Remembering Georgia Benkart

Alejandro Adem, Tom Halverson, Arun Ram, and Efim Zelmanov

Georgia Benkart passed away unexpectedly in Madison, Wisconsin, on April 29, 2022. Georgia earned her BA from Ohio State University and her PhD in 1974 from Yale University under Nathan Jacobson. She was a profoundly influential scholar and leader in the fields of Lie theory, representation theory, combinatorics, and noncommutative algebra. She spent her career at UW–Madison, where she was the second woman to join the department and the second to earn tenure. At the time of Georgia's retirement in 2006, she was the E. B. Van Vleck Professor of Mathematics. Georgia is survived by her sister, Paula Benkart, who also attended Ohio State University and earned a PhD in History from Johns Hopkins University in 1975.

Georgia was an inspiring teacher, the advisor to 22 PhD students, and a mentor to scores of mathematicians around the world. She published more than 130 articles and research monographs and gave more than 350 invited talks, including plenary lectures at AMS meetings, the AWM Noether Lecture at the Joint Mathematics Meetings, and the Emmy Noether Lecture at the International Congress of Mathematicians. Her lectures were works of art. Without fail they were accessible to nonexperts, told a compelling and creative story, delighted her audiences with literary allusions and puns, and invited everyone into the fun.

Figure 1. Georgia Benkart at the graduation of her PhD student, Dongho Moon, on May 15, 1998.

Georgia's service to the mathematical profession is legendary. After retiring from teaching in 2006, she continued an active research program in which she published nearly 40 papers. At the same time, she focused her attention on service to her professional societies. She was

Alejandro Adem is a professor of mathematics at the University of British Columbia. His email address is adem@math.ubc.ca.
Tom Halverson is a professor of mathematics at Macalester College. His email address is halverson@macalester.edu.
Arun Ram is a professor of mathematics at the University of Melbourne. His email address is aram@unimelb.edu.au.
Efim Zelmanov is a professor of mathematics at the University of California, San Diego. His email address is ezelmanov@ucsd.edu.

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president of the Association for Women in Mathematics and an associate secretary for the American Mathematical Society. In fact, she was the lead organizer of the 2020, 2021 and 2022 Joint Math Meetings, the last of which took place online just three weeks before her death.

However, Georgia's most meaningful and enduring impact on our community lies outside of what is found in her impressive CV. It is about the people whose lives she changed. She was a pioneer in building research collaborations, starting when she worked with teams of graduate students and continuing with the many research networks that she built among early-career women mathematicians.

A recent article in March 2022 *Notices*, "Gems from the Work of Georgia Benkart," profiles her mathematical work. We are enormously pleased that she was able to see this before her death. In this memoriam, we have asked several of her colleagues and collaborators to describe their experiences working with her. In our opinion, this is the best way to know our friend, Georgia Benkart.

Sheila Sundaram

I met Georgia in May of 1988, while I was a postdoc at the University of Michigan. Georgia had invited me to speak at a conference on Lie Algebras in Madison. As a recent PhD, I was overwhelmed by the distinguished list of other speakers, but Georgia's warm welcome and kindness helped to put me at ease.

Perhaps this marked the start of Georgia's interest in the work of the algebraic combinatorics community, from papers of Phil Hanlon, Bob Proctor, and John Stembridge. Indeed she initiated a long and fruitful research programme with her subsequent students and postdocs, investigating, for example, analogues of Cauchy identities and other classical character formulas due to Littlewood for the orthosymplectic Lie superalgebras, and developing the use of Robinson–Schensted analogues and jeu de taquin techniques in the representation theory of Lie algebras. A short list of my personal favorites among her papers that might serve as an introduction to Georgia's work for algebraic combinatorialists is: [BCH+94, BSR98, BR98, DG13].

Our paths crossed on a few occasions in the ensuing years. A particular highlight is a lunch we had at Yale with another legendary figure, Walter Feit, whom I would never have met were it not for Georgia. I had recently moved to Connecticut, beginning what was to be a long absence from academia. Some time later she took the trouble to reach out to me about a paper of mine. Personal circumstances had prevented me from submitting the final version; having just taken over as editor, she had found it in the files of the journal. Eventually I returned to doing mathematics, and wrote to her again. Almost two decades

Figure 2. Alberto Elduque and Georgia Benkart, in Asturias (Spain) in 1994.

had passed, and I was not sure she would remember me. I was astonished when she immediately wrote back, saying, among other things, that she had found the whole thread of the correspondence regarding my paper. She was solicitous and encouraging about my new mathematical endeavors, making it a point to attend a talk I gave at an AMS Special Session in Bloomington.

Georgia's mathematical legacy is of course legend. It is a source of comfort to me that she lived to read the beautiful tribute to her work by Tom Halverson and Arun Ram, which appeared in the March 2022 issue of the *Notices*. Most recently I saw her in November of 2021, during the virtual Northeast Women in Algebra and Combinatorics Conference, on the occasion of the 50th anniversary of the AWM. There, technical difficulties with Zoom notwithstanding, she gave an absolutely captivating talk on MacKay quivers, Schur–Weyl duality, and the rich interplay of algebra and combinatorics. (The slides are available online at `https://www.albany.edu/~sdc/AWM21/Georgia.awm50.pdf`, see Figure 8.) She had clearly taken great pains to make her "walking talk," as she called it, broadly accessible, and the delivery is interspersed with sly puns and subtle humor, both in words and graphics.

Georgia helped launch and establish the careers of countless young mathematicians. Her many collaborations are a testament to her dedication to sharing her passion and knowledge of mathematics. The loss to our community is indescribable. Those who knew her personally are left with deep sorrow, but also lasting memories of her extraordinary kindness, and her desire to help others advance in the profession.

Arturo Pianzola

Grace, Generosity, Kindness. We all know what these words mean, but just like in mathematics where there is a difference between understanding a proof and seeing the result behind it, knowing the meaning of these words is not the same as feeling them. If you were fortunate enough to have Georgia Benkart be part of your life, you certainly felt these words.

Georgia was the external examiner for my PhD. For some reason that I cannot explain, we remained close ever since. It is not that we saw each other on a regular basis, but whenever we did meet, we always found time for each other. You could vividly sense that she needed to know that you were doing fine. Whatever struggles or challenges you were facing, just talking to her had a soothing effect.

Her generosity and desire to help and serve was exemplary. A few years ago, even though she was overwhelmed with requests, she agreed to act as the main external reviewer of our mathematics department. She took the time to talk to students and support staff and left a lasting impression on them. The final recommendations of the report provided insightful guidance. It was not a "generic" document, but one that was written with care and a desire to force us to reflect. This was her style. To convince people, at times without them even noticing it, that they have the ability to be better.

