Summer 2010 REGS in Combinatorics — Final Report — D. B. West

Overview

Our REGS project in 2010 was quite large and quite successful, but it perhaps exceeded the optimal size. Some progress was made on many problems, but on the average the results were less impressive or extensive on individual topics than in recent years. Still, several will become journal papers.

Again the problems that were proposed by faculty, visitors, and students during the summer appear at http://www.math.uiuc.edu/∼west/regs/index.html, the website for the Combinatorics REGS program. Also on that page are the problems from 2009, 2008, and a few of those from 2007. This year students were more diligent about writing up the problems they presented for the web page. I edited these writeups, but in general they did not need as much editing as in previous years. Although I have not advertised it, this page of problems is visible to the world, and people elsewhere are beginning to use it as a source of problems to work on.

New this year is a Results Page with brief summaries of progress made during the summer; it appears at http://www.math.uiuc.edu/∼west/regs/10results.html. 53 problems were presented; progress of some sort was made on about 20 of them. Perhaps as many as ten may lead to papers.

The reason for having so many problems was the large number of participants. As usual, each student was expected to find a problem to present, and visitors also presented problems. I presented problems only on the first day because of the large population.

Last year there were four REGS0 participants, and all had reasonable background in combinatorics. This year there were 10 REGS0 participants, some without much experience in graph theory, where most of the presented problems lie. Most of the REGS0 participants had prior interest in combinatorics, but not all. 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.

If there continue to be large numbers of incoming students, perhaps a longer instructional component should be included. Paul Wenger presented a short crash course (only one hour) for the incoming students. However, comments from several students question the value of such an instructional component. It might be sufficient just to select the initial problems more carefully so that more of them are accessible without much background.

With funding assured earlier, the visitor program was more substantial this year. Three faculty visitors were invited and supported: Garth Isaak from Lehigh University, David Howard from Georgia Tech (a new PhD), and Oleg Pikhurko from Carnegie Mellon. Each visitor gave a seminar lecture in addition to presenting several problems and stayed for most of a week. In addition to the REGS funding, there was some support from the Graph Theory Seminar budget. Given the financial support, the faculty visitors were also quite responsible in writing up their proposed problems for the web page. An unexpected value in having outside faculty visitors was that students found them more approachable than at conferences and appreciated the opportunity for interaction.

Other visitors included former UIUC students, a former post-doc, and some students from regional institutions. Our "alumni" were familiar with the program, and their pres-

ence helped stimulate discussions in the small groups. Possibly one or two students who visited from Illinois Institute of Technology and Illinois Wesleyan may apply here.

As in 2007, we again had a visit from students and faculty at the University of Louisville for an intensive three days of morning and afternoon sessions at the end of the first week. Some of the continuing students thought that such an intensive start is beneficial even without the logistics of visitors dictating it. Again the Louisville people continued the program at home afterward. There was less post-visit interaction between our group and theirs this time, probably because our program was so full.

Altogether, more than 50 people participated substantially. The funded students (REGS0 and REGS1) attended diligently; more senior students and visitors were in and out due to other activities. Of the 10 REGS0 students, eight continued into Math 580; two were from other research areas. The three of last year's REGS0 students who did not take Math 580 last fall took part in REGS again and are now in Math 580.

Again easier problems attracted large groups of students. With so many problems to work on, this was less problematic (to my view) than in the past two years, but students still found many groups too large. Again students felt comfortable participating in multiple groups, though some found that confusing.

The main difficulty was the sheer enormity of the program. Group discussions became quite loud, so students began to spread all over the building. As a result, it was harder for me to keep tabs on what was going on (this was one reason for the development of the results page), and the working groups were more on their own than in past years when I was more involved in each group. Being unable to pay close attention to what was going on in all groups prevented me from breaking large groups into smaller ones on subtopics. Several students and visitors commented that having a larger room would lessen the logistical difficulties; however, we also need blackboards and movable chairs.

It does seem that the difficulties presented by (1) having large groups on individual problems and (2) insufficient attention to problems presented later can both be mitigated by maintaining an intensive schedule in the first week. This would "front-load" the problem presentations so that already in the second week more time would be spent working on problems, and groups would be smaller. I worry that this would make the array of problems more confusing, which is why I have wanted to get students started thinking about problems even on the first day, but maybe the overall management of the summer dictates arranging the first week differently.

