Summer 2011 Combinatorics REGS

Final Report — Douglas B. West

Overview

As in 2010, the Summer 2011 REGS group in Combinatorics was quite large. In terms of both student experiences and research output, this was clearly the most successful year yet (15 or more papers may eventually be written). The most important contributing factor to this success seems to have been changes in the format and schedule that helped a large group function more smoothly and provided a more intensive program.

In past years, the presentation of problems was spread through the summer, resulting in large groups of students discussing the first few problems (somewhat inefficiently) and relative inattention given to problems presented later. This year the schedule changed to reduce both difficulties. We met intensively during Week 1 every morning and afternoon. In Weeks 2–5 we met morning and afternoon three days per week, and for the last 2.5 weeks only in the afternoon. The morning and afternoon sessions had different functions: mornings were for presentation of open problems and occasional lectures by visiting faculty (and later, for statements of results proved), and afternoons were for research discussions. Weekly social activities helped the students and visitors feel comfortable together.

Weeks 3–5 saw one-week visits by three visiting faculty: David Galvin, Andrew King, and Sebastian Cioabă. Contributing via lengthier informal visits were Robert Jamison, Stephen Hartke, Daniel Cranston, and Kevin Milans. As in 2009 and 2010, U.S. students entering our PhD program this fall were invited (and supported) to come earlier to attend REGS during the summer. There were four such students this year. A new feature was that a substantial number of students from other institutions who requested to attend were supported via a housing subsidy. Six visiting students attended and made substantial contributions.

The proposed problems appear at http://www.math.uiuc.edu/∼west/regs/index.html, the website for the Combinatorics REGS program. A major improvement this year, implemented partway through the summer, was the introduction of MathJax to facilitate the preparation and the viewing of notation on web pages. 51 problems were posted.

The results are summarized at http://www.math.uiuc.edu/∼west/regs/11results.html. It seems likely that more than 15 of the the problems will lead to publishable papers. About a dozen more received substantial discussion and partial results that may not lead to papers, sometimes because results turned out to be equivalent to or implied by earlier results in the literature.

It is important to note the nature of the research done in the Combinatorics REGS. Although it is generally worthwhile and publishable, this work is not the deepest or most difficult in the field. Rarely are the solved problems long-standing conjectures. Typically the results are interesting and nontrivial advances on relatively new problems. The problems presented are of all types, including some long-standing conjectures, providing valuable exposure for the students. However, large group discussions in a limited period of time are better suited to brainstorming about new problems. Given the aim of REGS to introduce students to the research enterprise, limited depth of the results is not a deficiency of the program; it just "comes with the territory" in a natural way.

Involvement of visiting students and visiting faculty can greatly expand the outreach and impact of this REGS program. Students from institutions too small to have such programs participate in a research experience that expands their horizons and usually increases their determination toward academic careers. Participating faculty from other institutions see how the program operates and may be inspired to start similar programs. For example, the University of Colorado–Denver has expressed interest in sending several students and their advisor next summer to participate in an initial portion of the program. The advisor, Michael Ferrara, visited the combinatorics REGS informally in 2007.

The remainder of this report contains detailed comments on the format of this summer's program, its strengths and weaknesses, discussion of participants, publications progress for papers originating in this and prior years (pages 6–9), and feedback evaluations from 24 participants of this year's program (pages 10–24). Since the problems and results are on the web, this report does not describe them, except for titles of papers likely to be published and comments by participants about what they studied.

Format and Schedule

In prior years, we met three times per week in the afternoons throughout the eight weeks. Feedback from participants suggested that time could be used better. With problem presentations and discussions during the afternoon, students often felt rushed, without adequate time for discussion. Often results began to come just as the summer program was ending. Meanwhile, the more intensive first-week schedule used sometimes in the past when students from the University of Louisville visited was viewed favorably.

This summer we met in both morning and afternoon sessions, including all five days in the first week. Results came earlier in the summer, allowing more time for students to work on writing them up. After the intensive schedule established during the first week, various groups of students met informally on their own on Tuesdays and Thursdays during the rest of the summer to continue their discussions.

The morning sessions in the first two weeks were devoted to problem presentations, and subsequently they were also used for the instructional lectures by visiting faculty. Morning sessions ran 10:30am-12. This seems to be the right length for a plenary session, allowing discussion of several problems or of notions raised in an instructional lecture. It allows more flexibility in the length of instructional lectures and is perhaps the maximum for students' attention spans.

The lunch break before group discussions was unexpectedly valuable. It allowed students to give some thought to problems on their own before group discussion, possibly looking up references and making decisions about which problems to discuss. Also, since lunch occurred between sessions instead of before the first session of the day, lunch groups of multiple students or of students with visitors were more common and natural.

Afternoon sessions were 2-5pm. In effect, this more than doubled the time available for group research discussions in comparison to previous years. (Note also that last year the program was one week shorter because the SIAM Discrete Math meeting was held during the first week of the summer term; this year we had the full term.) The extra time enabled students to discuss problems more thoroughly and to participate in discussing a greater variety of problems.

With 25-30 students, the cacaphony of four to six research discussions prohibits staying in one room (not to mention the lack of board space). In 2010, our regular meeting room was on the second floor, which has only one neighboring classroom with movable chairs. Students escaping to quieter rooms essentially disappeared, making it difficult for the organizer to keep track of what was being discussed, answer questions, or offer suggestions. This year, our regular room was on the third floor, which has four such rooms together and hence was more suitable. Some were occasionally scheduled for classes. In the future, it would seem best to schedule into the fourth floor, which also has four such rooms in a row but is less used. If those rooms were also reserved for the afternoon meetings three days per week, then there would be sufficient proximate space so that faculty could maintain contact with the discussions.

In addition to the research meetings, there was a social event each week, alternating between restaurant dinners (mostly Chinese, large table) and pizza/barbecue at the organizer's home. Students paid reduced amounts for these meals, subsidized by the organizer. After the parties, there was opportunity for interactions via games and puzzles. These activities provided further contact with the visiting faculty and opportunity for the students (especially REGS0 and visitors) to get to know each other. Last year's social events helped establish close camaraderie among the first-year students during this past year, and with this summer's events the new students seem to be comfortably included.

Procedures

As usual, each student was expected to present a problem, as did visitors. The organizer presented only a couple of problems on the first couple of days to get things started, because there were many students who would be presenting problems and because several long-term faculty visitors also contributed at the start of the program. In light of past experience, students are told that the earlier they present their open problem, the more attention it will receive in research discussion during the summer.

During the first week, only the more advanced students with prior experience in REGS presented problems. By example, this showed the new students how to make presentations. The great variety of experience levels in REGS continues to be one of its main strengths. Younger students see how more experienced students approach problems, more experienced students and post-docs learn better how to mentor and how to present their ideas, faculty are available to offer broader perspective on how proposed problems relate to known problems or results, etc.

Students are told that problem presentations should be concise. Background, motivation, and statements of what is known about the problem are encouraged, but proofs are not. Proofs of earlier results can be appropriate later in the small group discussions. Questions and comments from the listeners are encouraged. This often leads to examples being examined at the board and, notably, to additional questions being posed that may be more interesting or more tractable than the original question.

In this plenary phase, the organizer has been perhaps too active, which has occasionally made some participants uncomfortable. Participants are learning to present material at a research level, but the presentations are also educational for the listeners. When vague or incorrect statements are made or it is clear that a redirection of the proposed problem would be more productive, the organizer has not shied away from requesting clarification or offering such redirection. On the other hand, it is of course not constructive to scare students away from making presentations, so careful balance is needed.

Again the problems appear at http://www.math.uiuc.edu/∼west/regs/index.html, the website for the Combinatorics REGS program. That page still contains the problems back to 2008 and a few from 2007. A major improvement this year, implemented partway through the summer, was the use of MathJax to permit typing the notation on problem pages in TEX. This made it much easier (and faster) for students and visiting faculty to prepare their web pages (also easier to edit). Pages also read more easily, since the notation displays as it should without being hampered by the inability of html to produce things such as binomial coefficients.

Students have been getting better at writing up their problems, and now they often don't need much editing. This may be due to more of the students turning to the Open Problem Garden at Simon Fraser to find problems. Nevertheless, more experienced students often bring problems encountered in their own research or in seminar or courses.

The role of the official invited faculty visitors still needs a little refinement. For example, the web pages for the problems they presented were delayed for a while after they returned home. Due partly to this, their problems were less actively studied than the problems proposed by students. Now that Mathjax has been incorporated and many examples of problem pages are available on the website, it should be possible to avoid this difficulty by asking the faculty visitors to prepare drafts of web pages for their problems before they arrive. This was suggested by one of the visitors.

Also, more "ice-breaking" is needed for the visitors to be comfortable working with student groups they have just met, and vice versa. It was suggested in the feedback comments that students be assigned to take the visitors to meals during the week; this would probably be more effective and useful than the organizers always taking them out. Another suggestion was to have the visitor give only one problem area on the first day in order to focus on working with just one group.

Although it is not advertised, the page of problems is visible to the world, as evidenced by email received from people elsewhere using it as a source of problems to work on or offering feedback on what is known about the problems.