We had an inordinate number of meaningful coincidences, like unknowingly working on the same mathematical problems for completely different reasons. Sometimes these coincides were simply hilarious. Georgia had invited me to Madison and had booked a special reservation at a Japanese restaurant (my favorite food). Upon looking at the menu, the following exchange took place:

- (me) Right on! Yellowtail and take me to jail, baby!
- (Georgia, with a mixture of perplexity and her unmistakable laughter) What?
- I love yellowtail, Georgia. Anyways. It is a long story. The expression comes from a live performance by Ben Sidran, an American jazz piano player. As you know, I think that Jazz is the greatest contribution that America has made to the arts.
- Ben Sidran?
- Yes. Have you heard of him?
- He is in my yoga class!

The next time I saw her, more than one year later. We went for coffee, and she said, "I got you a little something." It was an autographed copy of a book that Sidran had written. Great book. I am reading it again and when I hold it in my hands, I know that it was also in hers at one point, and I let my mind wander through the times we spent together.

In a play where any part of the script can be rewritten except for the ending, fond memories are a valuable currency. You've blissfully touched so many lives, Georgia, and will always be remembered. You were never meant to be gone, but rather just not to be around any longer. You will be missed. Until we meet again.

Figure 3. Zongzhu Lin, Georgia Benkart, Brian Parshall, Jens Carsten Jantzen, Daniel Nakano, James Humphreys; Representations of Algebraic Groups, Quantum Groups, and Lie Algebras: AMS-IMS-SIAM Joint Summer Research Conference, July 11–15, 2004, Snowbird, Utah.

Ruth Charney

Reading through tributes to Georgia from her colleagues, former students, and friends, one cannot help but be impressed by the impact she had through her research, her mentorship, and her collegiality. In this note, I would like to focus on another aspect of her life's work, namely her contributions to the profession through her involvement in professional societies.

Georgia retired from her academic job at the University of Wisconsin–Madison, in 2006. Far from gearing down her involvement in mathematics, she continued full speed ahead on her research (publishing nearly 40 papers post-retirement) and turned her attention to advancing the profession through service with professional societies. In 2009, she became president of the Association for Women in Mathematics (AWM). This is an organization with a small staff and limited budget that is highly dependent on volunteers. As described in a recent issue of the *AWM Newsletter*, her accomplishments as president

Arturo Pianzola is a professor in the department of mathematical and statistical sciences at the University of Alberta. His email address is a.pianzola@ualberta.ca.

Ruth Charney is Theodore and Evelyn Berenson Professor of Mathematics at Brandeis University. Her email address is charney@brandeis.edu.

over the next two years were extensive. They culminated in a spectacular conference celebrating AWM's 40th anniversary, "40 Years and Counting: AWM's Celebration of Women in Mathematics." This was the first in what subsequently became a biannual series of AWM Research Symposia. After her term as president ended, she continued her involvement in AWM. In 2015, AWM initiated an NSF-funded program of Research Collaboration Conferences for Women, designed to promote collaborative research projects and create research-based networks. Georgia was one of the first to organize such a workshop, the WINART1 (Women in Noncommutative Algebra and Representation Theory) workshop. With Georgia's help, this network has continued to grow and to thrive. The most recent workshop, WINART3, took place in April 2022.

In 2010, Georgia agreed to serve as an associate secretary for the American Mathematical Society (AMS). The AMS has four associate secretaries, one for each geographic section, whose primary responsibility is to oversee the scientific meetings of the Society. In the case of sectional meetings, that includes approving proposals for special sessions, screening abstracts, and inviting speakers for named lectureships. In addition to organizing two sectional meetings per year, the responsibility for organizing the annual Joint Mathematics Meetings (JMM), as well as yearly international meetings, rotates among the four associate secretaries. Associate secretaries work largely behind the scenes, so most people are not aware of the important role they play in planning and implementing successful meetings. Georgia was the associate secretary for the Central Section which spans a large region of the US and Canada, north to south from Manitoba to Texas, east to west from Ohio to Nebraska.

As a highly respected member of the community, Georgia was able to recruit top-notch speakers and session organizers for these meetings. In addition, she was instrumental in engaging the Portuguese and European Math Societies to hold a joint international meeting with the AMS in 2015. Most importantly, she served as the primary organizer for four JMMs, including the most recent one, JMM2022. In the past, the AMS has shared responsibility for these meetings with the Mathematical Association of America (MAA). The 2022 JMM, scheduled to take place in Seattle in January, was the first "JMM reimagined" in which the AMS took over as primary organizer. This required considerably more work for the associate secretary in charge. Then, at the last minute, the meeting in Seattle was cancelled due to concerns about the pandemic, and it was rescheduled as a remote meeting to be held in April. This resulted in a whole new set of challenges for the organizers. Georgia, as usual, took the reins with confidence and guided the transition smoothly. Sadly, though none of us knew it, by the time the JMM took place in April, she was suffering the effects of her cancer and she died just three weeks later.

In addition to her work with AWM and AMS, Georgia served on multiple other committees including the National Academy's US National Committee for Mathematics (2013–2020) and the Board of Trustees of the Mathematical Sciences Research Institute (2011–2022), as well as the editorial boards of several journals. Viewed from the outside, Georgia's service contributions are indeed impressive. She was extremely good at her job, highly organized and methodical, and made sure everything got done as planned. Seen from the inside, by those who worked directly with her, she was humble, kind, and treated everyone with the greatest respect. She also had a delightful sense of humor and brought a sense of joy to her work. So many remembrances comment on what a pleasure it was to work with her.

For me, Georgia will always be a role model—for her devotion to research, to service, and to mentorship, and for her unfailing ability to welcome everyone with an outstretched hand and a smile. I know that many of you feel the same.

Figure 4. WINART2 (Women In Noncommutative Algebra and Representation Theory 2), Leeds 2019.

Ellen Kirkman

Georgia Benkart was an extraordinary model for excellence in research, exposition, communication, service to the community, and expanding participation in the mathematical community that she loved.