It is important to note that this year the program was one week shorter than usual, since the first week of the term overlapped with the SIAM Meeting on Discrete Mathematics, which is a source for open problems. Usually, many projects come to fruition toward the end of the summer. Having an extra week that would be fully devoted to discussions of problems might having completed some partial results and reduced some students' feelings that time was lacking. Many felt that the total time for meetings should be even longer.

Feedback from 12 participants appears as the last section of this report.

There were several social events during the summer at my house or area restaurants. It was noted at the time that participants in small REGS groups did not have a social context during the summer; several of the comments mention this. The overall REGS program should include social events to give those students an opportunity to meet each

other early during their time in a new place. One of the unplanned benefits of the large combinatorics REGS0 group is the close-knit support system these students now have. Five of them were women (two other incoming women in combinatorics were not here for REGS but joined them this fall), and they all seem to feel quite comfortable here.

Participants

Since I was expecting large numbers of REGS0 participants, I did not solicit participants on campus as actively this year. This may explain why we had only one regular participant from Computer Science this year. Nevertheless, more than 50 people participated substantially during the summer.

REGS0 students: Aisha Arroyo, Nate Fieldsteel, David Hannasch, Hannah Kolb, Hong Liu, Thomas Mahoney, Amanda Olsen, Oliver Pechenik, Jennifer Wise, Grace Work.

REGS1 students: Daniel McDonald, Immanuel McLaughlin, Ben Reiniger, Greg Puleo.

REGS2 students: Jane Butterfield, Bill Kinnersley, Matt Yancey.

UIUC senior students (US): Tim LeSaulnier, Kevin Milans, Chris Stocker, Paul Wenger.

UIUC International students–precomp: Ping Hu, Jaehoon Kim, Wipawee Tangjai, Sogol Jahanbekan.

UIUC International students–senior: Kyle Jao, Ida Kantor, Younjin Kim, Mohit Kumbhat, Suil O, Hehui Wu.

UIUC Computer Science: Reza Zamani.

Louisville students (some already graduated and teaching): Ben Allgeier, Tim Brauch, Lucas Hoots, Adam Jobson, Jordan Lake, Max Leidner.

Other visiting students: Hee-Je Cho (Konkuk Univ.), Jinyu Huang (Ill Inst Tech), Wonjin Park (Seoul Natl. Univ.), Derrick Stolee (U. Nebraska), Taole Zhu (Ill Wesleyan).

Invited supported faculty: David Howard (Georgia Tech), Garth Isaak (Lehigh Univ.), Oleg Pikhurko (Carnegie-Mellon Univ.).

Visiting former UIUC students and post-docs: Stephen Hartke (U. Nebraska), Michael Barrus (Black Hills State U.), Daniel Cranston (Virginia Commonwealth U.), Seog-Jin Kim (Konkuk Univ.).

U. Louisville faculty: Csaba Biró, Andre Kézdy.

Other visiting faculty: Sobhan Babu (IIT Hyderabad)

Funding was provided for REGS0 and REGS1 domestic students. A very small amount of funding from the department was spread among a few 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.

The practice of having students register for a course was dropped this year.

Publications Progress

This is a partial list of papers that originated in past REGS. There may be some additional papers on which I am not a coauthor that I don't know about. This list includes updates on a number of papers that were listed last year.

REGS 2004.

Bunde, David P.; Chambers, Erin W.; Cranston, Daniel; Milans, Kevin G.; West, Douglas B.; Pebbling and optimal pebbling in graphs. *J. Graph Theory* 57 (2008), no. 3, 215–238.

Cranston, Daniel W.; Sudborough, I. Hal; West, Douglas B.; Short proofs for cut-and-paste sorting of permutations. *Discrete Math.* 307 (2007), no. 22, 2866–2870.

Liu, Qi; West, Douglas B.; Tree-thickness and caterpillar-thickness under girth constraints. *Electron. J. Combin.* 15 (2008), no. 1, Research Paper 93, 11 pp.

Milans, Kevin G.; Clark, Bryan; The complexity of graph pebbling. *SIAM J. Discrete Math.* 20 (2006), no. 3, 769–798

Vandenbussche, Jennifer; West, Douglas B.; Yu, Gexin; On the pagenumber of k-trees. *SIAM J. Discrete Math.* 23 (2009), no. 3, 1455-1464.

REGS 2005.