The Results Page at http://www.math.uiuc.edu/∼west/regs/10results.html was maintained by the organizer with submissions from students. This format seems preferable to something like a wiki, since statements can be edited and improved as results mature, and the aim is to have a summary at the end of the program. Maintaining the Results Page is facilitated by switching gradually from problem presentations to statements of results in the morning sessions as the summer progresses. MathJax also made this page much easier to maintain. Attention to the Results Page and to presentation of results lessens the danger of projects becoming lost when their groups move to auxiliary rooms for discussions.

As the Results Page indicates, some problems do not catch the fancy of the students at all, while others receive intensive study from large groups. Exposure to some problems that are too difficult has several benefits: students learn more about different areas of combinatorics, the organizers and participants don't need to fret about whether their particular problems will lead to results, and students begin to get a feel for what makes a problem easy or hard.

This summer saw more results than in the past, both partial and complete results. It seems very likely that more than 15 papers will be completed. If the partial results are further pursued, then the number could go as high as 20. Similarly, a few problems from last year received further study this year.

Nagging students to write up results for publication is somewhat haphazard. In response to some early feedback, students were given some advice around the beginning of Week 6 (when problem presentations ended) about how to go about writing papers, research "etiquette" to avoiding over-long lists of authors, publication venues, etc.; communication on these topics should be carefully planned in advance.

To stimulate writing, the REGS prize competition helps, but many students don't get around to writing up their work for that, especially the students not receiving funding. The organizer can inquire about the status from time to time, but that is not always sufficient. There is also the question of encouraing students to keep working after the summer on projects that had partial results. Students are encouraged to give talks about their results in our research seminar during the fall, which also can help.

Participants

This year the department's REGS program had a rudimentary application form available on the web. Although I think this was not used by students who did not already know about the program, both current and incoming students were directed there, and I believe it provided an effective way to keep track of people. I also told students from other institutions who inquired about the Combinatorics group to use that application form. This facilitated arranging housing subsidies. Enhancing the form with a few additional questions and places to provide information eventually made it more flexible for various types of applicants. Having the application form also makes it easier for the department to keep track of participants and make sure that matters such as housing and transportation are planned (summer sublets become cheaper as the summer term draws near).

Miscellaneous visitors included students from U Nebraska (2), Illinois Institute of Technology, Rutgers, Brandeis, and the University of West Bohemia (Czech Republic). Generally these students were here for between half and two-thirds of the program. They participated very actively, and the student from West Bohemia is now considering transferring to our program. We have already had at least two students come to do graduate work here after first experiencing REGS, and five years ago two students from our Computer Science Department transferred to mathematics after participating in REGS. (This year we had two student participants from that department.)

The role of REGS0 participants deserves special mention. These are students between undergraduate and graduate work who will enter our graduate program in the fall but arrive early for REGS. The availability of this option appears to be a successful recruiting tool. As in 2009, in 2011 there were four such participants, and all had some background in combinatorics. In 2010, there were 10 REGS0 participants, some of whom had no prior experience and not much interest in graph theory and combinatorics. The advisability of including REGS0 students who have no prior acquaintance with the field just because

there is no REGS group in their area is questionable when it strains the capacity of the large group. This year there were no such difficulties.

The program of official faculty visitors was again substantial: three one-week visits seems optimal. This year we had David Galvin (Notre Dame - week 3), Andrew King (Columbia U - week 4), and Sebastian Cioabă (U. Delaware - week 5). [In 2010, the visitors were Garth Isaak (Lehigh U), David Howard (Georgia Tech new PhD), and Oleg Pikhurko (Carnegie Mellon); in 2009, Joshua Cooper (U. South Carolina)]. The visitors are chosen for expertise in techniques different from those typically used by the organizer, with a preference for younger faculty to enhance the mentoring aspect of the program.

Each visitor presents several problems and gives one or two seminar/instructional lectures featuring proof techniques and perhaps additional problems. Last year the seminar lectures were separate from the regular meeting times (Tuesdays or Thursdays), but some students had other activities then. With the added morning sessions this year, it was more effective to have these contributions during the regular morning sessions. One of the values in having outside faculty visitors is that students find them more approachable than at conferences and appreciate the opportunity for interaction. These visitors also guided discussions of small groups working on their problems during the afternoon sessions.

The careful thought given to problems and presentations by the visitors was gratifying; the funding for travel expenses contributes to the seriousness with which visitors approach the project. Galvin's presentations were stellar; he gave an easily understood explanation of the use of the entropy method, with well-chosen examples. King was the least experienced of this year's visitors, and the level of his presentation was a bit above what the students could absorb. He sensed this and will use the experience to design more effective presentations to groups of graduate students in the future. Cioabă's presentations were well-organized and accessible; he emphasized eigenvalue methods.

Although the students did not work on many of these problems, they found the presentations valuable. The reasons for less attention to these problems are worth exploring. The ultimate reason is that each visitor was gone after one week. As mentioned earlier, refinements to the handling of visitors are needed to reduce this difficulty.

Unofficial faculty visitors helped support the program during the other weeks. Robert Jamison (Clemson) was a UIUC faculty visitor during the spring and participated through the first two weeks of REGS. Former students Kevin Milans (U South Carolina post-doc) and Dan Cranston (Va. Commonwealth U) were present for much of the summer; each presented problems and a lecture. Former post-doc Stephen Hartke (U Nebraska) arrived at the beginning of the second week. Well-experienced in REGS, he is very helpful in working with many of the student groups and serves as a second organizer.

The presence of Jamison, Cranston, and Milans in the two weeks before the start of official visitors helped contribute problems and variety in the presentations and guidance for the group research discussions. There is also some concern that most of the problems studied in the program come from extremal combinatorics or graph theory. Alex Yong attended one session before the official visitors arrived and proposed an interesting structural problem motivated by algebraic combinatorics. Regular participation by more than one main organizer would help maintain breadth. Another post-doc, Bernard Lidicky, has arrived in the department and is likely to participate next summer.

Funding for visitors was adequate because the MCTP funds were combined with some leftover money from the Graph Theory Seminar budget (supporting seminar talks given in REGS before the end of June) and some leftover support funds contributed by our faculty visitor Robert Jamison. This made it possible also to provide some support for last year's UIUC graduate Kevin Milans (who gave an instructional lecture during Week 2) to travel from South Carolina to spend most of the summer helping with REGS.

Funding for the organizer is an issue. Due to the more frequent and longer meetings, the contact time for the organizer this year was more than 100 hours, more than twice the contact time of a regular course. Although no grading is involved, additional time is needed for inviting visitors, arranging the details of their visits, correspondence with students, and creation of the web pages. In terms of the effect

on time-to-degree, recruiting, and visibility, the program provides more value to the department than teaching of a graduate course does, but the funding for the organizer provided by the MCTP grant is half what the department pays for courses taught by visiting faculty. The program may need to fill this position in another way.

Altogether, 40 people participated substantially. The funded students (REGS0 and REGS1) attended throughout; some senior students and visitors had shorter stays. Of the four REGS0 students, three continued into Math 580 this fall. The large contingent of students completing their first year came back for more. Participation by senior UIUC graduate students was not as extensive as in recent years, probably due to the fact that 13 of them have completed PhDs in the past two years. Overall, although the total population was less than last year, there was less appearing and disappearing of participants, so the average attendance was perhaps higher than last year, and yet the program did not feel crowded this year due to steady commitments from the participants.

Below are the regular participants in the 2011 large-group Combinatorics REGS.

REGS0 (0th year): Michelle Delcourt, Meghan Galiardi, Sarah Loeb, Michael Santana.

REGS1 (1st year): David Hannasch, Hannah Kolb, Hong Liu, Thomas Mahoney, Amelia Tebbe, Jennifer Wise, Elyse Yeager.

REGS1 (2nd year): Daniel McDonald, Ben Reiniger, Greg Puleo.

REGS2 (advanced): Jane Butterfield, Bill Kinnersley.

UIUC US unsupported (graduating): Tim LeSaulnier.

UIUC Internatl–pre-prelim: Ilkyoo Choi, Sogol Jahanbekan, Jaehoon Kim, Mu-Tsun Tsai.

UIUC Internatl–post-prelim: Kyle Jao, Suil O, Hehui Wu.

UIUC Computer Science: Reza Zamani, Lars Erickson.

Visiting students: James Carraher (U Nebraska), Gergely Balint (IIT), Elizabeth Kupin (Rutgers), Šarka Petrickova (U West Bohemia), Derrick Stolee (U Nebraska), Jordan Tirrell (Brandeis).

Official invited faculty: Sebastian Cioabă (U Delaware), David Galvin (Notre Dame), Andrew King (Columbia U)

Unofficial visiting faculty: Daniel Cranston (Virginia Commonwealth U), Stephen Hartke (U Nebraska), Robert Jamison (Clemson U), Kevin Milans (U South Carolina).

Funding was provided for REGS0 and REGS1 domestic students. A small amount of funding from the department was spread among some of the junior international students. Funding for those not covered by the MCTP grant remains an issue, as does the nature the program will have after the MCTP grant ends. A few senior students were supported by appointments as TAs, RAs, or graders.

Publications Progress

This is a partial list of papers that originated in REGS. There may be some others on which I am not a coauthor that I don't know about. Updates are given on some papers listed last year.

REGS 2004 - 5 papers.