An Extraordinary Communicator

Georgia and I worked in different research areas of algebra, and I first knew of Georgia from her beautifully

Ellen Kirkman is a professor of mathematics at Wake Forest University. Her email address is kirkman@wfu.edu.

constructed invited lectures that were understandable to wide audiences. She was an MAA Pólya Lecturer (2000–2002), an AWM-AMS Noether Lecturer (2014), and an ICM Noether Lecturer (2014). She visited Wake Forest University in 1994–1995 as our tenth Gentry Lecturer, giving a lecture aimed at a general audience: "Life in the Aftermath—The World Beyond the Symmetric Group" and a more specialized talk: "Commuting Actions—A Tale of Two Groups" (on one of her favorite topics, Schur–Weyl duality!). There was usually a pun or a literary reference; "A Tale of Two Groups" began: "It was the best of times, it was the worst of times." Her papers were carefully constructed so that a novice could gain admission to some lovely mathematics. Both her lectures and her papers appeared so polished because she worked intently on every detail.

A Prolific Researcher

Georgia wrote over 130 research publications, with over a hundred collaborators, spanning a wide variety of research areas. Her paper [BR98] on down-up algebras (with almost 100 citations) was constructed from her point of view of generalizing the representation theory of $U(\mathfrak{sl}_2)$, but the graded down-up algebras provide examples unexpected by their original context: to those studying noncommutative algebra and algebraic geometry they are a convenient family of examples of Artin–Schelter regular algebras of global dimension three, generated by two elements, with two cubic relations, in contrast to the other family of Artin–Schelter regular algebras of global dimension three (including commutative polynomial rings in three indeterminates) that are generated by three elements with three quadratic relations.

Georgia was always exploring new areas of research. Our work with the WINART groups arose because Georgia wanted to learn more about Hopf algebra actions. Georgia told me that one reason that she retired early was so that she would have younger colleagues who could expand her mathematics.

A Facilitator of Research Collaborations

Georgia was one of the organizers of the "Connections for Women Workshop," held during the MSRI semester "Noncommutative Algebraic Geometry and Representation Theory" in 2013. When Chelsea Walton started WINART (Women In Noncommutative Algebra and Representation Theory), Georgia was one of the co-organizers as she had experience with similar collaboration conferences for women including Algebraic Combinatorixx (May 2011) and Algebraic Combinatorixx2 (May 2017).

The first WINART conference was held at BIRS in May 2017. Forty-eight women were divided into eight research groups and spent the week working on research projects that generally continued following the conference. Georgia and Rosa Orellana led a WINART1 group "Diagram algebras, tensor invariants, representation theory." Georgia was a co-organizer of WINART2, and she and I led a WINART2 group "Tensor invariants under Hopf algebra actions," at the University of Leeds in May 2019. Before most virtual meetings Georgia would send TeXed notes that outlined clearly where we were in the project. This group produced two papers [BBK+22a, BBK+22b]. With Georgia's encouragement to apply for further opportunities to work together, we received offers to continue our research at both MSRI and IAS in summer 2020. Unfortunately COVID interrupted these plans, but we continued meeting virtually every week. Three members of the WINART2 group met at IAS for two weeks in June 2022 under their Summer Collaborators program. Georgia was to be part of this group and she was very much missed.

Preparations for WINART3 began in 2021, and Georgia and I again led a collaboration group that met weekly in 2022. As Georgia was the AMS associate secretary in charge of the Joint Mathematics Meetings, she was able to meet with us only virtually. This time our topic was "Verlinde-type formulae for fusion coefficients." Our work on this exciting project continues.

Georgia was an encouraging mentor to me, personally, and to all the women in our groups. Her enthusiasm for mathematics was infectious. She provided expert mathematical and professional advice, was incredibly patient as we made mistakes, and wrote countless letters of recommendation. Even when intensely busy in her role as an AMS associate secretary, Georgia would somehow magically appear at the AMS session when one of our group members spoke. Georgia was a kind, gentle, warm, brilliant, humble, and generous person, with a wonderful sense of humor and much common sense. Her commitment to equity, diversity, and inclusion was clear.

So Much Service to the Profession!

Georgia provided service to the profession in many different ways. She was a longtime member of MSRI's Board of Trustees and Committee on Women in Mathematics, the Scientific Advisory Board of the American Institute of Mathematics, an AMS associate secretary, a president of the Association for Women in Mathematics, and she served on a number of editorial boards. From 2015–2016 Georgia agreed to be a member of a three-person external evaluating committee for my department's program review, a task I knew she had performed for several other universities. Typical of Georgia's many service activities, the carefully written review was helpful to the department as it advocated for new tenure track positions, and it was

supportive of the department's efforts in teaching and research.

Georgia Benkart, extraordinary model.

Figure 5. Eleanor and Frank Lemire, Dan and Susan Britten, Paula and Georgia Benkart; dinner at the Benkart's during the 2002 AMS meeting in Madison.

Rolf Farnsteiner

During the academic year 1987–1988 Georgia Benkart and Marshall Osborn organized a Special Year on algebraic Lie theory in Madison. They had obtained NSF funding to invite long-term visitors and to host several meetings. This was a good time for such an undertaking: Richard Block and Robert Wilson had just completed the classification of the restricted simple Lie algebras, there were interesting developments concerning certain infinite-dimensional Lie algebras, the so-called Kac–Moody algebras, and, by work of Friedlander-Parshall and Jantzen, the geometric approach to the representation theory of restricted Lie algebras, first set forth by Jon Carlson in the context of finite groups, had emerged as a powerful tool.

Having the privilege of being a long-term visitor, I got a closer look at Georgia as a researcher and teacher. I had met her before at conferences and heard of her even earlier, but I had not witnessed her interaction with her students and colleagues to such an extent. Her warm personality greatly facilitated the collaboration of her various guests. She valued informal discussions and organized a number of social gatherings that included her local colleagues working in group theory and ring theory. I have fond memories of our weekly tennis matches and, like many others, I enjoyed her great sense of humor. All of this was part of her leadership and guidance that proved to be very effective and in my opinion was key to the success of the Special Year.

During the Special Year the classification of the finite-dimensional simple Lie algebras over algebraically closed fields of characteristic $p>0$ was the main focal point. This was a long-standing problem, whose inception is often dated back to Witt's 1937 discovery of a nonclassical simple Lie algebra. The challenges involving the classification were perhaps best described by George Seligman, one of Georgia's mentors at Yale, in his 1967 monograph: "It is not simply the case that new methods must be found to establish analogues of the theorems for characteristic zero, but rather that almost the only analogues which remain true (with the same degree of generality) are those whose traditional proofs turn out to have been independent of the characteristic anyway."

In their above mentioned work, Block and Wilson had overcome these obstacles in the context of those simple Lie algebras $\mathfrak{g}$ over an algebraically closed field of characteristic $p>7$ that afford a p-th power operator $x \mapsto x^{[p]}$ that enjoys the formal properties of taking p-th powers of square matrices. This self map turned out to be of major importance and even though at the time many simple nonrestricted Lie algebras were known and a conjecture was formulated, it appeared that the relevance of George Seligman's comments had resurfaced on a different level.

