Teaching Statement
Nikolai Matni

Teaching & Outreach   Although I have only officially been a teaching assistant for one class (ACM/CMS/EE 218 Statistical Inference, taught by V. Chandrasekaran at Caltech), I was unofficially involved with the teaching of courses on optimal control theory for the majority of my time at Caltech. My duties consisted mostly of giving 2-3 weeks worth of guest lectures in CDC 212: Modern Control Theory (taught by John C. Doyle) on fundamental topics such as convex optimization and optimal control, as well as on advanced research subjects such as distributed optimal control. My most important experience was as unofficial co-instructor (w/ John Doyle) of CDS 110b: Introduction to Optimal Control, for which I taught approximately 90% of lectures.

This course covers the core elements of optimal control: LQR, Kalman Filtering and LQG. As a student, I always found it confusing and unsatisfying that each of these results could be derived using seemingly disconnected mathematical approaches (e.g., the LQR optimal control problem can be solved using dynamic programming, H2 theory or semidefinite programming). To address this, I developed a new approach to teach- ing this material that used convex optimization and Lagrangian duality to connect these solution methods to each other. For example, I showed the students how complementary slackness can be used to connect the semidefinite programming solution to the H_2 optimal control problem with the Algebraic Riccati Equation that arises from the dynamic programming approach to LQR optimal control. I believe that this approach allowed the students to gain a deeper understanding of the material and of how the different solution methods related to each other, and in the process exposed them to fundamental concepts from optimization theory.

The philosophy that I took in teaching this class should be viewed as part of my broader pedagogical agenda of making deep but accessible connections between control theory, optimization and inference – how we teach these subjects must adapt to reflect the increasingly interdisciplinary nature of research. These areas will undoubtedly be the foundation upon which a broader theory of analysis and design of cyber-physical systems will be built, and I believe that my academic and research background have uniquely prepared me to make such connections, and present them to a broad audience in a clear and understandable way.

As evidence of my abilities to make difficult concepts from feedback control and optimization accessible to a broad audience, I was selected as one of four graduate-student Caltech Everhart Lecturers in 2016: these lecturers are selected annually from the entire graduate student body to present their work to a campus-wide audience based on dynamic speaking skills, ability to communicate their research field's broader importance and impact on the scientific community. My talk is available on my research website, YouTube (`http://youtube.com/watch?v=lS-Y5iVNQ-U`, 1600 views) and iTunes U.

Mentoring   During my time at Caltech, I acted as a co-advisor (w/ John Doyle) to three students: Yuh- Shyang Wang (since 2013), Yorie Nakahira (since 2014) and Dimitar Ho (since 2015). In my role as advisor I have provided technical guidance, helped direct each student's line of research and helped them with clarity and exposition in their writing. Under my mentorship these students have published 11 peer reviewed conference papers, including the **ACC 2017 Best Student Paper Award** winning paper [1], with several others in submission or preparation – further, Yuh-Shyang recently successfully defended his thesis in Dec 2016 and is currently at GE Research.

I believe that the most important role that an advisor can play in a student's development is to help them learn how to ask the right questions and determine what a "good" problem is. Gaps in technical ability can always be filled in with course work, writing style can be improved with practice, but if a student lacks the depth and intuition needed to identify important problems and potential paths to solving them, they cannot be considered strong researchers. I use a three step approach to help students in this respect. First, I provide a high-level overview of several different research directions, as well as a brief description of potential projects and impact. Second, once they decide on a broad research direction, I provide them with a reading list that allows them to gain an appreciation of the state of the art and open problems in this area. Finally, via an iterative process of discussion, reading and basic research, we converge on what we believe to be an important problem in an area of interest to the student. Throughout the process, I try to emphasize that as applied mathematicians and engineers a good problem is one that is both technically challenging and practically relevant. Although solid technical work is necessary for the success of a student, it is not sufficient. A student must also learn that clear, concise and precise exposition of material is as important as deep technical results. This involves writing conference and journal papers that clearly define a problem and why it is worth solving, and that rigorously present the problem

solution. Most importantly however, I believe that a good writer is one who provides the reader with intuition about both the challenges of the problem and the ideas behind its solution. This is something that can often be difficult to convince junior students of as the excitement of proving new results tends to overshadow the relatively mundane task of carefully choosing notation and terminology, but it is a point that I intend to emphasize.

A new approach to teaching control theory   Feedback is one of the most fundamental concepts in science and engineering, and yet it is also one of the most poorly understood within the broader scientific and engineering communities. I believe that the way in which control theory is taught is responsible for this: basic ideas such as instability and delay are currently taught using advanced mathematical techniques, thus discouraging domain-experts from other less mathematical fields from learning or using our tools. More concretely, it is difficult to convince a biologist that tools from robust control theory can be used to better understand glycolytic oscillations or heat shock if this means convincing them to learn mathematics that they are not normally exposed to, such as complex variables and Cauchy's integral formula. If we are to make control theory a cornerstone of science and engineering, as I believe it should be, we need to find a better common language and approach to teaching the subject.

I believe that our new approach to control synthesis, System Level Synthesis (SLS), which I describe in more detail in my Research Statement, will be an important component of this new approach. The benefit of this approach is that it very transparently converts linear control theory into linear algebra, making the material much more broadly accessible. John is already teaching this material at Caltech, and we had a very successful tutorial session at the 2017 IEEE Conference on Decision and Control.

References

[1] Y. S. Wang, N. Matni, and J. C. Doyle. System level parameterizations, constraints and synthesis. In *2017 American Control Conference (ACC)*, pages 1308–1315, May 2017.