Bunde, David P.; Chambers, Erin W.; Cranston, Daniel W.; Milans, Kevin G.; West, Douglas B.; Pebbling and optimal pebbling in graphs. *J. Graph Theory* 57 (2008), 215–238.

Cranston, Daniel W.; Sudborough, I. Hal; West, Douglas B.; Short proofs for cut-and-paste sorting of permutations. *Discrete Math.* 307 (2007), 2866–2870.

Liu, Qi; West, Douglas B.; Tree-thickness and caterpillar-thickness under girth constraints. *Electron. J. Combin.* 15 (2008), Paper #R93, 11 pp.

Milans, Kevin; Clark, Bryan; Complexity of graph pebbling. *SIAM J. Disc. Math.* 20 (2006), 769–798.

Vandenbussche, Jennifer; West, Douglas B.; Yu, Gexin; On the pagenumber of k-trees. *SIAM J. Discrete Math.* 23 (2009), 1455–1464.

REGS 2005 - 7 papers.

Barrus, Michael D.; Kumbhat, Mohit; Hartke, Stephen G.; Graph classes characterized both by forbidden subgraphs and degree sequences. *J. Graph Theory* 57 (2008), 131–148.

Bunde, David P.; Milans, Kevin G.; West, Douglas B.; Wu, Hehui; Parity and strong parity edge-coloring of graphs. *Proc. 38th Southeastern International Conference on Combinatorics, Graph Theory and Computing. Congr. Numer.* 187 (2007), 193–213.

Bunde, David P.; Milans, Kevin G.; West, Douglas B.; Wu, Hehui; Optimal strong parity edge-coloring of complete graphs. *Combinatorica* 28 (2008), 625–632.

Choi, Jeong-Ok; Hartke, Stephen G.; Kaul, Hemanshu; Distinguishing chromatic number of cartesian products of graphs. *SIAM J. Discrete Math.* 24 (2010), 82–100.

Chambers, Erin W.; Kinnersley, Bill; Prince, Noah; Douglas B. West; Extremal problems for Roman domination. *SIAM J. Discrete Math.* 23 (2009), 1575–1586.

Hartke, Stephen G.; Vandenbussche, Jennifer; Wenger, Paul; Further results on bar k-visibility graphs. *SIAM J. Discrete Math.* 21 (2007), 523–531.

Liu, Qi; West, Douglas B.; Yu, Gexin; Implications among linkage properties in graphs. *J. Graph Theory* 60 (2009), 327–337.

REGS 2006 - 5 papers.

Balogh, József; Hartke, Stephen G.; Liu, Qi; Yu, Gexin; On the first-fit chromatic number of graphs. *SIAM J. Discrete Math.* 22 (2008), 887–900.

Choi, Jeong-Ok; West, Douglas B.; Decomposition of regular hypergraphs. Under revision.

Cranston, Daniel W.; Nomadic decompositions of bidirected complete graphs. *Discrete Math.* 308 (2008), 3982–3985.

Cranston, Daniel W.; Kim, Seog-Jin; List-coloring the square of a subcubic graph. *J. Graph Theory* 57 (2008), 65–87.

Cranston, D. W.; Korula, N.; LeSaulnier, T.; Milans, K. G.; Stocker, C.; Vandenbussche, J.; West, D. B.; Extremal problems for overlap number of graphs. *J. Graph Theory*, in press (2011).

REGS 2007 - 9 papers.

Barrus, Michael D.; Hartke, Stephen G.; Jao, Fang-Kai; West, Douglas B.; Length thresholds for graphic lists given fixed largest and smallest entries and bounded gaps. *Discrete Math.* in press (http://dx.doi.org/10.1016/j.disc.2011.05.001).

Butterfield, J.V.; Grauman, T.; Kinnersley, W.B.; Milans, K.G.; Stocker, C.J., West, D.B.; On-line Ramsey Theory for bounded degree graphs. *Electron. J. Combin.* 18 (2011), Paper #R136, 22 pp.

Cranston, Daniel W.; Kim, Seog-Jin; Yu, Gexin; Injective colorings of sparse graphs. *Discrete Math.* 310 (2010), 2965–2973.

Grauman, T.; Hartke, S.G.; Jobson, A.; Kinnersley, W.B.; West, D.B.; Wiglesworth, L.; Worah, P.; Wu, H.; The hub number of a graph. *Inform. Process. Lett.* 108 (2008), 226–228.

Kantor, Ida; Prague dimension of trees. Submitted.

LeSaulnier, Timothy; Prince, Noah; Wenger, Paul; West, Douglas B.; Worah, Pratik; Total acquisition number of graphs. Submitted.

Milans, Kevin G.; Stocker, Christopher; West, Douglas B.; Wiglesworth, Lesley; Game acquisition number of graphs. Draft.

Wenger, Paul; West, Douglas B; Unit acquisition in graphs. Draft.

Wu, Hehui; West, Douglas B.; Packing of Steiner trees and S-connectors in graphs. *J. Combin. Th. B*, in press (2011).

REGS 2008 - 6 papers.

Balogh, József; Lenz, John E.; Wu, Hehui; Complete minors, independent sets, and chordal graphs. *Discus. Math. Graph Theory*, in press (2011).

Busch, Arthur H.; Ferrara, Michael J.; Hartke, Stephen G.; Jacobson, Michael S.; Kaul, Hemanshu; West, Douglas B.; Packing of graphic sequences. *J. Graph Theory*, in press (2011).

Downey, Rodney G.; Greenburg, Noam; Jockusch, Carl G.; Milans, Kevin G.; Binary subtrees with few path labels. *Combinatorica* 31 (2011), 285–303.

Kinnersley, Bill; Milans, Kevin G.; West, Douglas B.; Degree Ramsey numbers of graphs. Submitted

Kostochka, A. V.; Stocker, C. A new bound on the domination number of connected cubic graphs. *Sib. Èlektron. Mat. Izv.* 6 (2009), 465–504.

Milans, Kevin G.; Pfender, Florian, Rautenbach, Dieter; Regen, Friedrich; West, Douglas B.; Cycle spectra of Hamiltonian graphs. *J. Combin. Th. B*, accepted.

REGS 2009 - 6 papers.

Cooper, Joshua; Lenz, John E.; LeSaulnier, Timothy; Wenger, Paul D.; West, Douglas B.; Uniquely C_4-saturated graphs. *Graphs and Combinatorics*, in press (2011).

Cranston, Daniel W.; Kinnersley, William B.; Milans, Kevin G.; Puleo, Gregory; West, Douglas B.; Chain-making games in grid-like posets. Submitted.

Fox, Kyle; Kinnersley, William B.; McDonald, Daniel; Orlow, Nate; Puleo, Gregory; Spanning paths in Fibonacci-sum graphs. Submitted.

Kinnersley, William B.; West, D. B.; Zamani, Reza; Game domination number. Draft.

LeSaulnier, Timothy D.; Stocker, Christopher J.; Wenger, Paul S.; West, Douglas B.; Rainbow matchings in edge-colored graphs. *Electron. J. Combin.* 17 (2010), Paper #N26, 5pp.

Milans, Kevin G.; Schreiber, Daniel H.; West, Douglas B.; Acyclic sets in k-majority tournaments. *Electr. J. Combin.* 18 (2011), Paper #P122, 8 pages.

REGS 2010 - 10 papers.

Biró, Csaba; Füredi, Zoltán; Jahanbekam, Sogol; Large chromatic number and Ramsey graphs. arXiv:1103.3917v2 [math.CO] 14 Jun 2011, and submitted.

Butterfield, Jane V.; Cranston, Daniel W.; Puleo, Gregory J.; West, Douglas B.; Zamani, Reza; Revolutionaries and spies: Spy-good and spy-bad graphs. Submitted.

Butterfield, Jane V.; Hartke, Stephen G.; LeSaulnier, Timothy D.; Milans, Kevin G.; Stolee, Derrick; Wenger, Paul S.; Immersion-closed families. In preparation.

Choi, Jeong-Ok; Milans, Kevin G.; West, Douglas B.; Linear discrepancy and width of posets. Draft.

Hannasch, David; Kim, Seog-Jin; Milans, Kevin; West, Douglas B.; On-line chain-partitioning for semiorders. In preparation.

Hartke, Stephen G.; Stolee, Derrick; West, Douglas B.; Yancey, Matthew; Extremal graphs with a given number of perfect matchings. Submitted.

Jahanbekan, S.; Kim, J.; O, S.; West, D.B.; r-dynamic chromatic number of graphs. In preparation.

Kim, Seog-Jin; Park, Won-Jin; List dynamic coloring of sparse graphs. Submitted.

Pechenik, Oliver; Wise, Jennifer I.; A-cordial colorings. Submitted.

Yancey, Matthew; Crossings in horizontal drawings. In preparation.

In 2010 there were partial results on a number of problems that could grow into papers with additional attention (some of those above were originally in this status). These include work on score sequences of tournaments, reconstruction of posets from ideal sizes, edge-antipodal colorings of hypercubes, edge-reconstruction of multigraphs, and b-coloring of graphs. Some other problems received such attention during the 2011 program.

REGS 2011 - 18 papers, tentatively.

Butterfield, Jane V.; Choi, Ilkyoo; Cranston, Daniel W.; Kinnersley, William B.; West, Douglas B.; Game matching number of graphs. In preparation.