Barrus, Michael D.; Kumbhat, Mohit; Hartke, Stephen G.; Graph classes characterized both by forbidden subgraphs and degree sequences. *J. Graph Theory* 57 (2008), no. 2, 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), no. 6, 625–632.

Choi, Jeong-Ok; Hartke, Stephen G.; Kaul, Hemanshu; Distinguishing chromatic number of cartesian products of graphs. *SIAM J. Discrete Math.* 24 (2010), no. 1, 82100.

Chambers, Erin W.; Kinnersley, Bill; Prince, Noah; Douglas B. West; Extremal problems for Roman domination *SIAM J. Discrete Math.* 23 (2009), no. 3, 1575-1586

Hartke, Stephen G.; Vandenbussche, Jennifer; Wenger, Paul; Further results on bar k-visibility graphs. *SIAM J. Discrete Math.* 21 (2007), no. 2, 523–531.

Liu, Qi; West, Douglas B.; Yu, Gexin; Implications among linkage properties in graphs. *J. Graph Theory* 60 (2009), no. 4, 327–337.

REGS 2006.

Balogh, József; Hartke, Stephen G.; Liu, Qi; Yu, Gexin; On the first-fit chromatic number of graphs. *SIAM J. Discrete Math.* 22 (2008), no. 3, 887900.

Chambers, Erin W.; Kinnersley, Bill; Prince, Noah; Mobile eternal security in graphs. Submitted.

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), no. 17, 3982–3985.

Cranston, Daniel W.; Kim, Seog-Jin; List-coloring the square of a subcubic graph. *J. Graph Theory* 57 (2008), no. 1, 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*, accepted.

REGS 2007.

Barrus, Michael D.; Hartke, Stephen G.; Jao, Fang-Kai; West, Douglas B.; Thresholds for graphic lists with and without gaps. Submitted.

Butterfield, Jane; Grauman, Tracy; Kinnersley, Bill; Milans, Kevin G.; Stocker, Christopher, West, Douglas B.; Online degree-Ramsey theory. Submitted.

Cranston, D. W.; Kim, S.-J.; Yu, G.; Injective colorings of sparse graphs. *Discrete Math.* 310 (2010), no. 21, 2965-2973.

Grauman, Tracy; Hartke, Stephen G.; Jobson, Adam; Kinnersley, Bill; West, Douglas B.; Wiglesworth, Lesley; Worah, Pratik; Wu, Hehui; The hub number of a graph. *Inform. Process. Lett.* 108 (2008), no. 4, 226–228.

Kantor, Ida; Prague dimension of trees. Submitted.

LeSaulnier, Timothy; Prince, Noah; Wenger, Paul; West, Douglas B.; Worah, Pratik; Acquisition number of graphs. Preprint.

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

Prince, Noah; Wenger, Paul; Unit acquisition in graphs. Preprint.

Wu, Hehui; West, D. B.; Packing of S-trees. *J. Combin. Th. B*, accepted pending revision.

REGS 2008.

Balogh, József; Lenz, John; Wu, Hehui; On the independence number and clique minors. Submitted.

Busch, Arthur H.; Ferrara, Michael J.; Hartke, Stephen G.; Jacobson, Michael S.; Kaul, Hemanshu; West, Douglas B.; Packing of graphic sequences. *J. Graph Theory*, accepted pending revision.

Downey, Rod; Greenburg, Noam; Jockusch, Carl; Milans, Kevin G.; Binary subtrees with few path labels. *Combinatorica*, to appear.

Kinnersley, Bill; Milans, Kevin G.; West, Douglas B.; The degree-Ramsey number of graphs. In preparation.

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

LeSaulnier, Timothy; Wenger, Paul; West, Douglas B.; Acyclic coloring of orientations of graphs with bounded degree. In preparation.

Milans, Kevin G.; Rautenbach, Dieter; Regen, Friedrich; West, Douglas B.; Cycle spectra of Hamiltonian graphs. Submitted.

REGS 2009.

Cooper, Joshua; Lenz, John; LeSaulnier, Timothy; West, Douglas B.; Uniquely C_4-saturated graphs. Submitted.

Cranston, Daniel W.; Kinnersley, Bill; Milans, Kevin G.; Puleo, Gregory; West, Douglas B.; Chain games on posets. Submitted.

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

Kinnersley, Bill; West, D. B.; Zamani, Reza; Game domination number. In preparation.