There were, however, initial results indicating the validity of the generalized Kostrikin–Shafarevich conjecture, which stated that simple Lie algebras over algebraically closed fields of sufficiently large characteristic $p > 0$ are either classical or of Cartan type. Building on earlier work by Kaplansky, Ermolaev, and Block, Georgia Benkart and Marshall Osborn had shown in their 1984 *Annals* article that the conjecture was true for simple Lie algebras having a one-dimensional Cartan subalgebra in the cases $p>7$. In their technically sophisticated paper, Benkart and Osborn showed that, aside from $\mathfrak{sl}(2)$, only the so-called Albert–Zassenhaus Lie algebras can occur. During the Special Year, Georgia and Marshall, partly in collaboration with Helmut Strade, made further significant contributions which paved the way for the announcement of the proof of the conjecture by Strade and Wilson a few years later.

One important milestone in the classification was Kac's Recognition Theorem from 1970. This result, which gives technical conditions ensuring that a Lie algebra is classical or of Cartan type, was widely used even though its proof contained some inaccuracies. Together with Tom Gregory, Georgia started in 1987 a long-term project which aimed at providing a complete proof of Kac's Theorem. First results, which improved the theorem by showing that one of its conditions was redundant, were published by them in 1989. It took another 20 years until the entire story was told in a monograph by Benkart–Gregory–Premet. The publication of this work in my opinion represents a great service to the community and exemplifies Georgia's attention to details, clarity, and accuracy that was a hallmark of her work in general.

The foregoing remarks do by no means adequately reflect the breadth of Georgia's interests and contributions. Aside from her list of publications, a quick glance at the topics of the 22 PhD theses written under her guidance provides a good impression of Georgia's sharing her broad expertise with the mathematicians of the generations following her. Moreover, not only her students have benefitted from her captivating lectures and the clarity of her exposition.

Figure 6. Left to right: Alberto Elduque, Consuelo Martínez, Georgia Benkart, and Santos González, in Zurich, on the occasion of the ICM in 1994.

Alberto Elduque

I had the good fortune to meet Georgia Benkart during my first mathematical workshop, near Boston, in 1983. I was a first-year graduate student, it was the first time I had crossed the Atlantic, and I was excited and nervous about the possibility of meeting mathematicians from different places around the world. I vividly remember how impressed I was after Georgia's beautiful talk, so carefully prepared, with the right pace, some puns here and there, deep mathematics,... I was absolutely fascinated. There I had the model to follow. I never told her how much she had impressed me and had influenced and strengthened my desire to become a mathematician.

After that initial encounter, we continued to be in touch, and met either at workshops, or in short visits either of mine to Madison, or hers to Spain. She once wrote to me "Zaragoza is one of my favorite places." And certainly she enjoyed visiting Spain, and not just mathematically, as can be seen in Figure 2. Our mathematical collaboration started during the academic year 2000–2001. I was on sabbatical leave and asked her about the possibility of spending it at the University of Wisconsin. She was very supportive from the beginning and, together with Marshall Osborn, helped me and my wife and daughter, who was ten years old at that time, to settle smoothly in Madison. When we arrived, she had even put flowers in our apartment and bought us food. This care for the details, both in mathematics and otherwise, was one of her wonderful characteristics.

I cannot explain in a few words how much I enjoyed doing mathematics with Georgia throughout that year, benefiting from her insight, her advice, and her brilliant questions, which forced me to think deeper and deeper. She had been working with Efim Zelmanov [BZ96] on the description of Lie algebras graded by non-simply-laced root systems, following the work for simply-laced root systems initiated by Berman and Moody [BM92]. The clue to understand these Lie algebras is a construction, due to Tits [Tit62] that relates Lie and Jordan algebras. During that year we tackled the analogous problem for Lie superalgebras.

I would like to share with the readers one "aha" moment that Georgia and I enjoyed together, motivated by her ability to ask the right questions. It was during the spring of 2001. Georgia had many students and visitors, so we had fixed a weekly one-hour meeting. In one of these meetings we had just finished successfully some computations that we needed and we were relaxed talking about different things. The conversation turned to the exceptional basic classical simple Lie superalgebras $D(2,1;\alpha)$ of dimension 17, $G(3)$ of dimension 31, and $F(4)$ of dimension 40. The classification by Victor Kac [Kac77] of the finite-dimensional simple Jordan superalgebras over algebraically closed fields of characteristic 0 was based on the famous Tits–Kantor–Koecher (TKK) construction of a Lie algebra starting from a Jordan algebra.

Kac used his former classification of Lie superalgebras to check which of them are 3-graded as above, and to conclude from there the classification of the simple finite-dimensional Jordan superalgebras. Among these there is a family of 4-dimensional Jordan superalgebras related to the Lie superalgebras $D(2,1;\alpha)$ and a mysterious 10-dimensional Jordan superalgebra, nowadays known as Kac superalgebra K_{10}, related to $F(4)$. Kac gave a multiplication table for this exceptional object. No direct proof that this was indeed a Jordan superalgebra, other than through its connection with $F(4)$, was known. Well, as usual, Georgia started to ask natural and interesting questions: *what does the structure Lie superalgebra of* K_{10} (that is, the homogeneous component $\mathcal{L}_0$ above) *look like?, and the Lie algebra of derivations?* A few easy mental computations with the dimension of the subspaces that appear inside $F(4)$ convinced us that this structure Lie superalgebra had to be the orthosymplectic Lie superalgebra $\mathfrak{osp}(2,4)$, and the Lie algebra of derivations should be the direct sum of two copies of $\mathfrak{osp}(1,2)$. The next question Georgia asked was: *and*

then, what is the structure of K_{10} as a module for its derivation algebra? And at that point we looked at each other realizing at once that this was the clue! The Jordan superalgebra K_{10} had to be the direct sum of a trivial 1-dimensional module spanned by the unit element, plus the tensor product of the 3-dimensional irreducible module for each of the two copies of $\mathfrak{osp}(1,2)$. But this module is the so called "tiny Kaplansky superalgebra" K_3, related to $\mathfrak{psl}(2,2)$ by TKK. Therefore, we must have $K_{10} = \mathbb{F}1 \oplus (K_3 \otimes K_3)$ [BE02]. Of course, there was some extra technical work to do, but we both knew that the multiplication in K_{10} was essentially determined from this decomposition, something we completed in the next few days.