Butterfield, Jane V.; Choi, Ilkyoo; Hartke, Stephen G.; Kim, Jaehoon; Kolb, Hannah; Kupin, Elizabeth; Tebba, Amelia; West, Douglas B.; The equal union property. In preparation.

Carraher, James; Choi, Ilkyoo; Delcourt, Michelle; Erickson, Lars; West, Douglas B.; Cops locating a robber on a graph. Draft.

Carraher, James; Cranston, Daniel W.; Kinnersley, William B.; Reiniger, Benjamin; West, Douglas B.; Game $\mathcal{F}$-saturation number of graphs. In preparation.

Carraher, James; LeSaulnier, Timothy D.; Milans, Kevin G.; Stolee, Derrick; West, Douglas B.; Track number of line graphs. Draft.

Carraher, James; Loeb, Sarah; Mahoney, Thomas; Tsai, Mu-Tsun; West, Douglas B.; Bounds on paintability of graphs. Preprint.

Cranston, Daniel W.; Kim, Jaehoon; Kinnersley, William B.; t-tone colorings of graphs. Preprint.

Cranston, D.W.; Puleo, G.J.; Santana, M.; Counting k-paths in transitive tournaments. Preprint.

Cranston, Daniel W.; Reiniger, Benjamin; West, Douglas B. Toppling games on graphs. In preparation.

Cranston, Daniel W.; Smyth, Clifford D.; West, Douglas B. Revolutionaries and spies on trees and unicyclic graphs. Submitted.

Erickson, Lars; Hannasch, David; Wise, Jennifer I.; Yeager, Elyse; Acyclic digraphs with many linear extensions. In preparation.

Hartke, Stephen G.; Liu, Hong; Milans, Kevin G.; Stolee, Derrick; West, Douglas B.; k-dimensional corners in subsets of d-dimensional grids. Draft.

Hartke, Stephen G.; Liu, Hong; Petrickova, Šarka; Coloring of fractional powers of graphs. In preparation.

Kolb, Hannah; Wise, Jennifer I.; West, Douglas B. Visibility number of hypercubes. In preparation.

Kupin, Elizabeth; Reiniger, Benjamin; Stolee, Derrick; Number of chains in posets of width 2. Draft.

Liu, Hong; Loeb, Sarah; Santana, Michael Biranking number of graphs. Preprint.

McDonald, Daniel; List ranking of paths, trees, and cycles. Preprint.

Wise, Jennifer; Yeager, Elyse; Game matching number of paths and cycles. In preparation.

Other 2011 topics with partial results that could grow into papers with additional attention: mean size of subtrees of a tree, sorting of permutations with stacks and queues, art gallery problems, monosources and rainbow cycles in tournaments, expected appearances of patterns in permutations avoiding other patterns, colorful paths in colored graphs, universal words for subpermutations, embeddings of planar Laman graphs, precoloring list extension for planar graphs, etc.

2011 Participant Reports

Editing of these reports is only to achieve consistent format and spacing, etc.; mostly they are as submitted. For ease of reference, the responses are arranged roughly in decreasing order of seniority. The organizer suggested questions for participants to consider in giving feedback, in order to encourage more to respond. This explains the similarity in topics addressed by the comments. The questions were:

How does REGS compare to research experiences you had before coming to UIUC?

What were the most and least successful aspects of REGS?

How did you benefit from the program?

How can the program be improved?

What were the advantages and disadvantages of having so many people involved?

How did the presence of visiting faculty enhance the program, and what was your interaction with them?

Did the program provide adequate support (financial, intellectual, social) to make your experience productive?

You may briefly mention problems you worked on and results obtained, but please don't include proofs.

David Galvin – Week 3 Faculty Visitor (U. Notre Dame)

How does REGS compare to research experiences you had before coming to UIUC? My research experiences, both with undergraduates and graduates, have to date all been one-on-one. I very much enjoyed the large-group element of the REGS experience. With twenty-plus people in the room hearing problems being posed, the feedback & suggestions came faster, and came from a wider variety of perspectives, than I have previously been used to. As a result the initial discussion of problems was more exciting and dynamic than in my previous research experiences.

What were the most and least successful aspects of REGS? I think that the best aspect that I noticed, as already hinted at above, was the lively atmosphere of the large-group problem sessions, where everyone, even those who didn't really intend to think further about a particular problem, had a chance to chip in and provide their perspective, and their knowledge of the literature. Beginning graduate students may not be fully aware of the collaborative nature of much of mathematics research (and particularly discrete mathematics research). The large-group sessions certainly made that point very well.

A less successful aspect for me was the smaller group discussions. There were two issues here: the first was that I found it difficult to have effective interactions with people that I did not know very well - I didn't really know much about their particular interests, or their mathematical backgrounds. Being used to research interactions that develop slowly over time, I found myself unprepared to jump into discussions so quickly, and so I felt that my mentoring may not have been effective as it might have been. The second issue was that on some of the days, when I presented multiple problems, there were two or more small groups that I was interested in speaking with. I found it difficult to juggle the different groups and felt that perhaps by trying to divide my attention among all the groups, I was less helpful to each of individually than I could have been.

How did you benefit from the program? The experience of preparing for my visit was very beneficial. Thinking about problems that I might present helped me recall some very nice problems that I hadn't

thought about for a while, and renewed my interest in them. Planning for my two presentations was also valuable, as it focused my attention on which aspects of the two problems I was going to present were most important to get across to graduate students, some of whom may not have previously seen the techniques involved.

Being surrounded for a week by a large group of people excited about discrete mathematics was very energizing for me, since I am coming from a department where there is only myself and my two graduate students in this area.

How can the program be improved? I might have had a better experience with the small-group discussions if I had only presented one problem each day, so that during the break-out period there would have been just one group discussion to focus on. It might have been nicer, too, if I (and the other participants) had been encouraged at the end of each problem day to make more formal arrangements for meetings on the free days. At the end of Monday and Wednesday, I told everyone that I had been talking with that I was free to be visited in my office anytime during Tuesday and Thursday (and you sent an email reiterating that), but I had very few people take me up on that offer, so I felt that the value of my presence wasn't being fully utilized. Had there been a culture of groups making definitive plans to meet on the off days, I might have been able to get involved in more in-depth discussions of the problems that I presented, and perhaps help those who were interested in those problems to make more progress on them.

What were the advantages and disadvantages of having so many people involved? The clear advantage was that it helped create a vibrant atmosphere, and helped generate a lot of problems to be discussed. From the perspective of someone who only visited for just a week, the size of the group made it difficult to get to know the participants, which in turn made it difficult to have serious and in-depth interactions.

How did the presence of visiting faculty enhance the program, and what was your interaction with them? Being one of the visiting faculty, I can't really address this; I *hope* that at the very least my presentations & problems helped introduce the participants to some ideas (such as entropy) that they might not have encountered before, and that may be useful tools for them as their research careers progress.

Did the program provide adequate support (financial, intellectual, social) to make your experience productive? In intellectual and social support I found nothing wanting. The financial support was adequate, mainly because I could supplement the $800 available with a small amount from one of my grants. Had I not had that grant, I would still have managed with the offered $800 by staying at a hotel a little away from the center of campus. Given the convenience of the Illini Union to the math department, it would have been nice if the funding offered could have covered reasonable travel expenses, accommodations at the Union, and a little for day-to-day expenses. [Ed. - There was a miscommunication.]

Andrew King – Week 4 Faculty Visitor (Columbia Univ.)

The REGS program was a great experience for me, with two limitations coming to mind. First is the fact that I was only there for four days, which made it a little difficult to establish a lot of rapport with the students and to dig into the problems. Second was my choice of material, which at least at first was I think at a level quite a bit higher than the students were comfortable with. So in that respect it was a very good learning exerience for me, being that I have spent the last little while working with people at an upper-Ph.D. level and above. On the other hand the fact that I did not get it right the first time meant that my presentations were not as good a learning experience for the students as they could have been, which I regret.

The advantages of having such a large group are quite clear. The students are able to consider a large number of problems and can work in many different groups, moving quite freely from one problem to another. This is also a disadvantage in some respect, because it reduced the students' incentive to work on problems that were not immediately appealing or did not seem tractable at first. Since I arrived

after the program had been going on for quite a while, I could see that many of the students were already absorbed in or dedicated to other problems, which is not the worst thing that can happen but is a little bit frustrating.

The support offered by the program was excellent in every sense, in my opinion. One thing that might be interesting is for visiting faculty to choose a couple of problems in advance, and maybe have them up on the website so that any interested students can look at the problems and even work on them before the faculty arrives.

Sebastian Cioabă – Week 5 Faculty Visitor (Univ. of Delaware)

I had a great time at REGS. The students were motivated, active and persistent in their attempts at solving the given problems. The faculty did a great job organizing the students and keeping track of their progress. The only downside for me was that the students were already working on 2 or 3 problems when I showed up and it was difficult to find students interested in some of my problems. Nevertheless, I enjoyed my time at REGS and I would love to come back again.

Robert Jamison – Visiting Faculty (Clemson Univ.)