LeSaulnier, Timothy; Stocker, Christopher; Wenger, Paul; West, Douglas B.; Rainbow matchings in edge-colored graphs. *Electron. J. Combin.* 17 (2010), no. 1, Note 26, 5pp.

Milans, Kevin G.; Schreiber, Daniel; West, Douglas B.; Acyclic sets in k-majority tournaments. Submitted.

Yancey, Matthew; Monotone sequence games. In preparation.

REGS 2010.

Butterfield, J; Cranston, D.; Puleo, G; West, D.B.; Zamani, R.; Revolutionaries and spies. In preparation.

Butterfield, J; Hartke, S.; LeSaulnier, T.; Milans, K; Stolee, D.; Wenger, P.; Immersion-closed families. In preparation.

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

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

Hartke, Stephen; Stolee, Derrick; West, Douglas B.; Yancey, Matthew; Largest graphs with exactly p perfect matchings. In preparation.

Jahanbekan, Sogol; Kim, Jaehoon; O, Suil; Tangjai, Wipawee; r-dynamic chromatic number of graphs. In preparation.

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

Pechenik, Oliver; Wise, Jennifer; A-cordial colorings. Preprint.

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

Several other investigations from this summer may yet grow into papers, including work on score sequences of tournaments, reconstruction of posets from ideal sizes, edge-antipodal colorings of hypercubes, edge-reconstruction of multigraphs, cliques in graphs with large chromatic number, b-coloring of graphs, 3-cordial coloring, and the game of "Chaos" on graphs.

The large number of participants this year may have affected the depth of the results. There were minor or negative results on many problems. Perhaps it would be worthwhile

next summer to encourage some of this summer's groups (particularly those that had many REGS0 students) to continue work on the problems where they had partial results.

Another observation is that with so many participants the organizer should do some "post-processing" to push students to write up and submit results for publication. I am trying to do some of that now.

In previous years I included in the final report descriptions of some of the results obtained. This year I am taking advantage of the effort spent on the Results Page to skip that. Again, links to the statements and background for problems studied are at http://www.math.uiuc.edu/∼west/regs/index.html, and rough descriptions of the results are at http://www.math.uiuc.edu/∼west/regs/10results.html.

Participant Reports (ordered by seniority)

These reports have been very lightly edited to achieve consistent format and spacing, etc.; mostly they are as submitted. I provided some questions for students to consider in giving their feedback, in order to encourage more to respond. This is the reason for the similarity in topics addressed by the comments.

Oleg Pikhurko – Faculty Visitor (Carnegie-Mellon Univ.)

What were the most successful aspects of REGS? Being able to talk about problems that interest me to a large audience (over a week).

How did you benefit from the program? It was a new and interesting experience :-)

How can the program be improved? For me it is difficult to think and concentrate when people around talk. More separate classrooms for discussions?

What were the advantages and disadvantages of having so many people involved? Advantage: higher chance that somebody will get interested. Disadvantage: noise during discussions.

Derrick Stolee – Visiting Student (U. Nebraska, finishing)

As a visitor from Nebraska, it has been a privilege to participate in the Combinatorics REGS. The opportunity to hear about a large number of interesting open problems has opened my eyes to the amount of opportunity to do important research in discrete mathematics that I would not find solely in my home institution. Through the course of the past five weeks, I have made progress on two problems with two largely disjoint teams (my advisor is the only other common author, only because we are interested in similar things) and had many discussions about interesting problems. All of these problems were unknown to me until this summer, but the collaborative environment has driven results in a short amount of time. In the following months, I will work to keep these collaborations active as well as converting our shorthand notes and sketches of proofs into full papers.

The most significant benefit of my experience has been interaction with the large number of high-quality graduate students at UIUC. The time during REGS sessions and outside them has given me time to create friendships with people who will be colleagues long into the future. The amount of collaboration and sharing of problems is astonishing

and is to be admired. I hope to adopt some of that culture into the discrete mathematics group at Nebraska.

The invitation for visitors to participate not only made my own experience possible, but enlivened the sessions with new problems from new faces. I have met more mathematicians and built stronger relationships with them than I could at any conference. This social aspect of research was something I found challenging during my first year of attending conferences. This summer has given me more confidence that I am welcome among mathematics researchers.

I thank Douglas West for inviting us to visit and hosting us in Illini Hall. The entire combinatorics group at UIUC has been very welcoming.