Some years later, in 2014, my daughter returned to Madison, but this time as a new math graduate student at the University of Wisconsin. The last time I met Georgia in person was on the occasion of my daughter's doctoral thesis defense in 2019. Georgia had retired from teaching some years ago, but she continued to be very active in research and service, and we had the opportunity to talk about some mathematical problems. She was planning to attend, as an invited speaker, a conference on Nonassociative Algebras organized in Coimbra (Portugal) in 2020, to celebrate my 60th birthday. The pandemic forced the conference to be postponed to July 2022. At the meeting we all remembered her, we all missed her.

Konstantina Christodoulopoulou

Georgia was a great mentor and an inspiration not just to me but to many mathematicians. I became aware of her work as an undergraduate student at the University of Athens in Greece and during my first semester as a graduate student at UW–Madison I took her representation theory course. That course was an unforgettable experience; not only did it provide me with a strong background in Lie theory but it also revealed its beauty and complexity, and inspired me to work in that area.

I was truly lucky to have had Georgia as my PhD advisor. We met almost every week for three years and I am grateful for her patience and gentle guidance! I am also grateful for the semesters that Georgia provided me with a research assistantship that made it possible for me to concentrate on my research.

Georgia's wisdom, generosity, kindness, and humor will always stand out to me as I think back to graduate school. After I graduated, Georgia continued to support me and advise me as I navigated life after graduate school. I will always be indebted to Georgia for her encouragement, guidance, and inspiration.

Konstantina Christodoulopoulou is an associate instructional professor and undergraduate coordinator at the University of Florida. Her email address is kchristod@ufl.edu.

Sarah Witherspoon

Georgia was my postdoctoral mentor at the University of Wisconsin twenty-some years ago. I had first met her when I was a PhD student working in group theory under Jon Alperin. At that time, Georgia was writing a paper in combinatorics with my husband Frank Sottile, also a student. I could count on one hand then the senior women mathematicians I knew of in my research area or a closely related field. Georgia was one of them, and an important role model. She was an inspiring speaker, presenting mathematics in beautiful diagrams and pictures, keeping it as simple as possible, with many jokes and puns. She was an exceptional mentor to many young mathematicians, with a resulting impact on mathematics that goes far beyond the excellent research she personally contributed.

I first benefited from Georgia's enthusiastic welcome of all young mathematicians shortly after I had graduated and was at an AMS sectional meeting for a special session. The topic was Hopf algebras, which arose in my PhD thesis but was only tangential to the group theory community I had gotten to know as a student. I felt a stranger to this new community and I was desperate to be a part of it. Georgia remembered me and reached out to make sure I was invited to join others for meals. A few years later, when my tenure track job search was not going well and I was pregnant with my first child, Georgia pushed for Van Vleck Assistant Professorships for both Frank and me at the University of Wisconsin. This was a fantastic opportunity for both of us to join the vibrant culture there in algebra and combinatorics, with many students and postdocs and seminars and teas. Much activity centered on Georgia and her research group.

Georgia greatly influenced my career over the course of many years. My time in Madison was a very uncertain one for me due to new parenting responsibilities. Georgia expressed confidence in me as a mathematician and pushed me gently to begin and to keep working on a joint project she suggested, on down-up algebras. These are algebras that are defined combinatorially and are connected to Hopf algebras and quantum groups—rings that not only have a multiplication but also a dual structure called a comultiplication. Quantum groups arose in mathematical physics and representation theory, and down-up algebras can be viewed as subalgebras of some quantum groups in a natural way. In our regular meetings on

Sarah Witherspoon is a professor and head of the department of mathematics at Texas A&M University. Her email address is sjw@math.tamu.edu.

down-up algebras and beyond, Georgia was always full of ideas and questions, probing for what I could best learn and contribute, facilitating mathematical and professional growth.

Georgia and I continued collaborating long after I moved on to jobs elsewhere, providing important encouragement during my second pregnancy as well. She mentored me through my first PhD student, Mariana Pereira, whose thesis grew out of ideas from my ongoing research collaboration with Georgia. In fact the three of us have a joint publication on representations of quantum groups, research that was primarily carried out during a semester that we all spent at the Mathematical Sciences Research Institute.

Over the many years since, I continued to see Georgia at conferences, and would sometimes visit her in Madison. She was always warmly welcoming, often opening the doors of her and her sister Paula's house to current and former students and postdocs, of whom there were many, and we would enjoy the excellent food and company and conversation with Paula and Georgia.

In recent years, I often saw her at AMS meetings where she was in charge as associate secretary for the AMS Central Section. There she would calmly deal with any number of issues that came up, and pop in and out of special sessions as time permitted. I am honored and proud to have known Georgia as a mentor, as a collaborator, and as a friend. Her impact on mathematics and on many mathematicians is immeasurable and enduring.

Figure 7. Pandemic working smiles: Shraddha Srivastava, Rosa Orellana, Elizabeth Manosalva, Georgia Benkart on August 6, 2021.

Efim Zelmanov

On February 19, 1992 I entered the USA with my family and a green card and proceeded to Madison, WI, to join the Department of Mathematics. Before that I stayed for two semesters at Yale and the University of Virginia as a visitor.

In Madison, Georgia and Marshall Osborn became our guardian angels. I cannot think of a word that would fit Georgia better than angel, the way she behaved, spoke, even looked.... Georgia was a very special (rare) angel, the one with down-to-earth common sense and a fantastic (also down-to-earth) sense of humor. Now when I am writing these words I imagine Georgia looking over my shoulder and making comments. I know that it won't happen and that is painful.

Rosa Orellana

An inspiration, a role model, a mentor, and a friend, these are the words that come to mind when I think of Georgia Benkart. I didn't realize until many years later how important it was to have such a strong female role model before I knew that I needed one. I first met Georgia when I was a second-year graduate student at a Connections for Women Workshop at MSRI. I remember that she came to talk to me, she knew my advisor, and asked me about my research. At the time I didn't know who she was, but I will always remember that she made the effort to come and talk to me. I continued to meet Georgia at conferences and our friendship developed into a mentor-mentee relationship.

In the years that followed, she always demonstrated interest in my work by inviting me to speak if she were organizing a conference. She visited me at Dartmouth in 2009, when she became the first female mathematician to deliver our department's distinguished Kemeny Lecture series. At this time, I had the opportunity to ask her why she retired so young, if she continued working as hard, if not harder. She answered my question with a smile and said that sometimes to do more meaningful work, you must quit your job.