I participated in the REGS at U of I for one week at the end of June as a visiting problem-presenter. I presented three problems, or more accurately, problem areas: rankings of graphs, average number of nodes in a subtree of a tree, and the achromatic number of the line graphs of complete graphs. All three of these problems were vigorously discussed by groups of students, but the most significant progress was made by Daniel McDonald on rank choosability. He devised a surprising necessary and sufficient condition on list sizes for the existence of a rank choice function on a path. Over the course of the summer he honed this work into a very interesting paper.

The organization of REGS was very well worked out with just the right amount of time for problem presentation and for working groups. The working groups were self-selected so that everyone in a group had a real interest in the problem. Working groups that were too large were split so that there could be active participation in each group. Groups met in two adjacent rooms so that students were free to move to other groups in which they were interested. Although I was there only one week, students working on my problems kept in touch by email over the summer.

The rigors of mathematics were also relieved by weekly common meals which provided an opportunity for socializing and continuing discussion in a more relaxed setting. I did not have the opportunity to attend, but I am aware of them since I remained on the email list. This impressed me as the ideal conference atmosphere where intense working is alternated with opportunities for relaxed discussions.

Students come to REGS with an astonishingly high degree of enthusiasm. I noticed that even returning students from U of I who had already been to REGS several times were looking forward to it weeks in advance.

In short, the program is extremely well run, the students are of top caliber, the enthusiasm is high, and good mathematics is produced.

Stephen Hartke – Visiting Faculty (Univ. of Nebraska)

I was an assistant professor at the University of Nebraska-Lincoln (UNL) during Summer 2011. I was a VIGRE Research Assistant Professor at UIUC during 2004–2007 and have participated in REGS both while I was a postdoc and several times since I have been at UNL. This summer two of my Ph.D. students at UNL (Derrick Stolee and James Carraher) participated in REGS. Derrick visited for only 2 weeks, but James was there for most of the program (6 weeks). I visited for 5 weeks.

For myself, REGS was a great experience. I worked with several groups, mainly consisting of UIUC students, but also including other visitors (such as Šarka Petrickova) and UIUC alums (such as Kevin Milans). For my students, though, I think REGS was a fantastic experience that they could not otherwise experience at UNL. UIUC has many more graduate students, top-notch faculty, and can attract young stars as faculty visitors. The opportunity to interact with so many like-minded students and strong researchers, particularly not at one's home institution, is extremely beneficial during a graduate student's career. In particular, Derrick Stolee is graduating this year, and his work done at REGS during Summers 2010 and 2011 has significantly bolstered his research portfolio and job applications.

The schedule of the program this summer was very successful: having presentations and talks in the morning left more uninterrupted time to work in the afternoon. Meeting only in the afternoon later in the summer gave groups that had already formed the flexibility to meet at different times to work on their problems.

I benefited quite a bit from discussions with the visiting faculty and from hearing about problems and techniques in their talks. However, I'm not sure that the students had a lot of interaction with the visitors. Perhaps having a different group of students act as hosts each day to take the visitor to dinner, etc., would be a way of facilitating more interaction.

In particular, we could designate a different set of (say) three students for each of the nights (except maybe the first when we pick them up at the airport) to take the visitor to dinner, and maybe similarly for lunch. Other students could of course join them. Since you pay the students, I think it's very reasonable to require this. Other students participating can sign up to be "hosts" as well. I think this really would help to get more interaction going between the students and visitors, and it would reduce the burden on the organizers to go out to dinner all the time with the visitors.

The math department and Doug West were great hosts during our (my and the 2 students from UNL) stay. The department provided some funding for my students, and provided all of us with office space and computer, network, and library access. Prof. West lent us some lamps for our dark sublet apartment, among other hospitality. I think having a social event each week (dinner or party at West's home) was a great way for visitors to meet the other participants in a social setting; it certainly helped me to meet more of the UIUC students.

Daniel Cranston – Visiting Faculty (UIUC PhD 2007; Va. Commonwealth Univ.)

I know that REGS is designed primarily for students who have completed 2, 1, or 0 years of grad school. Thus, as an assistant professor, I am not the target audience. Nonetheless, I will comment about the usefulness of the program for me.

How does REGS compare to research experiences you had before coming to UIUC? I didn't really have any research experiences before coming to UIUC, but I have participated in REGS many times. I thought the program this year worked better than it did last year, because this year we had far fewer REGS 0 students, so most students were able to more usefully think about problems with minimal guidance.

What were the most and least successful aspects of REGS? I really like the wide variety–both in subject area and in difficulty level–of the problems discussed. The frequent social activities were of little use to me (although I can see how they could meet more of a need for others).

How did you benefit from the program? I was exposed to a wide variety of problems; I had many potential collaborators; I gave a lecture and heard two others (I really enjoyed David Galvin's lecture on entropy); I will likely have at least 3 papers come out of work started in REGS this summer (t-tone coloring, toppling games, and game saturation).

What were the advantages and disadvantages of having so many people involved? One disadvantage was the presentation of problems by everyone. This took a long time, and I generally found that these presentations went slower than I preferred (I think this is partly because I'm more experienced than many

of the other listeners, but I believe it is also largely due to the inexperience of the presenters). I think many presenters are scared of and frustrated by what they perceive as Doug taking over their presentation with lines of questions (and sometimes even his going to the board) that they had not prepared for. I do see a value in this, but suspect that much of this value could be imparted more constructively. I experienced this during my presentation on Ramsey numbers, and found it fairly frustrating.

How did the presence of visiting faculty enhance the program, and what was your interaction with them? I talked a little with Kevin, Andrew, and David (as mentioned, I enjoyed his entropy lecture), and a little more with Stephen. I didn't find that my research interest matched all that closely with any of the first three visitors, and I generally found that Stephen was already working with many students.

Did the program provide adequate support (financial, intellectual, social) to make your experience productive? I didn't receive financial support, although I did appreciate the office space. Intellectually: I appreciated having Bill around to work with, although I would have enjoyed having other more experienced researchers. I also enjoyed talking with Doug, although his time was (understandably) split many ways. More than in previous years, I really got a sense that I was not the target audience (it was REGS 0/1/2 students). As a result, I do not plan in the future to participate in REGS for such an extended period (although I may come for 3 weeks or so). I was not looking for social support from REGS. I have not understood this to be a significant aspect of the program in the past, and was surprised at the prominent role that social activities played in REGS this summer. I suspect there is a reason for this change. Can I ask what it is?

Kevin Milans – Visiting Faculty (UIUC PhD 2010; U. South Carolina)

This year, REGS was another great success. It was a wonderful opportunity to meet new researchers in discrete mathematics and begin new projects. I had the opportunity to work on three such projects. Two of these have already produced some interesting results, and I look forward to continuing this work with my colleagues to produce research articles.

This year, REGS held two sessions on meeting days. In the morning, participants presented open problems. In the afternoon, participants worked on problems in groups. This system allows time for all participants to present problems while ensuring that participants have enough time to engage in active research. (In previous years, the presentations seemed to eat into research time a little too much.)

In short, Prof. West's REGS program is excellent and seems to improve with every passing year. I am especially grateful for the financial support from the university which helped tremendously to defray expenses. It is an honor to be involved in REGS and I hope to continue my participation for many years to come.

Derrick Stolee – Visiting student (Univ. of Nebraska)

This summer was my second visit to the Combinatorics REGS. The previous summer yielded a single, strong project whose collaboration carried through the year resulting in one joint paper and a single-author paper of my own. These results will be prominently featured in my dissertation.

This summer, I had only two weeks to hear problems and make enough progress to solidify a collaboration before I had to return to Nebraska to teach. I found the intense first week schedule to be very helpful to this goal, as I had two very interesting projects with moderate progress within this week. I found a third project early in the second week and was able to make progress along that line as well. My collaborators for these projects are mostly disjoint, with only one collaborator appearing in two of the three projects. This would not have been possible without the large number of people participating.

One downside of the large participation is that groups tend to be TOO large in the first few days. The groups tend to get smaller as problems are revisited, so this is a tolerable issue. It is much better to have too many people at the beginning than not enough in the second week.

REGS is unlike any research experience I've ever had. UNL does not have a strong collaborative environment among graduate students so I would otherwise only work with my advisor and possibly some of his students. Without REGS, I would not be able to work on so many interesting problems with so many other strong researchers. This rapid-fire approach allows me to try several different research problems and keep the ones that "stick". The problems where I don't make immediate progress are still very interesting and I keep them in a file for later.

The schedule of REGS the summer was greatly improved. Having a break between problem presentations and work time was particularly helpful. Not only did I get a break to stretch my legs and eat lunch to feel refreshed, I frequently spent time looking for references for the problems I was considering. Depending on what I found, this sometimes changed which problem I would work on. At minimum, it changed the way I worked on a problem, since having the previous results at hand made sure I wasn't reinventing the wheel or working on a false conjecture.

Here are summaries of the projects I worked on:

The first project regards a conjecture that every sufficiently large number is the number of chains in some poset of width exactly two. Working with Elizabeth Kupin (Rutgers) and Ben Reiniger (UIUC), we developed an automated method of counting chains in width-2 posets with small "configurations". We then generated these small configurations and evaluated the formulas on millions of inputs, finding that all numbers from 5 to about 7.3 million are achievable. In addition, these numbers are represented several times and by very small configurations. This provides strong evidence that the conjecture is true. We are working to formalize our counting method to attack the infinite problem.