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Jane Butterfield - REGS2 Student (4th-year)

REGS really recharged me this summer. I had been looking for a new problem for about two months, with little success. I was thrilled when I managed to find just one problem to bring to REGS. After just the first week I had already heard several problems that interested me. By the end of summer I had gotten involved in two groups, each of which should lead to papers. Besides that, there are still more problems I heard of that I would like to think about next. This has really set me up for the coming year.

I particularly liked the way REGS was structured this summer. Because of visitors' schedules, we had twice as many meetings in the first week as usual. This intensive schedule allowed us to see many more problems in the first week than we generally would, which I think was beneficial. Problems presented early are more likely to get worked on, and each student will have longer to work on his or her problem if it was presented sooner. I think that future summers should be conducted in the same way, whether or not there are visitors with schedule restrictions.

I also appreciated how many visitors there were this summer; it made REGS an opportunity to meet and collaborate with researchers from outside the university. It was a great environment for actually working with visitors, who seemed more accessible than they do during the semester or conferences. I twice ended up in groups with visiting faculty. Each visiting faculty gave a seminar talk outside of REGS, which was also good–it broke up the routine and was an opportunity for a more instructive presentation. I would like to see this continue in future summers as well, possibly even during weeks when there is no visiting faculty member, because it helps the students to keep up with current research rather than only open problems.

The only problem I had this summer was that there were too many problems I wanted to stay active in. Because my groups tended to form for the whole afternoon, I had to choose just one to stay with each day. This meant that I ended up not exploring new problems after getting involved in two, because I didn't think I could spread my attention thin enough. This is perhaps unavoidable, although later in the summer (after presentations have ceased) it would be possible to divide the sessions into two parts so that we could meet with two groups. Because REGS meets only MWF, I was able to meet my other

group on off-days, so two problems were manageable; I still think I would have trouble working actively on more than two.

Bill Kinnersley - REGS2 Student (4th-year, finishing)

This summer, as in several previous summers, I participated in Professor West's Combinatorics REGS group; the experience was, as always, quite valuable.

Each participant in the REGS group is responsible for finding and presenting an open problem. This is a beneficial exercise: finding problems and giving formal presentations are both important skills to develop. In addition, during a presentation, listeners will often suggest new questions or directions that may not have occurred to the presenter. I also benefited from listening to so many student presentations. Since there are so many students, there are many different types of problems presented. Several presentations got me interested in problems outside my "comfort zone"; had I seen one of these problems in a journal, I probably would have ignored it in favor of something more familiar.

While the REGS group does benefit from having so many students, it seems that the group has grown past its optimal size. As the number of participants rises, so does the average size of a group on a given problem. (Although with more participants there are more problems presented, students tend to flock to a few problems that seem particularly accessible and/or were presented early in the summer.) It is difficult to communicate effectively in groups having more than three or four people. Moreover, large groups often get quite loud; this can be distracting for students in other groups. Unfortunately, it is unclear how to resolve this issue. Perhaps it would help to compile and distribute several problem writeups before the official start of REGS, so that a wider variety of problems would be available for research right off the bat; these problems could be contributed by faculty and senior graduate students.

This year, the REGS group included substantially more REGS0 students than in the past; they were welcome additions. However, many lacked substantial background in graph theory, and thus were unfamiliar with some terms and ideas that continuing graduate students usually take for granted. This was only a minor inconvenience, but even so the issue should be addressed. The proposed "instructional component" for REGS0 students would probably be excessive, but the students would benefit from one or two short lectures on common notation and terminology. Paul Wenger organized a similar session this summer; this was a good start, but it would be best to have something more extensive, more "official", and announced farther in advance.

Matthew Yancey - REGS1 Student (2nd-year)

I considered the REGS of 2010 to be a personal success. Results were obtained on two problems, and each of those problems I consider to be more significant than the problem I worked on last summer. I met faculty and students from the University of Louisville and the University of Nebraska. I would say that I am very grateful for the program during 2009 and satisfied with my personal progress during it, and very grateful for the program in 2010 and excited with my involvement in it.

Visitors: Although many visitors came to the program, the only ones I talked to about math outside the classroom discussions were Derrick Stolee and Stephen Hartke. I did have lunch with the group from Louisville, but that was mostly a social situation. It is not a coincidence that the group from Nebraska was the set of visitors I worked most with: I usually take thinking over a problem before I dedicate myself to solving it. Usually by that time I have no results but only ideas of how to get results. The group from Nebraska was still in town weeks after their problems were presented, and it was easy for me to find a room with them and discuss how follow a path of thinking towards a result. No other group stayed that long, and without results and only a desire to re-try a problem, it seemed difficult to include them in further work using email.