In 2011, Georgia co-organized Algebraic Combinatorixx with Monica Vazirani and Steph van Willigenburg. The workshop was organized at Banff and the objective was to create small research groups of female mathematicians. Part of the activities included mentoring meetings where everyone shared personal experiences and tips about what worked for them to keep research going. To me, personally, this was Georgia's most meaningful contribution to our community. At the time I was the mother of a young child, had recently experienced the loss of my second child, and was finding it difficult to get research going again. I was one of the lucky people to get an invitation to the first

Rosa Orellana is a professor of mathematics at Dartmouth College. Her email address is Rosa.C.Orellana@dartmouth.edu.

Algebraic Combinatorixx at Banff. This workshop transformed my career. I was able to make professional connections that led to collaborations; it focused my research plan that became my next research proposal which was funded by NSF, and it allowed me to feel confident to apply for full professorship two years later.

In 2015, Georgia invited me to co-lead a research group for the newly funded WINART group. The first workshop was going to be held at Banff and it was going to follow a similar format as the Algebraic Combinatorixx. Although, she didn't say it directly, she was training me to take a more leading role. It was with her encouragement that Julie Beier, Tricia Brown, Steph van Willigenburg, and I co-organized the second Algebraic Combinatorixx at Banff in 2017. An admirable quality of Georgia was that she knew that she didn't have to be a co-organizer to contribute. She was equally happy being a participant, a group leader, or a co-organizer.

Toward the end of 2020, it was becoming clear that the pandemic was negatively affecting the research output of many female mathematicians. In fact, a letter by the European Women in Math, among others, discussing this issue was one of the factors that led Susanna Fishel, Pamela Harris, Steph van Willigenburg, and me to organize a Research Community in Algebraic Combinatorics workshop to support women research groups. The workshop was organized with the support of ICERM and all the research activity was done via zoom meetings. Georgia, although she was already leading another group for WINART, decided to also lead a group for the ICERM workshop.

Georgia was an inspiring speaker, and her talks were full of beautiful mathematics. In 2014, she delivered the AWM-AMS Noether Lecture on the topic of the McKay correspondence. A big portion of her later work was related to the McKay correspondence. This correspondence says that the subgroups of SU(2), the group of 2 x 2 unitary matrices with determinant 1, are in bijection with some graphs known as the simply laced affine Dynkin diagrams. The McKay matrix arises as the adjacency matrix of these graphs. In 1985, R. Steinberg generalized McKay matrices to any group using tensor products. Two of Georgia's last publications were with her WINART group. In this work she generalized McKay matrices to finite-dimensional Hopf algebras. Our collaboration, which was ongoing at the time of her death, was on generalizing McKay matrices to finite-dimensional monoids.

At the time of her death, Georgia was leading three all-female research groups, had advised 22 PhD students, and had 134 publications with over 90 collaborators, of which I count myself lucky to be one. She had organized many conferences, workshops, and many AMS meetings as associate secretary of the AMS for the central section; her conference organization work led to the inclusion of more women and minorities as speakers. In numbers her contributions are immensely impressive; however, her most impressive and more difficult to quantify achievement is the impact that she had on many people like me. By meeting her at the beginning of my career at the Connections for Women in Math, it made it feel normal that a woman could achieve such a level of success as a mathematician.

Alejandro Adem

In 1988 I made a trip to Madison to deliver a colloquium talk in the Department of Mathematics at the University of Wisconsin. Being a topologist, I didn't know much about the algebraists there. That changed very quickly after meeting wonderful people like Lou Solomon, Marty Isaacs, and (of course) Georgia Benkart. She was extremely kind to me, and struck me as exactly the kind of person I would like to have as a colleague. One year later I received a tenure track offer from UW–Madison and I remember thinking that it would be a great place to be for a **very algebraic** topologist, and so I became a faculty member there for the next 15 years.

One of the highlights of my time in Madison was being a colleague and friend of Georgia Benkart. She was a world-class algebraist with many celebrated research accomplishments who commanded the respect of her colleagues. At the same time she was kind, modest, and highly supportive of other mathematicians, especially young researchers and students. She was a remarkable lecturer, I remember vividly how amazed I was by the meticulously prepared, entertaining lectures she delivered in her undergraduate courses. Her work on departmental committees was extraordinarily thorough, thoughtful, and impeccably presented. She was a role model for me and I will always be grateful for her advice and support when I was beginning my career. Attaining Georgia's high standards in research, teaching, and service was of course impossible for the rest of us! But she showed us that it could be done, and how to do it.

Georgia was also a dear friend of my family, and her participation in social events was an important ingredient in the wonderful experience we enjoyed while living in Madison. A visiting seminar speaker was typically treated to dinner and then a dessert party, and of course Georgia hosted some of the nicest events (the cakes were also amazing). During the bleak winter months the social glow of colleagues like Georgia helped keep us feeling warm and fuzzy. I also fondly remember a trip we made in January 1995 together with Efim Zelmanov to attend an algebra workshop in Morelia, Mexico, where we escaped from the snow to enjoy excellent mathematics and great sightseeing.

I discovered that she was also a delightful travel companion.

Georgia and I overlapped on the AMS Council for many years, and it was always a pleasure to meet her at the meetings and catch up on news from Madison. Her selfless work on behalf of the AMS was yet another example of her love for mathematics and mathematicians, but equally important was the fact that she was extremely effective, and our entire community benefited enormously from her work.

Georgia Benkart was one of a kind and she will be sorely missed by all who knew her. She was an extraordinary human being and a remarkable mathematician who leaves behind outstanding scientific and human legacies for us to celebrate and cherish.

Hélène Barcelo

It is a great honor to have known Georgia Benkart for more than 25 years. We first met in the early 1990s at various conferences in algebraic combinatorics. During the 1996 year-long program in combinatorics at MSRI, I had the good fortune of beginning a long-lasting friendship with her. Georgia was the epitome of a scholar-academician and showed boundless generosity with her knowledge, time, and friendship. Discussing mathematics with her was a privilege; she never once indicated surprise at my ignorance but rather shared her knowledge with patience and dedication. Finding someone with whom I could be myself without fear of negative judgment was an exceptional experience for me in those days. Despite Georgia's erudition, she had a humble approach to mathematics even in areas where she was a leading figure. Our mathematical conversations remained of this type through to the end.

In 2011, Georgia joined MSRI's Board of Trustees, which allowed us to work alongside one another for more than ten years. Georgia's commitment and diplomatic skills shined throughout her tenure and I came to rely on her invaluable counsel. Even while she was occupied as associate secretary of the American Mathematical Society, Georgia distinguished herself by never missing an MSRI board meeting in all her years of service. Georgia also played an instrumental role on MSRI's Committee on Trustees and Committee on Women in Mathematics, serving as chair of the latter from 2015 to 2020. In particular, she shaped MSRI's support of a collection of Celebratio Mathematica volumes in honor of women mathematicians.