The second project proved a conjecture on interval numbers and track numbers. With Tim LeSaulnier (UIUC), Kevin Milans (USC), and Douglas B. West (UIUC), we showed that the track number of the line graph of K_n has growth between $O(\log^* n)$ and $O(\log n)$. This yields graphs with interval number 2 and arbitrarily large track number. The work began with a strong, at-the-chalkboard collaboration that suggested some very interesting constructions and attacks. Later, Kevin came to the morning session with a beautiful proof laid out very nicely using some of these techniques but starting from a completely different angle (Ramsey theory). The collaboration continued by pushing that strategy to the extreme. By the time I left, we had reduced a bound from a tower of 10's of length $10t$ to a tower of 6's of length $6t$. This required some new definitions that may be of independent interest. These proofs are complete, but we are trying to find the exact asymptotics of these track numbers and perhaps extend the results to a more general conjecture regarding the chromatic number of a graph and the track number of its line graph.

The third project involves combinatorial geometry. Working with Stephen G. Hartke (UNL), Hong Liu (UIUC), Kevin Milans (USC), and Douglas West (UIUC), we are trying to find the extremal functions for axis-aligned k-corner-free sets in the d-dimentional integer lattice. We have found the proper polynomial degree for these functions and are working to find the proper leading terms and in a few cases the exact function. We also are working on the non-axis-aligned case, but this is a significantly harder problem in higher dimensions. Because this project did not start until the second week, a large amount of the work has been happening remotely.

Šarka Petrickova – Visiting internatl. student (U. West Bohemia, Pilsen, Czech Republic)

How does REGS compare to research experiences you had before coming to UIUC? I visited REGS for the first half of the program. Before REGS, I had always worked with just a few people on one particular problem. So, REGS program was different mainly in the number of people involved and the number of problems on which they were working.

The most successful aspects: The organization of the program was perfect. The following aspects stand out in my mind: It was convenient that the students received important information and directions by email several times a week.

I enjoyed the presentations of the participants. Furthermore, I liked that the students were asked to find and present their own proposals for research problems to be studied during REGS. This forced everyone to understand his or her problem in more detail so that he or she could explain it to the rest of the group at the beginning of the working section.

The schedule was also very convenient. The students were fresh enough to absorb new problems during the morning sections, got more interested in certain problems during the lunch break, and were able to continue working on them for the whole afternoon. It was also smart to start with daily meetings and relaxing the schedule as time passed and the students had already chosen problems to discuss independently in their groups.

I also appreciated weekly group dinners where the students could get to know each other better before working together. Lastly, Mathjax, which was introduced this year for displaying LaTeX notation on the REGS web pages, made posting problems much easier.

The least successful aspects: The only thing that comes to my mind is the broken AC in the class for few days during the program :).

How did you benefit from the program? I had the opportunity to work with various people with different backgrounds. I was exposed to many open problems. I was already aware of some of these problems, but most of them were new to me. Also, it was interesting to observe how work on the problems was developing and which approaches the students were using to solve them. Since I am not a native English speaker, talking in English was also highly beneficial to me.

How can the program be improved? Some of the students (including me) were too lazy to upload their problems to the REGS web page on time. I would prefer that each write-up be available online before the corresponding presentation so that people could concentrate on the presentation rather than taking notes.

What were the advantages and disadvantages of having so many people involved? Advantages: I think that the number of participants was just right. There was always somebody working on some problem I was interested in. I do not think that the number of problems presented was too high. I was glad that I had the opportunity to choose the one that fit me. *Disadvantages:* Sometimes it was too noisy in the class during the afternoon sessions, so it was hard for me to catch the English or to concentrate on math. In such cases I always tried to move to one of the next classes.

How did the presence of visiting faculty enhance the program, and what was your interaction with them? I liked the problems as well as the lectures given by the visiting faculty. Also, I found collaboration on open problems with the visiting faculty members useful. In particular, collaboration with Steve Hartke on the "Colorings of graph fractional powers".

Did the program provide adequate support (financial, intellectual, social) to make your experience productive? Yes, definitely. I am very thankful that I had the opportunity to participate in this program.

James Carraher – Visiting student (Univ. of Nebraska)

The REGS program was an educational and enjoyable program. The opportunity of participating this summer benefited me in particular by demonstrating to me the types of open problems in discrete math. It also allowed me to work with many different graduate students. Our free time allowed us to work on the problems and become better acquainted. The paintability group in particular was a fun group to work with. I enjoyed working on this problem and I feel we made great progress.

The program schedule worked smoothly. It was an excellent idea to have the visiting professors give their seminars in the morning. These seminars were very informative. I did not work extensively with any of the visiting faculty, but they did present interesting problems and were very informative and entertaining to have around. One disadvantage was having so many different groups in the same room. Working in multiple classrooms seemed to help the groups concentrate.

The support REGS offers is tremendous. I appreciate the financial support that REGS provided me this summer. The social gatherings were always entertaining.

I would like to thank Dr. West for offering his house on several occasions for us to visit. Hopefully I will be able to attend some summer in the future!

Gregory Puleo – Second-year REGS1 student

This summer was my third participating in REGS, and as always I found it to be an enjoyable and useful experience. The social aspect of the program is huge – it gives a very good opportunity for students from different cohorts to interact with each other where otherwise they might not have crossed paths. Beyond the purely social aspects it also fosters a cooperative and collaborative attitude towards mathematics in general, which is particularly useful in combinatorics. I did not interact extensively with the visiting faculty, but I appreciated the opportunity to be exposed to new ideas and methods that may not be well-represented here otherwise.

I did feel that the problem-presentation sessions began to drag on a bit when we were meeting frequently at the beginning of the summer, but given that the alternative might be presenting too few problems initially, it is possible that this is still the best approach.

Daniel McDonald – Second-year REGS1 student

This was my third year participating in REGS, and my experience was once again a positive one. One of the largest benefits of the combinatorics REGS group that I haven't experienced elsewhere is having access to such a multitude of open problems to work on with students and faculty every day of the program. It helped to prevent me from getting bogged down when progress on a certain problem would stall, or when I just felt like I needed a diversion, as I would always have a new problem to turn to. I could still go back at any time to the original problem should I feel I could figure out a way to make progress. Having access to so many problems did, however, make it easy for problems I found interesting to lose the attention of other students in favor of other problems, forcing me to either work somewhat alone or abandon the problem.

The abundance of visiting faculty was beneficial. Early in the program, Robert Jamison, a professor from Clemson University, presented several problems to research. One group of problems was related to rankings of graphs (a ranking on a graph is a labeling of its vertices with positive integers such that any path whose endpoints have the same label contains a larger label), a topic that I had never heard of before and that did not seem to be the subject of active research at the University of Illinois. I spent much of my summer working on this project, and a few nice results were obtained. Furthermore, I plan on looking at problems about graph rankings in my future research.

As a graduate student just entering the research phase of a doctoral program, actually having to find and present an open problem to the rest of the group is a process that I know I must come accustomed to but also one that I have not had much experience with outside of REGS. Without too much research of my own to motivate an interesting open problem, I had to read papers and conference proceedings until I found a set of problems that I wanted to present. As the presenter of that problem, I was responsible for bringing the rest of the group up to speed on the relevant definitions and prior research, which required nontrivial literature searches.

Finally, it is nice to have something to do during the summer that is relevant to my goals and interests. I doubt I would be anywhere near as productive in developing my research skills if I couldn't participate in a program like REGS. The financial support provided is very adequate, and the social activities planned were a nice diversion.

Benjamin Reiniger – Second-year REGS1 student

This is my third summer with Doug West's combinatorics REGS. As usual I have greatly enjoyed the experience. This year I feel I have made better progress on problems than in the past; in particular I expect to be able to write two or three papers from this summer's problems.

This year we met more intensively at the beginning of the summer. I do appreciate the longer contact times and think it has helped research get moving early on; however, I was very glad when the morning sessions were over. Sleeping in over the summer is a nice perk to research.

The social events seemed more frequent this summer. I think these are an important way to get the participants together outside of the usual schedule, making it easier for groups to get together to work on problems on the off-days later in the summer.

I also found myself working more with the visiting students and faculty. It's very nice to have some people from outside the department to bring problems and lectures.

Jaehoon Kim – Second-year international student

What were the most and least successful aspects of REGS? I think REGS provided a lot of good problems, and that's a successful aspect. I think some groups were too large, so it was not efficient to discuss ideas.

How did you benefit from the program? I learned a lot of good problems, and I got to know some good people outside the school.

How can the program be improved? Maybe we can invite more great mathematicians to join REGS, so we can get more out of REGS.

What were the advantages and disadvantages of having so many people involved? Some groups were too large to have efficient discussions. However, the chance of meeting various people was helpful.

How did the presence of visiting faculty enhance the program, and how did you interaction with them? They provided good problems and ideas, so I think they enhanced the program a lot. Frankly, I didn't interact with them much. It's not REGS's problem, it's me. I need to learn how to interact with people.

Did the program provide adequate support (financial, intellectual, social) to make your experience productive? I got grader position and RA-ship for the summer, I didn't get any funds from REGS. In intellectual and social aspect, I think REGS provided enough. There were enough chances to meet people and to discuss ideas (which I didn't take an advantage of much.)