Even though I did not work with the other visitors, they still contributed much to the experience for me. Many of them brought problems that were different than the set introduced by students from Illinois. I especially liked 'Lines tangent to four unit balls' by Professor Kezdy for its geometric flavor that is uncommon in the list of problems and the problems of Csaba Biro and David Howard for problems relating to fundamental areas of combinatorics.

Advantages and Disadvantages: REGS, besides being a good source of research projects, acted strongly to integrate new students to Illinois. The incoming grad students seemed to acquaint themselves to Illinois well. One disadvantage of this is that new first-years that did not come to REGS mentioned feeling left out during orientation.

The new students managed to keep pace on any project that I worked on, but few of them worked on the projects that I worked on. One suggestion for handling incoming grad students with a less instructional background is to get problems that require little background to present early. The start of REGS this year began with problems about Ramsey theory and Posets. The new students seemed to get a better grip on the problems after they learned more about posets as well as when easier-to-approach problems like 3-cordial coloring and games like Chaos were presented. If a game like Chaos was presented earlier they may have joined a problem with full interest earlier in the program.

Ben Reiniger – REGS1 Student (1st-year)

This is my second year working with Doug West in the combinatorics REGS. Both years I have really enjoyed taking part in the program. The summer begins with a frenzy of problems to consider. After a couple of weeks, the new problems slow down, and time to work on old problems increases. By the end of the summer we have heard over fifty open problems. This allows for personal interest to dictate which problems are studied most intensely, which is very nice. It is sometimes also a detriment, in that sometimes it's hard to find a group to work with on a problem that you like.

In addition to all the problems introduced by Doug and REGS participants, we also had a few visitors from outside the program give us some very nice problems. One of these problems was of particular interest to me: if the edges of a hypercube graph are colored with two colors such that *antipodal* edges have different colors, then does there necessarily exist a monochromatic path between some pair of antipodal vertices? There is such a path in cubes of dimension up to 5. Some interesting methods of attack have been employed during the summer, but the problems remains open.

The problem I introduced was of my own creation this summer, a spinoff from the problem I presented last year. It defines the graph parameter *quack number* (or queue/stack number) and asks how it relates to the earlier parameters *queue number* and *stack number*. I had hoped to make some easy but interesting statements about this parameter before moving on to harder questions, but it seems to be a harder problem than I anticipated: we still don't know the quack number of complete graphs.

This year seemed to be pretty full of combinatorial games. One game in particular, involving stacks of tokens on vertices which occasionally "toppled" onto neighboring vertices, has attracted a lot of my attention. We now know how the game works on complete graphs, cycles, trees, and complete bipartite graphs. We have changed gears a bit recently and are now looking at a nonpartisan version of the game, which seems to have some deeper game theory involved.

Hong Liu - REGS0 Student

As last summer, I learned a lot from the problems people presented. It was a lot of fun to work in groups. I got the chance to know all the other incoming students in Combinatorics.

I think an instructional component for entering students is necessary. The visiting faculty brought many interesting problems of different flavors (like posets).

I was working on Gold grabbing game and 3-cordial coloring. In Gold grabbing game, we showed that when the graph is a double star of even order, the first player can secure at least one half of the total gold. Some of Steven's students proved the same result on even order trees.

In 3-cordial coloring, we showed that uni-cyclic graphs are 3-cordial colorable. We are trying to show cacti can be 3-cordial colored.

Thomas Mahoney – REGS0 Student

What were the most and least successful aspects of REGS? The most successful aspect of REGS was the wide variety of problems to work on and not ever running into the problem of being "stuck" working on a particular problem. The least successful aspect, at least early on, was having limited time to play with problems after hearing problem presentations.

How did you benefit from the program? I gained exposure to many problems I had not seen before, and I benefited from seeing how returning students presented and wrote about their problems and results.

How can the program be improved? I would enjoy a better balance of lecture time of presentations and results and getting to work on problems.

What were the advantages and disadvantages of having so many people involved? It was great to know that on almost any problem, multiple people would be thinking about it. In a small room, it generally felt cramped and we had to move into several rooms to have space to work. A larger room in the future would resolve some of the issues.