One exciting event Georgia, Estelle Basor, Jill Pipher, Frank Ferris, and I organized was the inaugural American Women in Mathematics (AWM) Research Symposium in March 2013, marking the 40th anniversary of the AWM. With nearly 300 women in attendance, this launched a new series of biennial symposia showcasing the work of women in mathematics. It was a memorable event and a testament to Georgia's passionate commitment to gender equity.

In 2017, Georgia and I participated in the BIRS workshop Algebraic Combinatorixx II with the goal of bringing together women from a wide variety of backgrounds and experiences to strengthen their presence in the mathematical community by catalyzing research collaborations. While the intensity of the program was palpable and energizing, a week is inevitably a very short time to make progress on new research. Toward the end of the workshop, Georgia and I worried that many of the women would return home to heavy professional and personal obligations and that maintaining research momentum would be difficult. We discussed how to enable these research groups to further their collaborations and bring their projects to fruition after leaving BIRS. This marked the inception of MSRI's Summer Research in Mathematics (SRiM) program, which provides the opportunity for two weeks of in-person collaboration to small groups of mathematicians, especially women and gender-expansive individuals who are disproportionately affected by various obstacles.

From its modest beginnings, SRiM has gained remarkable popularity. During the pilot program in summer 2017, 13 women from the BIRS workshop Algebraic Combinatorixx II met at MSRI. The program was formalized in summer 2018 and the number of applications exceeded expectations with 81 women applying from among 22 groups. Since then, SRiM has become increasingly competitive with the number of applications nearly doubling year over year; 291 women applied from among 80 groups in 2020. Georgia's support and advocacy on the Board of Trustees were key to the development of SRiM.

Deeply committed to service and as generous a friend as she was a colleague, Georgia leaves an extraordinary legacy in mathematics which I know will continue to inspire us all. She was a steady presence, and I will forever miss her mathematical insights, friendship, and kindness.

Hélène Barcelo is the deputy director at the Mathematical Sciences Research Institute, Berkeley. She is an emerita professor of mathematics of the school of mathematical and statistical sciences at Arizona State University. Her email address is hbarcelo@msri.org.

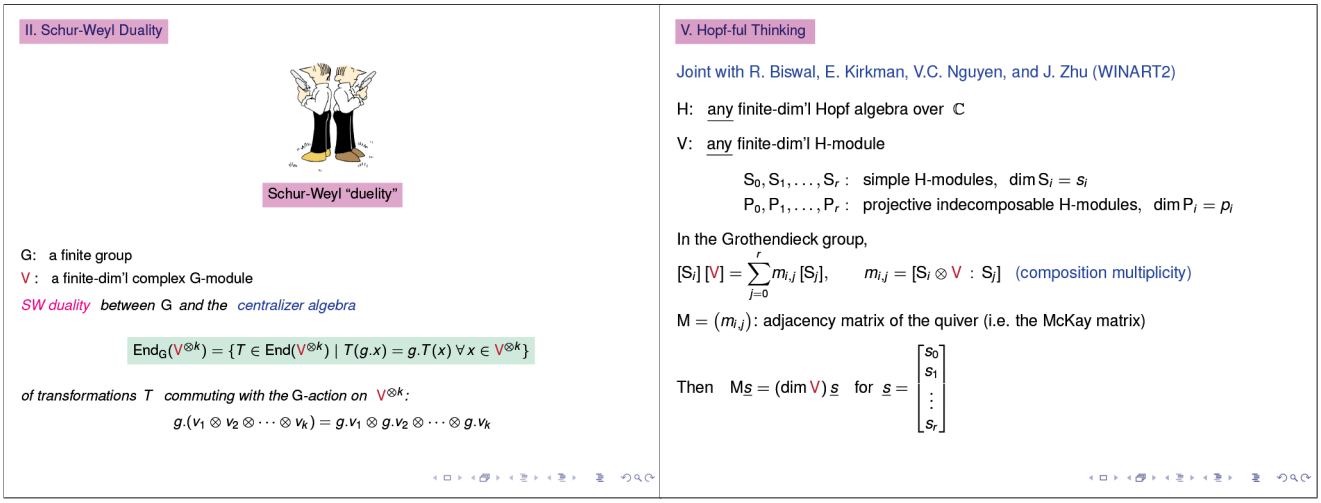

Figure 8. Schur–Weyl duality and Hopf-ful thinking: Slides from Georgia Benkart's talk at AWMs 50th anniversary conference, November 20, 2021.

Daniel Nakano

On February 4th 1992, I met Georgia Benkart when she was a Professor at the University of Wisconsin–Madison and I was an NSF Postdoc at Northwestern University. I invited Georgia to give a talk in our algebra seminar. Little did I know that this invitation would lead to a strong mentoring relationship and profound friendship that lasted over 30 years until her untimely passing.

Georgia was a unifying force in bringing people together and had a wonderful talent for community building. During my postdoctoral years (1991–1995), I had many significant interactions during my visits to Madison. Georgia introduced me to Arun Ram, Dan Britten, Frank Lemire, Tom Gregory, and her PhD student Karl Peters. Karl and I wrote four papers together (with Jon Carlson and Steve Doty). One early wintery Saturday morning, Georgia called us up on the phone. She said that Efim Zelmanov, who had just joined the faculty at Madison, "wants to go out to eat blueberry pancakes." Later that morning, my wife RuthElizabeth and I met them halfway between Chicago and Madison at a quaint pancake joint in southern Wisconsin.

Even with her busy schedule, Georgia was able to find time to visit us twice during my six years at Utah St. University (1995–2001). On one visit to give a research colloquium, my adventurous colleague, LeRoy Beasley, led us on a challenging hike in Logan Canyon to the top of the Crimson Trail (a 4.7 mile hike with a 1345 ft elevation gain). We all know that Georgia gave beautiful talks. She negotiated the hike as smoothly as she presented her colloquium talk.

Daniel Nakano is a distinguished research professor in the mathematics department at the University of Georgia. His email address is nakano@uga.edu.

Georgia had a very close relationship with her older sister, Paula, throughout her life. They were born in the same calendar year, both attended Ohio St. University as undergraduates, and both earned PhDs. Paula moved to Madison to help take care of their mother in the 1980s, and Georgia and Paula lived together since that time. Our daughters, Susanna and Aneesa, were born in Logan, Utah. They are three years apart in age, and had the opportunity to interact with Georgia many times during her visits and at mathematics conferences throughout their childhood. RuthElizabeth and I are convinced that our daughters were divinely inspired by Georgia and Paula's sisterhood. Our daughters shared a bedroom, and participated in the same activities (golf, orchestra, and journalism) in high school. Georgia was very excited when she heard that Aneesa would be attending U.C. Berkeley and joining her sister Susanna who was currently there as an undergraduate.

