EDITOR'S NOTE:

For more than a decade, *OR/MS Today* has invited the most recent recipient of the INFORMS Prize for the Teaching of OR/MS Practice to contribute an article to the magazine's annual special issue on innovative education. We ask for a brief description of the award-winning O.R. program and the reasons for its success, as well as an outline of the recipient's educational background, teaching philosophy, mentors and advice for their fellow O.R. educators. Following is the story of the 2016 teaching prize recipient S. Raghu Raghavan.

Industry experiences shape teaching philosophy

Teaching of OR/MS Practice Award-winning professor's advice: be yourself, be enthusiastic, be prepared.

By S. Raghu Raghavan

What a wonderful honor to receive the 2016 INFORMS Prize for the Teaching of OR/MS Practice and to join a distinguished cohort of educators. As an undergraduate the applied nature of operations research is what drew me to the subject. I was an aerospace engineering major who happened upon an O.R. course purely by accident (it was classified as satisfying a social sciences requirement that all engineering undergraduates were supposed to take). The immediate connection between real-world problem-solving and the analytical models was so powerful that I immediately became a convert. Quite frankly it is an immense joy (and perhaps for me the best job in the world) to have the opportunity to teach and excite students on OR/MS topics as well as their immediate real-world applications.

In my teaching, I aim to popularize the need and use of OR/MS techniques for decision-making, and to teach students OR/MS decision-making techniques with a specific emphasis on OR/MS practice. Prior to embarking on my academic career, I was fortunate to spend four years at the telephone company U S WEST (now known as CenturyLink) as a freshly minted Ph.D. out of MIT's Operations Research Center. U S WEST was a recipient of the 1994 INFORMS Prize, and the experiences I gained working with a group of OR/MS

professionals in practice went a long way in developing my teaching goals and philosophy.

First off, I quickly realized that there are some significant differences between OR/MS in academia and OR/MS practice. OR/MS in academia comes in the form of well-defined problems and solution methods, while OR/MS in practice often comes in the form of poorly structured problem statements and vague notions of goals and constraints. One often finds that the fanciest technique learned as a graduate student may not be the best suited one for the project at hand. Further, the decision-makers (i.e., the ones who control the purse strings) have a great deal of domain or subject matter expertise but often have no exposure to OR/MS tools and techniques. This creates challenges in convincing them of the potential value of OR/MS techniques (my work at U S WEST predates the recent buzz surrounding business analytics) to "their domain."

OR/MS in academia has two distinct audiences and foci. The first audience is typically interested in developing strong methodological foundations and the academic focus is similar, with a large amount of exposure to theory. The second audience is typically interested in breadth, and the academic focus is on exposing students to the benefits of OR/MS techniques. What happens frequently with this second audience is they often get such a rapid exposure in a compressed amount of time that they sometimes lose sight of the value of the techniques or leave with the impression that OR/MS techniques can only solve simple problems. At Maryland (as well as many other business schools) these two audiences come as doctoral students (who are often engaged in providing OR/MS practice when they join the workforce) and MBA students (who are the consumers of OR/MS practice when they join the workforce).

For the long-term health of OR/MS it is important to connect these two audiences (to make them effective practitioners and consumers of OR/MS) much more strongly in an academic environment. I have tried to do this in my teaching. I try to provide the first audience a greater appreciation and understanding of issues related to applying OR/MS in practice. I try to provide the second audience a greater exposure to OR/MS methodologies and applications so they can make those connections and hire the right OR/MS professional when the need arises.

I encourage doctoral students to take summer internships at companies and to use real-world problems to motivate their thesis. Although the work is often very technical, it is clearly focused on problems motivated from OR/MS practice. I work closely with the student through the problem formulation phase (meeting with the industrial contact) and the development of solution techniques that are appropriate for the practical situation. With MBA students (who are critical to OR/MS as consumers of OR/MS practice), I spend a large amount of time exposing them to a wide variety of real-world cases and the application of OR/MS techniques. One important focus is to make those connections between business situations and OR/MS opportunities that I often do by bringing guest speakers from industry to my classes.

S. Raghu Raghavan was the 2016 recipient of the INFORMS Prize for the Teaching of OR/MS Practice.

I've had the opportunity to teach more than a thousand students over the past 19 years. My students have played the most significant role in shaping my teaching – and the ones I owe the greatest thanks to. Their probing questions and their desire to closely see OR/MS practice in the classroom have a large part to play in influencing my teaching. With them I have conducted many research projects from OR/MS practice. Most of these projects are used in my teaching materials for my master's- (MBA, Executive MBA and M.S. programs) and Ph.D.-level courses. The two projects described below provide a snapshot of how I engage my students in real-world OR/MS projects and help them develop into effective OR/MS practitioners

My students have played the **most significant role** in **shaping my teaching –** and the ones I owe **the greatest thanks to.**

Budget Allocation at Catholic Relief Services

It all began with a class project, and it ended up changing the budgeting process for an international relief agency. We (MBA student Rick Nidel, Ph.D. student Ioannis Gamvros and I) used optimization methods to help decision-makers at Catholic Relief Services (CRS) allocate the agency's budget in a way that was aligned with their strategies and goals. Nidel, who had worked for CRS for 10 years before becoming an MBA student, was taking an MBA elective course with me. The exposure to OR/MS techniques and applications in the course helped Nidel see the potential for OR/MS tools in helping the agency with its budgeting process (which he described at a very high level in his class project). To take this to fruition Nidel approached the two of us.