Would it be a good idea to augment the program with an instructional component for entering students (perhaps lectures and problem-solving)? Having lectures and problem-

solving sessions would be helpful to entering students. It would be useful to help "jump-start" entering students' confidence in the case that so much unfamiliar material is presented in the problems.

How did the presence of visiting faculty enhance the program, and what was your interaction with them? I enjoyed the visiting faculty very much. In several cases, I talked with them more than I did with returning graduate students. They were particularly helpful in getting a problem "started" in a group with good ideas on how to attack the problem.

If you wish, you may briefly mention problems you worked on and results obtained, but please don't include proofs. I worked on unicyclic 3-cordial graphs, Z2xZ2-cordial prisms, ladders, and grids, and early on in the complete bipartite chaos problem.

Amanda Olsen - REGS0 Student

The most successful aspect of REGS was the exposure to many diverse research topics. Being an incoming graduate student, this exposure is beneficial in the process of determining a research topic for the focus of my graduate study. However, this is also what I consider to be the least successful aspect of REGS. I felt the exposure to the many problems presented was a little extreme. This can be overwhelming to incoming graduate students and cause them to remain focused only on the problems that were presented early in the program, not wanting to strain yet again to learn a new topic. I will admit that the compilation of all the problems on the website was helpful in keeping up with all the problems and instrumental in deciding on what problems to focus.

I benefited from the program in a number of ways, starting with the increase in my knowledge base in combinatorics. I do feel that the exposure to so many areas of combinatorics was beneficial in introducing vocabulary that will be essential in later research. I also had the opportunity to work with other graduate students with whom I will be working in the upcoming years. The program also gave me the opportunity to get to know a little bit more about what to expect in the upcoming year, mainly by conversing with upper level graduate students.

Besides the addition of an instructional component for the incoming graduates and implementing a better system for the number of problems presented, I can think of no other improvements for the program.

One advantage of having so many people in the program is that there are a variety of inputs from people of varying levels of experience. Conducting research with so many experience levels helps everyone in the group to grow intellectually. Of course the incoming graduate students get an opportunity to work on research and learn new topics, but it is also effective for teaching those upper level graduate students and professors more about a certain topic just by having to explain it to incoming graduate students. It is said that a person learns more from teaching than from sitting in any lecture. Going back to the exposure, another advantage is the number of topics that get introduced. Again, this number should maybe be limited so as not to appear overwhelming.

One disadvantage of having so many people is that the later problems were not discussed as much as the earlier ones. Requiring everyone to introduce a topic is a great idea, but when there are so many people the topics introduced later have no chance of competing with the ones that have already been discussed for several weeks. Another disadvantage

was apparent at the beginning of the program. With so many people and so few problems presented, the groups of people working on any given problem were massive. I felt this allowed the incoming graduate students to fade into the background or even feel intimated.

I do feel that the addition of an instructional component for incoming graduates would be beneficial. I felt that by requiring additional instruction during REGS meeting times, we were using time that could have been devoted to playing with the problems. Perhaps when people decide to present a problem, they should notify others of the topic in advance. This would allow for an optional instruction on the off days of REGS for the incoming graduates to come in and learn the necessary definitions and background. Also, there could be some recommended reading that incoming graduates could do before attending REGS.

The presence of visiting faculty was beneficial to the program. The professors with whom I had a chance to work were experienced in their research area and were excellent sources of information. They provided extra explanation for definitions and background whenever I asked and had great insight to lead the research in a profitable direction.

Thank you for the opportunity to participate in this program. Overall it was a beneficial experience, and I would gladly participate again.

Oliver Pechenik - REGS0 Student

1) There were several REGS0 students outside of combinatorics. No one gave them contact information for any of the rest of us, so they spent the summer alone. This is sad. It would be great to have some kind of meeting of all the REGS0 people, for them to get to know each other. Or since the combinatorics group is by far the largest, just invite everyone else to stop by at the end of one of our meetings and introduce themselves.

2) The program was most successful in exposing us to a wide variety of research topics in combinatorics. I think I have a much clearer picture than before of what combinatoricists in general are up to. However, this was also the biggest shortcoming of the program–there were so many problems, that our attentions got scattered. Not to mention that by the time all the problems had been presented, there was very little time left to work on them.

3) I understand why you want to have everyone present. However, with such a large group, if everyone presents a new problem, there will be too many problems. Perhaps it would make sense to have the REGS0 students present results that have been obtained, and have only the older folks present problems.

