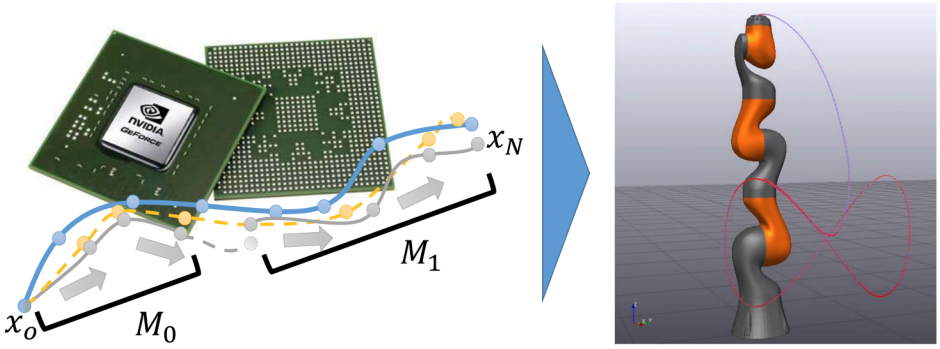
COMS BC3159: Parallel Optimization for Robotics



Semester: Spring 2024 | **Instructor:** Brian Plancher
Credit: 3 points | **Meeting time:** MW 1:10pm-2:25pm | **Room:** TBD
Prerequisites: COMS W3251 Computational Linear Algebra, MATH UN1201 Calculus III, and COMS W3157 Advanced Programming or CSEE W3827 Fundamentals of Computer Systems. Contact the instructor if you have equivalent prior experience but do not have prerequisites.
**Enrollment Capped at 75 Students (Instructor Managed Wait List)*

Description:

Many stages of state-of-the-art robotics pipelines rely on the solutions of underlying optimization algorithms. Unfortunately, many of these approaches rely on simplifications and conservative approximations in order to reduce their computational complexity and support online operation. At the same time, parallelism has been used to significantly increase the throughput of computationally expensive algorithms across the field of computer science. And, with the widespread adoption of parallel computing platforms such as GPUs, it is natural to consider whether these architectures can benefit robotics researchers interested in solving computationally constrained problems online. This course will provide students with an introduction to both parallel programming on GPUs as well as numerical optimization. It will then dive into the intersection of those fields through case studies of recent state-of-the-art research and culminate in a team-based final project.

Learning Outcomes:

By the end of the semester, you will be able to:

- Understand the opportunities and limitations of parallel programming on GPUs
- Understand the opportunities and challenges of numerical optimization algorithms
- Engage critically with recent research on parallel optimization algorithms for robotics
- Collaborate with a team to develop and present an open-ended final project

Grading:

- 35% Problem Sets
- 30% Exam
- 30% Final Project Presentation, Report, and other Milestones
- 5% Attendance, Collaboration, and Participation

Note: requests for regrades can only be made for 1 week following the return of a grade.

Preliminary Course Schedule:

Week	Day	Date	Topic	Description	Assignments	Readings	Module
0	W	Jan 17	Intro Class	Overview of the Course, Nuts and Bolts, Optimization in Robotics	PS 0 Released (W): Math and Coding Background and Environment	Intro to Git [1,2] Math Reference Dive Into Systems Ch 1.2	Intro
1	M	Jan 22	Computer Systems, and Parallel Programming Concepts	Review on Computer Systems and Memory Hierarchy, Basic Parallelism including: Threads and Synchronization		Dark Silicon Dive Into Systems Ch 11 OpenCSF Ch 6.1-6.3, 7.1-7.2	(GPU) Parallel Programming
1	W	Jan 24	GPU Parallelism and CUDA	The GPU Computational Model (Blocks, Threads, SMs), NVCC, Host, Device, Synchronization, Shared, Global, Local, Host, and Unified Memory, I/O, Reductions	PS 0 Due (F) PS 1 Released (W): GPU Parallel Programming		
2	M	Jan 29				Dive Into Systems Ch 14,15 Kirk Ch 2, 3.1-3.2, 4.1-4.5, 5.1, 6.1	
2	W	Jan 31	PS1 "Party"				
3	M	Feb 5	Advanced GPU Topics	TBD			
3	W	Feb 7	Convex Optimization and Vector Calculus	Convexity, Global vs. Local Optima, Gradient Descent, Vector Calculus		Boyd Ch 1.1-1.4, 2.1, 3.1-3.1.4	Optimization Algorithms for Robotics
4	M	Feb 12	Nonlinear Optimization	Taylor Expansions, Line Searches, Trust Regions	PS 1 Due (M) PS 2 Released (M): Optimization	Nocedal Ch 2 Underactuated Ch 1.1-1.6, 2	
4	W	Feb 14	Constrained Optimization	(Non-)Holonomic Constraints, Penalty Methods, (Augmented) Lagrangian, KKT System			
5	M	Feb 19	PS2 "Party"				
5	W	Feb 21	Numerical Optimization in Robotics	The Trajopt Problem, Direct Transcription and Colocation, Solving Linear Systems, iLQR, and DDP and its ties to Bellman, Dynamic Programming		AIMA Ch 17.1-17.3 Underactuated Ch 7.1-7.3, 8.1-8.2, 10-10.4	

6	M	Feb 26	Trajectory Optimization I		PS2 Due (M) PS 3 Released (M): Trajectory Optimization		
6	W	Feb 28	Trajectory Optimization II				
7	M	March 4	PS3 "Party"				
7	W	March 6	Advanced Optimization Topics	TBD	PS 3 Due (F)		
8	M	March 11	Spring Break				Putting it All Together
8	W	March 13					
9	M	March 18	Course Review		Project Instructions Released (M)		
9	W	March 20	Practice Exam Questions "Party"				
10	M	March 25	Exam				
10	W	March 27	Putting it All Together: Parallelism in Robotics Optimization	Project Overview, Parallel DDP, GRiD and Code-Generation, Instruction vs. Algorithm Level Parallelism	Project Instructions Released (W)	MPPI Paper GRiD Paper PDDP Paper	
11	M	April 1					
11	W	April 3	FPGAs and Custom Chips for Robotics	TBD		FPGAs + ASICs Video	
12	M	April 8	Project Proposal Meetings		Project Proposal Due (Su)		Final Project
12	W	April 10	Final Project Lab Time				
13	M	April 15					
13	W	April 17	Project Update Meetings		Project Update Due (W)		
14	M	April 22	Final Project Lab Time				
14	W	April 24					
15	M	April 29	Final Project Presentations		Project Report Due (M)		