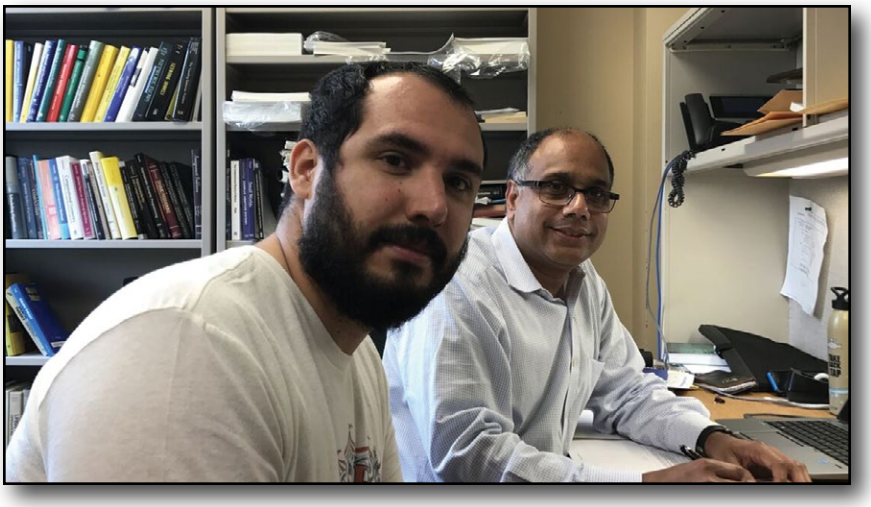
Each year, CRS allocates about $70 million in unrestricted funds – donations which have not

The **decision process** needed to be **equitable, transparent and easily** understandable to the **agency's stakeholders.**

been designated for a specific purpose – to relief and development efforts in 90 countries. CRS wanted its budget allocation process to reflect its priorities: the alleviation of poverty, the reduction of HIV/AIDS, the empowerment of women, and the preservation and promotion of civil liberties and human rights. The decision process needed to be equitable, transparent and easily understandable (i.e., it needed to be simple enough so that people without extensive mathematical backgrounds could use it and understand it) to the agency's stakeholders, including donors and managers of relief programs around the world that receive support from CRS.

Together, we designed a model and a spreadsheet tool for the agency, defining a metric that helped the agency maximize the investment impact of unrestricted funds. The model considered a plethora of complex factors, such as the agency's philanthropic goals, the size of a country's population relative to its need, the availability of public funding and the efficiency of the relief program. The leadership at CRS was very pleased with the results of our team's work as it allowed the agency's decision-makers to approach budgeting decisions with increased consistency and professionalism.

An important lesson we learned while conducting this project was how important it was for our non-quantitative audience to understand the methodology (in terms of what the model was trying to achieve and what the objective and constraints meant in simple words) to gain acceptance of the tool and become engaged users. In fact, the first model we developed (a classic knapsack problem with lower and upper bounds) resulted in a solution that was perceived to be unfair by the stakeholders. This required a better understanding of their concerns and the development of a second model that they bought into. This case also illustrates to students the iterative process that OR/MS practice requires. The work was selected as a finalist for the Wagner Prize competition in 2005, and the *Interfaces* article [2] associated with it is used extensively in my teaching.



Former student Mustafa Sahin (left), who just earned his Ph.D. and will be joining the data science team at Uber, and professor S. Raghu Raghavan.

High-Stakes Government Auctions Around the World

This project was based on the interactions among my student Bob Day and me, with the staff at the Federal Communications Commission (FCC), as well as Power Auctions Inc. and Market Design Inc. (two of the worlds' leading firms in the design and implementation of high-stake auctions). Day was a pure math student who wanted to switch to working on applied problems in the real world. Given his background as an economics and mathematics undergrad, I got him involved in my research interactions with the FCC.

Auctions typically involve the sale or purchase of many related items. Unlike a traditional auction where a single good is auctioned off to the highest bidder, a combinatorial auction allows bidders to bid on combinations of objects (i.e., on packages). This may make sense if goods are complementary (for example, the value of wireless spectrum for Washington, D.C., and Philadelphia may be worth $10 million each, but together may be worth $25 million) or substitutes. At the time, governments in many countries across the world (including the U.S. and the U.K.) were interested in using combinatorial auctions to auction off their telecommunications spectrum and landing rights at airports. A vexing problem they faced was how to determine the payments of the winners in the combinatorial auction.

