositions need not be unique (eg. [**Wie99**]). Along with Alberto Facchini and Dolors Herbera, Roger was one of the first proponents of studying direct-sum decompositions of modules by viewing the set of isomorphism classes of modules as a commutative monoid with operation induced by the direct sum. This approach simplifies the structure and allows the use of arithmetic tools from factorization theory to study direct-sum decompositions. In [**Wie01**] Roger showed how badly the Krull-Schmidt theorem fails for an R-module M by considering all factorizations in the monoid $+(M)$ of isomorphism classes of all direct summands of finite direct sums of M. Moreover, he gave a realization theorem showing that every finitely generated Krull monoid arises in this way. Roger's work since the 1990s has shown a more homological tendency, and he has worked extensively on vanishing (see [**CW15**]) of Tor/Ext and torsion in tensor products. His papers with Craig Huneke [**HW94**, **HW97**] reignited interest in Auslander's work from the 1960s, studying torsion in tensor products and the rigidity of Tor and Ext. Roger finally believes in the derived category, but only because it gives him a chance to bellow 'RHom!'. His 2012 book *Cohen-Macaulay Representations* [**LW12**] (with PhD student Graham Leuschke) touches on many facets of his work over the years; from classifying rings with finite representation type to describing non-unique direct-sum decompositions, and beyond.

Sylvia's interest in the structure of prime spectra has led her to work with students and with frequent collaborators Heinzer and Rotthaus on the behavior of prime ideals in ring extensions (eg. [**HLW94**, **HLW95**]), on spectra of mixed polynomial/power series rings [**HRW06b**], on the structure of generic fibers of extensions of domains [**HRW07**, **HRW06a**], and on constructing examples. The culmination of their joint work is the any-day-now monograph *Integral domains inside Noetherian power series rings: Constructions and examples* [**HRW21**], written with Heinzer and Rotthaus. This book provides techniques that can be used to build examples using power series to answer the questions "What rings lie between a Noetherian domain and its field of fractions?" and "What rings lie between a Noetherian domain and an ideal-adic completion?" The book continues the tradition of finding pathological examples in ring theory, going back to Akizuki and Schmidt in the 30s, and reaches the limits of what is currently known, or possibly will be known, by the time it comes out.

Their mathematical contributions far exceed what we have summarized here. Officially retired since 2011, Roger and Sylvia continue to produce new and interesting mathematics and to serve the mathematical community. A decade of retirement has, if anything, given them more time to devote to travelling to conferences, editing journals, and collaborating and writing papers with mathematicians across the globe. They show no signs of slowing down. Individually and together, they have contributed much to the mathematical community over their combined more than 150 years. And so, on behalf of the mathematics community, we say: Thank you Sylvia. Thank you Roger. Thank you Roger and Sylvia.

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