You may briefly mention problems you worked on and results obtained, but please don't include proofs. I worked on EMP, t-tone coloring, game matching number, monochromatic empty triangle.

I got various results from EMP. I found complete characterization of graphs with no 2-EMP, graphs with no 2-EUP. I found an upperbound and lower bound of the maximum number of edges in graphs with no t-EMP. (I think the lower bound example can be generalized to hypergraph, to get a lower bound of the maximum number of edges in hypergraphs with no t-EMP. But the lower bound is something like $(t-1+c)n - c'(t)$ with for some $0 < c < 1$.) I found an upperbound of the maximum number of edges in hypergraphs with no 2-EMP or t-EMP. I found the exact maximum number of edges in graphs with no weak 3-EMP.

In t-tone coloring, I found an example to show lower bound of t-tone chromatic number. And I modified Bill's proof to show an upper bound of t-tone chromatic number of chordal graphs.

In game matching number, I found a connected example of $\alpha_g(G) = 2/3\alpha'(G)$, which is $\overline{K_n} \vee K_n$. Also, I helped Suil to figure out game matching number of some cubic graphs. I don't think I contributed to this problem enough; if this becomes a paper, I will not join as an author.

In monochromatic empty triangle, I couldn't get any result. But I am still interested in the problem.

Mu-Tsun (Donald) Tsai – Second-year international student

How does REGS compare to research experiences you had before coming to UIUC? Nearly always my research was just me and perhaps my advisor, so this is a great opportunity to work with other people.

What were the most and least successful aspects of REGS? I like the part where it allows me to participate in various problems with various people. The only problem I think is that the current design have the tendency that people would be likely to ignore the problems proposed later and keep working on their current problems.

How did you benefit from the program? I think the most beneficial part is that I get to know lots of interesting recent problems.

How can the program be improved? Might be better if the morning section can take place in a slightly larger room, like 245. :)

What were the advantages and disadvantages of having so many people involved? I think having a lot of people is always a good thing. More opportunity to work with others and to solve problems.

How did the presence of visiting faculty enhance the program, and what was your interaction with them? Many of them provides knowledge that I haven't learn before. Although eventually I didn't make progress towards their problems, understanding what they're doing is a good thing on its own.

Did the program provide adequate support (financial, intellectual, social) to make your experience productive? I got some funding, which really helps a lot on my situation.

Amelia Tebbe – First-year REGS1 student

For me, the most successful aspects of REGS were having so many problems presented at the beginning and having visiting faculty. It took me a little while to find problems that I really wanted to work on, so having a lot of options at the beginning was helpful. The visiting faculty added a lot of diversity to the group and to the problem pool, although some of their problems seemed less accessible. I didn't end up working in groups with many of the visiting faculty, but I did go to lunch with several of them and it was interesting to get their perspectives on things. I also enjoyed the weekly dinners. No aspects of the program come to mind for me as unsuccessful or needing to be changed.

Having such a large group of people was nice because no two problem groups I worked in were the same and there were a variety of problems. However, for both the cops and robber problem and the problem I presented, I found myself in groups that were too big, but for various reasons the groups did not want to split up. For the cops and robbers problem, there were a couple other students who didn't see why having 6 or 7 people in a group was an issue and this caused some tension. In the end, Ilkyoo found a paper that apparently solved our question, so it became a moot point. For the Equal Union problem, we had 7 or 8 people that worked on it in the course of the summer which seems like a large number of authors, but we rarely had more than 4 or 5 people meeting at once, so I don't think it caused any problems in group work.

Thomas Mahoney – First-year REGS1 student

The schedule for this year's REGS was comfortable and effective. I liked the split of problem presentations in the morning and group sessions in the afternoon. Not only did the split help to organize the schedule to know what was happening when, but also the two-hour lunch break gave time to think about what problem to work on or to talk to others further about their presentations.

Meeting five days a week for the start of the program seemed necessary, but it was a nice change when Tuesdays and Thursdays were freed up for writing and more group work. The weekly group dinners

were a lot of fun, and since there was one every week, I didn't feel like I was missing a big event if I couldn't go to one or two.

The problem and result presentations were stimulating, as well as the visiting lecturers. The financial support was certainly adequate and allowed me to go into the summer without worrying about the months were I wasn't getting a TA stipend.

The size of the program this year didn't seem to be as much of an issue as it was last year. Perhaps this is because I have had a year to be around people, or maybe because there are fewer incoming students in REGS, or possibly groups were just better at forming this time around.

At the start of the program, I worked briefly on game matching and t-tone coloring. The bulk of the summer, however, I spent working on paintability. We consistently had 4-5 people working on the problem on any given day (Carraher, Loeb, Mahoney, Puleo, Tsai, West), and I feel like we made significant progress with many results of various kinds. In the begining, we all worked on chromatic paintability and tried to work on specific cases of Ohba's conjecture. Later, we had one subset of people working on claw-free perfect graphs, while another subset (with some overlap) was working on complete bipartite graphs. Each student contributed their own write-ups to the group write-up that we hope to turn into a paper.

Elyse Yeager – First-year REGS1 student

How does REGS compare to research experiences you had before coming to UIUC? The only research I'd done was alone, and mostly self-guided.

What were the most and least successful aspects of REGS? The schedule was great–lots of problems at first, lots of time to break up into groups so we could work through time conflicts.

Sometimes the problems presented were pretty well picked-over, so it was disheartening to work on them and we were likely to give up quickly. But I can't say that it wasn't still a good experience to look at harder things.

How did you benefit from the program? I learned methods for researching problems in the literature. I got research experience, which I was lacking.

How can the program be improved? no ideas, sorry

What were the advantages and disadvantages of having so many people involved? There were lots of time conflicts, so I opted out of some interesting problems in order to allow the rest of the group to have a good meeting time. Also, having so many students made it a little impersonal–I mostly worked with the same group on all my problems in the end. It was nice (if intimidating) to interact with the more advanced students, and it was good having lots of people to present problems.

How did the presence of visiting faculty enhance the program, and what was your interaction with them? Dr Jamison was amazing! He made an effort to be approachable and seemed genuinely interested in our work. I didn't interact much with the others. It was exciting to see new problems that are popular in other places.

Did the program provide adequate support (financial, intellectual, social) to make your experience productive? Absolutely.

You may briefly mention problems you worked on and results obtained, but please no proofs.
Graph ranking: upper bound for grids (turned out this was already published).
Linear extensions (the robot problem): a variety of small results comparing the number of extensions of different arrangements.
Game matching: exact number for paths, preliminary results about the disjoint union of paths.
Graph decontamination (the game that grew out of a cops and robbers variant): a counterexample to a conjecture of David's about cycle permutation graphs, also helped with David's theorems characterising the decontamination number of certain graphs.

Hong Liu – First-year International Student

I enjoy REGS this summer. After taking 580, I found it more productive than last summer. The most difference is that we met more often during the first week of this summer. As a result, we already had a lot of problems to work on at the early summer.

As usual, there are a lot of participants this summer. The good thing is I got to know and work with different people and it's always helpful to work in a group. The disadvantage is that lots of groups have too many people. Having visiting faculties is another successful part of REGS. They brought different taste of problems and the lectures they gave are very beneficial. Although most of the visitors didn't stay for long. It would be great if they could send the problems that they are going to present with some references before they come here. Then the students will be more prepared to work on those problems and make use of their short visit.

I'm working on "the coloring of fractional powers of graphs". We found a counterexample to the conjecture (by Iradmusa) that we were working on. We showed that the conjecture holds for graphs with maximum degree at least 4 when m is even. When m is odd, the conjecture holds for some class of graphs, in general, we bound $\chi(G^{m/n})$ by $\omega(G^{m/n}) + 2$.

I'm also working on "k-corners in d-dimension grids". We gave some upper and lower bounds for the maximum size of a set of points in d-dimension grids with no k-corner. In particular, we are now trying to show the maximum size of a set of points in a cube with no axis-aligned right angle is $3\binom{n}{2} + 1$. We have an argument showing that the leading term $3n^2/2$ is correct.

Last but not the least, the weekly dinner/party is great!

Ilkyoo Choi – First-year international student

Being in a room packed with many other combinatorics fanatics, struggling with questions that are unknown to be true, and discussing math enthusiastically without getting stared at, REGS was a novel experience. It was certainly beneficial and worthwhile in many difference aspects. Although it was my first REGS, I can see myself coming back for most, if not, all, summers in order to share more information, conduct more research, and interact more with discrete mathematicians.

Many aspects of REGS were beneficial because of there were so many participants. I was able to watch and learn numerous methods of research such as trying to generalize small examples, applying classroom theorems, and confirming computation evidence. It was interesting to see how people approach the same problem in a wide variety of ways as well as looking for historic significance. I was exposed to many problems, networked with students and faculty members from several universities, and went through the entire process of conducting research: getting introduced to a problem, conducting research, and presenting results.

The mass number of participants also results in a few downsides of the program. Certain problems attracted many people, and different skill levels made it hard for everyone who wanted to contribute to actually contribute. Also, focusing on one problem became nearly impossible since people from different problems would want to meet and discuss problems.

The social activities accelerated the process of getting to know non-UIUC participants, and are always an opportunity to eat good food. As an international, one personal hope is that there will be more financial support in the future in order for internationals to focus more on research rather than looking for part-time jobs.