4) I think most of us wouldn't have minded meeting for more time. A 3-hour chunk isn't very much, when you spend the first half listening to presentations. As soon as you feel like you are making progress on a problem, it is time to go home. Perhaps having presentations of things before lunch and then using the full 3-hour block in the afternoon to play with them would be a better solution.

5) I would not want an educational program for incoming students. A lot of us already had sufficient background; those that didn't, picked it up extremely quickly. The first few days must have been pretty confusing, but it wasn't long before everyone knew what was going on.

6) I enjoyed having visiting faculty, but again they were partly responsible for there being too many problems.

7) The research groups also got too large. I'm not sure what can be done about that. This was particularly noticeable with the antipodal hypercube stuff, which didn't break into components that could be attacked separately. So we ended up with about 8 people all trying to do the same thing at the same time, and getting thoroughly in each other's ways. The 3-cordial people, I believe, had similar problems.

8) Most of my complaints above aren't actually complaints. I came into this summer a bit burnt out, and was hoping for something relaxing, which is exactly what I got. It was fun; it was educational–there is still part of me that wishes I had worked harder and gotten more research accomplished, but I think it is for the best that I didn't because now I have energy back for school.

Thanks for running a thoroughly enjoyable program!

Jennifer Wise - REGS0 Student

For me the most helpful aspects of REGS were having to choose a topic to present to everyone else and working with people of different levels of experience. Having to choose a topic helped me to understand how to find and pick a feasable topic for myself and gave me an idea of what all is out there and what has been done on some of it. I benefited from this program by gaining new experience in research and proof techniques, and I also learned more about different aspects of combinatorics that I had not really delved into before. There were many different topics presented to the group that introduced new ideas or definitions to me.

The number of people involved was advantageous in that it allowed for many different view points and perspectives on the problems and the opportunity to work with different people and find some you meshed with. It also allowed for many different styles of problems to be presented so there was something for everyone. The disadvantage to this is that there were problems presented that people expressed an interest in originally but then never really got very far off the ground as there were other problems to work on to distract the interested people.

This summer there was a short tutorial in the first week for incoming students that covered some basic ideas and definitions that I think was very helpful in letting us understand what was going on in some of the presentations without the presentor having to go into as much background as they might otherwise. I do not know how helpful much more would have been as no one knew at that time which topics would come up later in the summer so the concepts presented were general. The more specific ideas and definitions were (and should still be) given in the presentations for everyone (since incoming students might not be the only ones not to recognize these).

Grace Work - REGS0 Student

Most successful: The wide variety of problems allowed me to find several that I was interested in and understood. Because I started the program with no background in combinatorics, the review at the beginning of the summer was especially helpful.

Least successful: I think it is beneficial that every participant be forced to present, but because of the large number of people, perhaps only the current students should be

required to present. Incoming students can present if they have a problem they are particularly interested in. It was difficult for me to find a problem that I understood enough to present. I found the 3 hour sessions too long, perhaps if it were broken down with a lunch break in the middle I would have more stamina to work on problems during the session.

Benefits: I benefited greatly from the program, I learned the basics of graph theory, gained experience working with problems, and also was able to meet and interact with current and incoming students. It allowed me to get comfortable before classes start.

Improvements: I'm not sure what the ideal layout would be, for me at least, perhaps an hour from 11 to 12 of presentations, a break for lunch and then 1-3, or later, we work on problems. Some groups did get large very fast, I do not know how one would force the groups to remain small. When they got large it was much harder for each person to contribute and be heard.

On the number of people: With the large number of people we were exposed to a large number of problems. In some ways this was beneficial, each person managed to find at least a couple of problems they were interested and wanted to work on. It also served to overload me with information and a lot of problems that I did not understand. This is not necessarily a bad thing though. I didn't really get to interact with many of the other participants, except the incoming students, I'm not sure whether this is a result of the large number of people, or just the way it usually goes.

Entering Students: I would have benefited from, and enjoyed, more instructional components, but I'm not sure how many of the other incoming students would have. Most of them already have a good background in combinatorics and are certain they want to continue studying it. I think I might just be an anomaly.

Visiting Faculty: I enjoyed attending the lectures of the visitors, though, to be honest, a lot of their presentations went over my head. I did not have very much interaction with any of them, but it is still interesting to hear from other people and to learn about what others are currently researching and working on.

Overall I enjoyed the program and am very glad I had the opportunity to participate.