I moved to the University of Georgia (UGA) in 2001 and was awarded a Distinguished Research Professorship in 2010. On both occasions, Georgia wrote recommendation letters on my behalf. Back in 1977, Georgia received a tenure-track offer from the University of Georgia, and often toyed with the confusion, honor, and puns that could have been generated if she had taken the job.

In 2004, Georgia and I served together on the organizing committee with Brian Parshall, Jens Carsten Jantzen and Zongzhu Lin for the AMS Summer Research Conference in Snowbird, Utah (see Figure 3). This was a high-pressure gig. The AMS provided a large amount of funding for the conference with a clear expectation that the conference should attract the best mathematicians in the field. A conference volume, with the organizing committee serving as editors, was published. In retrospect, Georgia's

Figure 9. A Georgia pun: The state of Georgia signed by Georgia (recreated by Daniel Nakano from a conference memory).

leadership on the organizing committee played a major role in making Snowbird 2004 the landmark international conference in Lie and representation theory in the early 2000s.

Georgia visited UGA five times since 2001 to speak at research conferences, give colloquia and seminar talks, and interact with our algebra group. On one of Georgia's visits to UGA, I was serving as VIGRE director and also coled our UGA VIGRE Algebra Research Group (which included faculty, postdocs, graduate students, and undergraduates). Our research group published seven papers under the aforementioned name and was described in her President's Report in the May–June 2009 issue of the Association for Women in Mathematics (AWM) newsletter. At this point, I would like to make an addendum to the AWM article. Georgia was one of first pioneers in the modern era who was able to successfully vertically integrate research and education. I drew insight and ideas for designing our research group from Georgia's successful six author collaboration with her five PhD students on the walled Brauer algebra that was published in the *Journal of Algebra* in 1994.

Georgia was a frequent research visitor to Korea and I was on her first flight to and her last flight from Korea. In 1995, we were invited to speak at one of the first representation theory conferences in Korea organized by Seok-Jin Kang (a Yale classmate, and Georgia's future collaborator). In those days, in order to get decent airticket prices to Korea one had to go to a wholesale vendor. RuthElizabeth and Liz Jurisich, who was a postdoc at the University of Chicago at that time, also travelled with us. So we bought four tickets in economy class on an old rickety 747. The experience was surreal: as the plane was descending into Seoul, we were surrounded by a bevy of eager travelers who stood up on their seats to snag their overhead luggage while the airline flight attendants were grabbing them and scolding them to get back into their seats.

Fast forward 20 years later in 2014: I see Georgia at the Incheon International Airport after the Seoul ICM. Georgia had presented the prestigious Noether address at the ICM. She was flying back to the states in first class. I was fortunate on that flight to be bumped up into first class, and was assigned to the seat across from her during the flight. At one point, while we were enjoying our gourmet meal, we looked at each other and almost on cue started to say the same thing: "Remember the first time when we flew to Korea, ... ".

Georgia was a woman with a strong faith conviction. After her magnificent journey of earthly life that has made a tremendous impact on all of us, I truly hope that she is seated in "first class" in her final resting place.

References

[BBK+22a] Georgia Benkart, Rekha Biswal, Ellen Kirkman, Van C. Nguyen, and Jieru Zhu, *McKay matrices for finite-dimensional Hopf algebras*, Canad. J. Math. **74** (2022), no. 3, 686–731, DOI 10.4153/s0008414x21000067. MR4430927

[BBK+22b] Georgia Benkart, Rekha Biswal, Ellen Kirkman, Van C. Nguyen, and Jieru Zhu, *Tensor representations for the Drinfeld double of the Taft algebra*, J. Algebra **606** (2022), 764–797, DOI 10.1016/j.jalgebra.2022.04.041. MR4432247

[BCH+94] Georgia Benkart, Manish Chakrabarti, Thomas Halverson, Robert Leduc, Chanyoung Lee, and Jeffrey Stroomer, *Tensor product representations of general linear groups and their connections with Brauer algebras*, J. Algebra **166** (1994), no. 3, 529–567, DOI 10.1006/jabr.1994.1166. MR1280591

[BE02] Georgia Benkart and Alberto Elduque, *A new construction of the Kac Jordan superalgebra*, Proc. Amer. Math. Soc. **130** (2002), no. 11, 3209–3217, DOI 10.1090/S0002-9939-02-06466-3. MR1912998

[DG13] Ennio De Giorgi, *Selected papers*, Springer Collected Works in Mathematics, Springer, Heidelberg, 2013. [Author name on title page: Ennio Giorgi]; Edited by Luigi Ambrosio, Gianni Dal Maso, Marco Forti, Mario Miranda and Sergio Spagnolo; Reprint of the 2006 edition [MR2229237]. MR3185411

[BR98] Georgia Benkart and Tom Roby, *Down-up algebras*, J. Algebra **209** (1998), no. 1, 305–344, DOI 10.1006/jabr.1998.7511. MR1652138

[BSR98] Georgia Benkart, Chanyoung Lee Shader, and Arun Ram, *Tensor product representations for orthosymplectic Lie superalgebras*, J. Pure Appl. Algebra **130** (1998), no. 1, 1–48, DOI 10.1016/S0022-4049(97)00084-4. MR1632811

[BZ96] Georgia Benkart and Efim Zelmanov, *Lie algebras graded by finite root systems and intersection matrix algebras*, Invent. Math. **126** (1996), no. 1, 1–45, DOI 10.1007/s002220050087. MR1408554

[BM92] S. Berman and R. V. Moody, *Lie algebras graded by finite root systems and the intersection matrix algebras of Slodowy*, Invent. Math. **108** (1992), no. 2, 323–347, DOI 10.1007/BF02100608. MR1161095

[Kac77] V. G. Kac, *Classification of simple Z-graded Lie superalgebras and simple Jordan superalgebras*, Comm. Algebra **5** (1977), no. 13, 1375–1400, DOI 10.1080/00927877708822224. MR498755

[Tit62] J. Tits, *Une classe d'algèbres de Lie en relation avec les algèbres de Jordan* (French), Nederl. Akad. Wetensch. Proc. Ser. A 65 = Indag. Math. **24** (1962), 530–535. MR0146231

Credits

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