Lars Erickson – UIUC Computer Science student

It was fun. I plan on coming back next year, so please make sure the panel keeps the program alive!

1) Comparision to prior research experiences: It was very different. I usually work alone, because the other people in my research group are not all that interested in combinatorics, so it was nice to work with other people for a change.

2) Most successful: Its format makes it very easy to find a lot of people interested in the same problems as oneself. This is particularly useful to someone in robotics like myself, where there is not a huge number of combinatorics-minded people. Least successful: I think that a bit too many problems proliferate over the course of the program. Maybe only allow new problems in the first 3 weeks? (Though perhaps interesting variants of previously presented problems could still be presented, or something).

3) I met a lot of people interested in combinatorics. The usefulness of this cannot be overstated.

4) No important improvements come to mind, although it may be useful if the website contains a list of good venues to publish the results at (for example, things like the special issue of Theoretical Computer Science on graph searching).

5) As far as I can tell, there is little downside to having a lot of people. More people = more people likely to be interested in the problems being presented. The groups working on individual problems get unwieldy if there are too many people in them (more than about 6), but groups that were that large tended to fracture into smaller groups working on different variations of the problems, so this was not actually an issue.

6) I enjoyed the presentations of the visiting faculty, although I did not work on any of the problems they brought up, and I did not interact with them all that much.

7) There was adequate support (I did not ask for financial support, so I can't comment on that). I would like to learn a bit more about the publishing traditions in mathematics (what types of articles are suitable for which journals and whatnot). I can check the journal's impact factor and other statistics to gauge its influence (in as much as these statistics are relevant), and I can see where other mathematicians are publishing their papers by checking their websites, but I think that those only provide me with an incomplete picture of how to go about publishing combinatorics articles.

8) I primarily worked on: Linearizations of posets and two variants of the cops and robbers problems. More briefly, I worked on art gallery problems and fractional powers of graphs.

Michael Santana – REGS0 entering student

This being my first summer doing any sort of research program, let alone the REGS program, I was very satisfied with the results. Of course, the program allowed me to get to know other students, especially the new ones like myself, and gave me the opportunity to familiarize myself with the campus. In the area of research, the REGS program helped give me a head start in research here at Illinois and has given me an idea of the level of competency expected. As for faculty interaction, I really enjoyed having the different faculty members come and share problems. In particular, I really enjoyed the seminar-like lectures they gave, which provided a lot of background information and methods for attacking problems. Now, I know that summer is when a lot of faculty members take off on vacation, but it might be nice to have some of the U of I Combinatorics faculty to share problems like Dr. Yong did. I think it would introduce new students to the staff and perhaps help the older students with choosing advisors.

On the flip-side, I think that the biggest aspect in which REGS can be improved is by providing some research "etiquette", so-to-speak. For example, how does one determine whose names go on the paper? What if someone was always there as a sounding board but didn't come up with any of the results? Etc. After talking with several people throughout the summer, I noticed that the biggest "problem" concerned individuals joining groups after results were being obtained, causing some confusion for the

original group. So, I think some sort of talk at the start of REGS, or maybe something posted on the REGS website, concerning research courtesy would be nice.

As for the problems I worked on, there were mainly two that achieved results. The first was the one I presented about counting the number of sets of arcs that decompose into k paths from the source to the sink in a transitive tournament. Dan Cranston and Greg Puleo found that for each k, a recurrence relation can be obtained and is the characteristic equation of a matrix defined by a partition number of recurrence relations of depth one. The main problem I spent the summer working on (and should have spent more on) concerned the birank number of graphs. Since practically no research had been done on biranking, there was quite a bit that could be done. While no exact numbers have been found, myself, Sarah Loeb, and Hong Liu were able to determine the order of the birank number for generalized theta graphs, the ladder, the prism, the Mobius ladder, and soon, well have the grid. We have also produced bounds for the hypercube, but they are quite trivial at the moment.

Sarah Loeb – REGS0 entering student

As an incoming student, REGS was beneficial in a number of ways. Probably more so than non-incoming students, one of the main benefits was social. In encouraging me to be here significantly before the start of the semester, it gave me time to get settled in Urbana-Champaign. It also meant that I could get a better feel for the department and interact with other combinatorics students before the start of the semester. This has allowed me to get a student's perspective on which classes to take for the next semester. Group dinners were nice because they encourage interaction with people in an informal social setting. They also gave me some ideas about the range of restaurants in the area.

Mathematically, it has been nice to work on a variety of projects. I had done REUs before, but in them I worked with a single group on a single project for the summer. Here, many more problems were presented. This gave me an idea on the types of problems that people are interested in and gave me a number of problems that I found interesting to choose from. Having the opportunity to work on a variety of projects also meant that I could work and learn from more people. This let me see how people approached problems differently. This was striking even within the paintability group, where Tom looked at extending choosability results, Greg wrote a program to calculate paintability or sum-paintability of a given graph, and Donald and James were able to have their own discussions.

The presence of visiting professors meant that I could learn a bit about a few different topics through the seminars. It was also interesting to see some of the directions and problems they were interested in within their respective specialties. However, the professors that came later on had to compete with established problems, which meant that their problems didn't get very much attention. For this reason, I think that it was good that the visiting professors were concentrated towards the beginning of REGS. I worked on problems with a couple of the visiting professors. The first was Robert Jamison who proposed the some of the ranking problem that Mike, Dan, and I have continued to work on. The other was Andrew King. His problems were different than the others I've been working on and it was nice to spend a week taking a break from my established groups and trying to think in slightly different ways.

Michelle Delcourt – REGS0 entering student

How did you benefit from the program? The REGS0 program greatly eased my transition into graduate school. Over the course of the summer I enjoyed learning about a number of stimulating problems and techniques. The program allowed me to work on problems of my choosing as well as to interact and discuss research with several professors in the math department at UIUC. I also enjoyed the weekly social events for the program; I appreciated being able to discuss with other students topics such as course load and classes in a less formal setting before registration. This summer I was able to meet and interact with

other students in the program, to sign a lease for housing for next year, file paperwork, meet with the graduate coordinator to discuss my schedule in the fall, and register for classes; as a result, I feel less nervous and much more prepared for the upcoming semester.

How did the presence of visiting faculty enhance the program, and what was your interaction with them? Having visits from faculty was one of my favorite parts of the program. I especially enjoyed the lecture portions which provided a broader context and motivation for problems. I especially enjoyed the visit with Professor Cioaba. I briefly discussed some of his problems for a few days. The first afternoon, we attempted to find a lowerbound on the number of face graphs by studying their degree sequences. We had hoped to find an algorithmic approach to generating degree sequences of face graphs formed by n+1 lines in general position in the plane from the sequences of those formed by n lines. We did not make much progress, and the next day we focused on trying to construct counterexamples to the proposed characterization instead. The smaller group of students working with him also went to lunch and had a great discussion about mathematics, and he gave us advice concerning teaching.

Results. The first two weeks I worked on a number of problems, but as the summer progressed I narrowed my focus to two problems. I worked on cops and robbers (distance version) and embedding Laman graphs. While working on the Laman project, I learned a lot from interacting with other students in the program. Motivated by Schnyder labelings, my initial interest was to study problems posed by Clemens Huemer and Sarah Kappes concerning embedding planar Laman graphs on grids. We discovered a second paper with Huemer and Kappes as two of the authors which discussed approaches to book embed Laman graphs and the focus shifted. We explored numerous approaches motivated by techniques in combinatorial geometry.

Seager's variation of the cop and robbers game was exciting to me initially because of the relation to the metric dimension problem from computer science. The cop scans a vertex and receives the distance to the robber on the graph. The cop wins if he or she can determine the location of the robber; otherwise, the robber either moves to an adjacent vertex or remains in the same location. The cop wins if the location of the robber can be determined regardless of the robber's strategy. In Seager's variation, the robber is not allowed to move to the vertex just probed (perhaps it is still "hot"). We decided to remove this constraint and analyze a few simple graphs. This simple change altered which cycles were cop-winnable. Inspired by a presentation of another problem presented during REGS, Coloring of fractional powers of graphs, we also looked at fractional graphs and conjecture that $G^{\frac{1}{\mu(G)+1}}$ is winnable, where $\mu(G)$ is the metric dimension of G.

The size of the program and suggestions. The number and variety of problems was stimulating, and the amount of intellectual freedom was exciting. However, I found the size of the program to be overwhelming. The rooms were often noisy and chaotic. At times I had trouble thinking and relocating was necessary. With the introduction of younger students to the program, imposing some additional structure would be beneficial; I felt that many of the problems lacked guidance or motivation.

Once students begin to research, it is perceived as a gamble to work on new problems. There is a reluctance to play around with promising problems if you feel your group is close to obtaining results. Allocating time to work on visiting professors' problems and newer problems posed by students may eliminate the fear of getting pushed out of an old group.

Concern specific to REGS0. This summer I tried to get a chickenpox vaccine. Since I am technically not a student yet, the Health Center would not see me and told me to try again in the fall. This brought to my attention the fact that incoming graduate students would need to go to the hospital if seriously ill. For my past summer programs at other schools arrangements were made with the Health Center to see non-students associated with the math department. Either making such arrangements or including emergency medical care information for the Urbana-Champaign region would be useful.