Gaussian Processes for Learning and Control

Tutorial with examples

Harshal Maske, Hassan Kingravi, Joshua Whitman, Girish Chowdhary,
POC email: girishc@illinois.edu

[1]

Conclusion

This tutorial introduced Gaussian Processes (GP) and Gaussian Process Regression (GPR) from the perspective of Bayesian nonparametric inference for use in control and reinforcement learning problems. It emphasized the key features of GPRs, including: *1)* how they allow for automatic data-driven feature selection, thereby not requiring practitioners to predefine feature numbers and locations; *2)* the way in which GPs offer uncertainty measures of predictions; *3)* how Bayesian inference allows for natural optimization and selection of GP hyperparameters; and *4)* how GPs offer a principled way for performing budgeted online inference. The tutorial provided concrete examples demonstrating how GPR for adaptive control and off-policy reinforcement learning, and also discussed the application of GPs to model value functions in optimal control and planning problems, and to model reward functions in inverse optimal control problems. Moreover, it showed how GPs can be used as the basis of a probabilistic framework capable of modeling system dynamics and measurement functions, with use in model predictive control and state estimation and filtering problems. In addition, the tutorial elaborated the connections between GPR and other widely-used regression techniques, so that readers and practitioners are able to understand the unique features of GPs and its generality. Finally, the tutorial discussed a few limitations of the basic GPR approach and provided a brief overview of several advanced GP models that overcome such limitations. The discussions presented here are by no means exhaustive; our intention is merely to highlight the key features of Gaussian Processes, through illustrative examples, in order to help interested practitioners to more efficiently explore the relevant literature.

References

[1] Hassan Kingravi, Harshal Maske, and Girish Chowdhary. Kernel observers: Systems theoretic modeling and inference of spatiotemporally varying processes. In *Advances in Neural Information Processing Systems (NIPS)*, Barcelona, Spain, 2016.

Sidebar: Limitations of Parametric Models – A Flight Control Example

Author Biography

Miao Liu is a research staff member in the AI Science Department at IBM T. J. Watson Research Center, Yorktown Heights NY. Prior to joining IBM in 2016, he was a Postdoctoral Associate in the Laboratory of Information and Decision System (LIDS) at Massachusetts Institute of Technology (MIT), where he worked on scalable Bayesian nonparametric methods for solving multiagent learning and planning problems. He received a Ph.D. degree in Electrical and Computer Engineering from Duke University in 2014. He received both his B.S. and M.S. degrees in Electronics and Information Engineering from Huazhong University of Science and Technology, in Wuhan, China in 2005 and 2007, respectively. Dr. Liu was a co-author of the best student paper at IROS2017 and received nomination of the best multi-robot paper in ICRA2017. His research interests include statistical machine learning, AI, and robotics.

Girish Chowdhary is an assistant professor at the University of Illinois at Urbana-Champaign and affiliated with Electrical and Computer Engineering, Agricultural and Biological Engineering, and the UIUC Coordinated Science Laboratory (CSL). He is the director of the Distributed Autonomous Systems laboratory at UIUC. He holds a PhD (2010) from Georgia Institute of Technology in Aerospace Engineering. He was a postdoc at the Laboratory for Information and Decision Systems (LIDS) of the Massachusetts Institute of Technology for about two years (2011-2013). He was an assistant professor at Oklahoma State Universitys Mechanical and Aerospace Engineering department (2013-2016). Prior to joining Georgia Tech, he also worked with the German Aerospace Center's (DLR's) Institute of Flight Systems for around three years (2003-2006). His undergraduate institution was the Royal Melbourne Institute of Technology in Australia. Girish's ongoing research interest is in theoretical insights and practical algorithms for adaptive autonomy.

Bruno Castro da Silva is an associate professor at the Institute of Informatics of the Federal University of Rio Grande do Sul (UFRGS), in Brazil. Prior to that he was a postdoctoral associate at the Aerospace Controls Laboratory, at MIT. He received his Ph.D. in Computer Science from the University of Massachusetts, working under the supervision of Prof. Andrew Barto, in 2014. Before that he received a B.S. degree *cum laude* in Computer Science from the Federal University of Rio Grande do Sul in 2004, and an MSc. degree from the same university in 2007. Bruno has worked in different occasions as a visiting researcher at the Laboratory of Computational Embodied Neuroscience, in Rome, Italy, developing novel control algorithms for the iCub robot. His research interests lie in the intersection of machine learning, reinforcement learning, optimal control theory, and robotics, and include the construction of reusable motor skills, active learning, efficient exploration of large state-spaces and Bayesian optimization applied to control.

Shih-Yuan Liu is a Senior Research Scientist at nuTonomoy Inc. Previously, he was a postdoctoral associate at Laboratory for Information and Decision Systems (LIDS) and Aerospace Controls Laboratory (ACL) at the Massachusetts Institute of Technology (MIT). He received the Ph.D. degree in Mechanical Engineering in Controls from University of California, Berkeley in 2014. His research interests include control, path-planning, coordination, and teleoperation of autonomous ground and aerial vehicles in dynamic environments.

Jonathan P. How is the Richard C. Maclaurin Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology. He received a B.A.Sc. from the University of Toronto in 1987 and his S.M. and Ph.D. in Aeronautics and Astronautics from MIT in 1990 and 1993, respectively. He then studied for two years at MIT as a postdoctoral associate for the Middeck Active Control Experiment (MACE) that flew onboard the Space Shuttle Endeavour in March 1995. Prior to joining MIT in 2000, he was an Assistant Professor in the Department of Aeronautics and Astronautics at Stanford University. He is the Editor-in-chief of the IEEE Control Systems Magazine and an Associate Editor for the AIAA Journal of Aerospace Information Systems. Professor How was the recipient of the 2002 Institute of Navigation Burka Award, a Boeing Special Invention award in 2008, the IFAC Automatica award for best applications paper in 2011, the AeroLion Technologies Outstanding Paper Award for the Journal Unmanned Systems in 2015, won the IEEE Control Systems Society Video Clip Contest in 2015, and received the AIAA Best Paper in Conference Awards in 2011, 2012, and 2013. He is a Fellow of AIAA and a senior member of IEEE.