Why We Do What We Do

I love control theory. I love the concept of feedback. I love applications of control theory. I especially love the mathematical rigor that comes with formulating problems in control, the odor of a freshly cooked proof, and the thrill of implementing an algorithm in a real device or application. I have also been extremely fortunate to have spent my entire life putting into practice the things that I love and working on problems that involve the use of feedback to design engineering systems. Many of these could be described as conventional problems of the type found in a traditional control course, such as my work on automotive control systems [1]. Some of the problems that I have worked on are less conventional, such as my work on the transmission control protocol [2], the COVID-19 pandemic [3], or the area of smart cities [4]. Despite all of this, my deep affection and love of the discipline, and the great fortune to have worked on a vast portfolio of projects (both theoretical and applied), one question returns to me over and over again: Why do we do what we do?

This question is not easily answered, at least from my own perspective. As a young engineer and researcher, my complete and unswerving attention was devoted to Lyapunov theory, as it pertained to time-varying linear systems [5]. While I never doubted the value of working on these types of problems, I guess—looking back at a young version of myself—I did subconsciously question whether I was transitioning to mathematics (instead of embracing my training as an engineer and developing the side of my personality that was more in tune with developing solutions to problems, as opposed to studying and analyzing the properties of idealized versions of these solutions). Upon reflection, I believe this personal sense of insecurity both motivated my several sabbaticals in industry with Daimler-Benz and IBM Research, and contributed greatly to the enjoyment and thrill I felt (and still feel) of working in industry and, subsequently, with a host of other industrial partners. Unsurprisingly, this time was fulfilling from the standpoint of being an engineer, and it also, to my surprise, served to put fuel in the tank in terms of academic pursuit. It was certainly my experience that working in industry sharpened my focus, introduced me to new and very relevant challenging problems, and helped me discover problems that are important from an economic perspective. For example, I encountered switching systems at Daimler-Benz (long before it was a mainstream topic in control engineering), and my work on closed-loop recommender systems was greatly stimulated by my time as a smart cities researcher at IBM Research (again, before it became a mainstream topic in the research community) [6], as was my interest in iterated function systems [7].

As a card-carrying control engineer, both from the perspective of theory and practice, you might now ask whether I could now tell you why we, as control engineers, do what we do. After all, I have been lucky enough to have had a direct and rich experience

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of seeing beautiful theories emerge, and also to observe firsthand their application across several industries. While this is certainly true, it is also true that many of my old insecurities linger (or perhaps mutated into related new ones). Any undergraduate engineer will tell you that control engineering is the study of feedback systems. The excitement of using the simple concept of a feedback signal to adjust the behavior of systems to make them behave as we wish is central to both enduring appeal of control theory as a discipline and the excitement that attracts many of the brightest students. It is also a principle that is found across society in many of its most important and challenging problems. Feedback is at the heart of some of those that matter most to humans. Yet in many of these problems, even though the technical challenges pertain directly to what we understand as control theory, there is a sometimes a dearth of interest in them from our community and a very real risk that many of the new emerging scientific boundaries in control will be pushed back by other disciplines (at least implicitly). In fact, this is already happening in some disciplines. Even when there is interest from our community, we sometimes struggle to influence policy. The ongoing COVID-19 pandemic is a very real manifestation of this effect. Even though many of the nonpharmaceutical interventions explored by governments across the world are manifestations of feedback control strategies and there is much interest in the control community in this topic, it is unclear to what extent policy makers have been assisted by the control community in developing and realizing these strategies (despite the fact that we as a community have so much value to offer in this context). The same is true of many of the other great contemporary global challenges. While we as engineers often focus on helping to develop more efficient technologies, it is becoming more clear that many of the fundamental challenges pertaining to climate change, pollution, and even poverty are mostly associated with human behavior, behavioral change, and with providing humans with fair access to good choices. Often, such problems can only be effectively tackled using ideas from systems and control, both help to manage access to a shared resource in a fair and ethical manner and ensure that demand for this resource is constrained in some way. While the need for this type of system was noticed and documented over a century ago as Jevons paradox (the effect that environmental innovation may sometimes stimulate demand, thereby making the original problem worse), Jevons paradox is today manifesting itself in many ways in contemporary society, providing a strong rationale for feedback control by motivating the sharing of resources and management of resource budgets using feedback. Many of the key ideas at the heart of new disruptive business models that are central to combatting climate change, poverty, and other global challenges (such as the circular economy and the sharing economy) reduce to orchestrating the behavior of ensembles and in using feedback to induce "good" behavioral change. These are the problems that really matter to society are at the very heart of the human experience. For example, servitization as an enabler for the circular economy (as we move from a pervasive notion of sole ownership of goods and services to that of servitized and shared access) has the potential to unleash fantastic new business models that will encourage the manufacture of durable goods and services, facilitate end-of-life collection, and perhaps even give consumers access to good (environmental and just) choices by removing the upfront cost of goods and services. Such technologies are not only beneficial for society by helping address the contemporary global challenges of climate change and pollution, but also by helping us to reimagine society in a manner that is socially just, ethical, and fair (as well as helping to alleviate the many forms of access poverty). Furthermore, these challenges are also a rich source of inspiration for control engineers. The control of ensembles is itself a frontier topic in control engineer. New digital technologies are emerging, which give rise to new methods to actuate, and to nudge and inform individuals. New notions of ownership and the incorporation of human level constraints such as fairness, adherence to social contracts, and quality of service are providing new and extremely challenging twists on classical control problems. Focusing the attention of the control community on such problems is not only very good for society, but also an invigorating departure for the control community.

So why do we do what we do? We all set out on our journey as control engineers with the same basic objective. We all want to work on problems that somehow matter, and we all want to make a meaningful contribution to solving these problems. This is the reason why we do the things we do. As my career has evolved, this desire has remained a constant one. However, the problems that matter have themselves changed, both as a result of my own (changing) personal priorities, but also as a result of how society has evolved. There can be no dispute now that some of the problems that really matter are

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ones of climate change, pollution, poverty, equality, and social justice. These problems are worth working on, deserve our attention, and (in my opinion) urgently need the attention of the control community. We have wonderful machinery at our disposal, and it is our duty to apply and adapt this machinery to the problems that matter in society. What are these problems? For sure they include climate change, pollution in our cities, and making better use of constrained resources. However, they encompass much more than these problems. Control theory has a very important role to play in these seemingly unfamiliar but important contexts (for example, ensuring equal access of opportunity for citizens, ensuring societal fairness, and alleviating poverty in society). We as a community should emulate the artificial intelligence community, in how we respond to these challenges. The control community has much to offer. So why do we do what we do? We all do control to make a difference on problems that matter. Perhaps it is now time to make a difference on the new forms of control problems that arise where technology meets human behaviors.

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