Economists had earlier suggested using Vickrey payments for winners in the combinatorial auction. Unfortunately, Vickrey payments had some well-documented problems. In simple terms, they could lead to situations where winners in the auction may make payments that are so low that a group of losing bidders is able to provide an alternative allocation and set of payments (bids in the auction that just concluded) that generate higher revenue than that paid by the winning bidders! This is clearly not perceived as being fair, or acceptable, especially in a government-conducted auction.

Consequently, there was consensus in the literature (and industry) for the use of core payments by winning bidders in the combinatorial auction. With these payments, no group of bidders can offer an alternative allocation and set of payments that both the bidders and seller prefer. In other words, core payments are perceived to be fair by all the bidders.

The problem was that there was no efficient way to compute these core payments until our work.

Using techniques from the mathematical programming toolkit we showed how to model the problem of determining core payments as a linear program with an exponential number of constraints. We then developed a novel constraint generation procedure that starts with a few constraints in the linear program and adds constraints iteratively to the linear program. The core constraint generation (CCG) technique we developed was several orders of magnitude faster than the previous techniques to obtain core payments. With our approach, the last step was now in place, and governments around the world (U.K., Portugal, the Netherlands, Denmark, Australia and Canada) started running combinatorial auctions using our algorithm. Indeed, billions of dollars have been raised by these governments using our algorithm as an integral part of their auctions.

This work was selected by EURO as a finalist for the 2009 EURO Excellence in Practice Award (an award given to recognize outstanding accomplishments in the practice of OR/MS). The *Management Science* paper [1] is used in my Ph.D. course, while a presentation that covers the work but without a discussion of the finer points of the constraint generation technique is used in my MBA class.

Teaching Advice

I find it hard to give specific teaching advice since I feel teaching is an experience where both the style and background of the instructor and student come into play. Having said that, here are three things to keep in mind that have worked for me.

Be yourself: Early in my academic career, I attended many INFORMS teaching workshops and attended the classes of colleagues who were "star teachers." I found that using many successful ideas didn't necessarily work well for me. I eventually realized that teaching is most effective when you are relaxed and yourself. This doesn't mean you shouldn't experiment with successful ideas from other faculty. Rather, it means you need to adapt things to best suit your own style and mannerisms. If you are consciously thinking about your teaching style while teaching, then you may not be able to engage with students and pay attention to other aspects of classroom interaction with students.

Be enthusiastic: There are many topics I know well, but I've found that I do better in teaching some of these topics better than others. Why? Enthusiasm for a topic rubs off on others. Just think back to the professors who have most excited or interested you in a subject or topic.

Be prepared: Students come from a variety of backgrounds, and discussions (especially of OR/MS techniques applied to practice) can veer off in different directions. One key facet in gaining students' trust is to be willing to explore these questions and to be sufficiently knowledgeable when the topic moves away from the presented material. I recall teaching a part-time MBA class the deferred acceptance matching algorithm due to Gale and Shapley that is used to match residents and hospitals. As I finished the discussion a student raised her hand and said, "I work for the Association of American Medical Colleges (AAMC), and that was the best explanation I have seen from an academic about how the method works." She proceeded to discuss other aspects of the match and asked me additional questions related to issues that are faced in practice with this matching process. Thankfully, this was a topic I had spent a fair amount of time studying and passed the test from the domain expert.

Closing Thoughts

Teaching the joys of OR/MS tools and techniques and their wide applicability in practice is what excites me every day, and something I consciously chose when I decided to give up industry for academia. I view my students' successes as my own success, and it gives me the greatest pleasure seeing them succeed. These students have won many awards for their practice-oriented research projects (e.g., INFORMS Dantzig Dissertation Award, INFORMS UPS-SOLA Dissertation Award, INFORMS Computing Society Prize, EURO Management Science Strategic Innovation Prize, to name a few) and it has been a privilege to work with each and every one of them. I'd like to mention former Ph.D. students Bob Day and Ioannis Gamvros for their great partnership in some very high-stakes OR/MS practice projects, and former MBA student Commissioner Mark Acton at the Postal Regulatory Commission for being an enthusiastic consumer of OR/MS practice. ORMS

S. Raghu Raghavan *(raghavan@rhsmith.umd.edu) is a professor of management science and operations management at the University of Maryland's Robert H. Smith School of Business. Raghavan was awarded the 2016 Prize for the Teaching of the Operations Research/Management Science Practice from INFORMS.*

Teaching the joys of **OR/MS tools and techniques** and their wide **applicability in practice** is what **excites me** every day.

REFERENCES

1. R. Day and S. Raghavan, 2007, "Fair Payments for Efficient Allocations in Public Sector Combinatorial Auctions," *Management Science*, Vol. 53, No. 9, pp. 1,389-1,406.
2. Gamvros, R. Nidel and S. Raghavan, 2006, "Investment Analysis and Budget Allocation at Catholic Relief Services," *Interfaces*, Vol. 36. No. 5, pp. 400-406.