Introduction & Career Goals

My intention to pursue a PhD in computer science is driven by various and different experiences in life which have all played part in forming my belief in the ability of technology to enhance peoples' lives in countless ways. As such, my primary goal as a future researcher is to contribute toward solutions to the most important problems and questions facing our society. Also, because I believe that nothing good is fully experienced until it is shared with others, I aim to educate and inspire others just as I have been fortunate enough to continually be surrounded by those who've helped and inspired me.

I believe that I have an established track record of excelling both inside and outside of academia, an aptitude in mathematics that has certainly biased my path towards my current trajectory, and a passion for solving problems that contain the possibility of truly influencing people's lives in a meaningful way. Two broad classes of problems which I believe wholeheartedly to belong to that set are those of (1) space and planetary exploration, and (2) robotics and machine learning. The former of which is of critical importance to furthering our understanding and exploring possibilities beyond our own planet, and the latter which has shown exponential growth in terms of progress and its role in our everyday lives. I can think of no more important, prudent, and challenging area to work than at the intersection of the two.

Prior Experience

During my junior year of college while studying abroad in Germany, I was given the opportunity to work with Dr. Henry Brighton at the Max-Planck Institute for Human Development - Center for Adaptive Behavior and Cognition in Berlin (MPIB). Our main projects during my six months there involved training various machine learning algorithms to model heuristic decision-making in real world situations. Most notably, we were able to prune a major healthcare questionnaire down to less than 1/10th of its original size while sacrificing less than 5% of its predictive capabilities in regard to the future healthcare needs of the respondents. In practical terms, the result meant that what began as a lengthy mail questionnaire (60 questions), could now be administered orally by practitioners who could be confident in the survey's predictive capacity in terms of future health risks facing their patients.

After graduating I found a home for my intellectual curiosities at RPX Corporation in San Francisco. RPX was a young company looking to change and "de-militarize" the intellectual property landscape through widespread collaboration between the major developers of new technologies. I began working as part of the Data Science & Analytics team where the theme of my work was in analyzing large amounts of data to develop insights into the patent market. This included applying machine learning methods to model patent asset valuation and developing a multi-factor approach to predict the likelihood of future occurrence of an infringement lawsuit.

At the start of my second year, I was recruited into the Corporate Development group where I was given the opportunity to develop market strategies cohesive with our own research into modeling and analyzing the particular risks our client companies were facing. Examples include the development of a patent co-defendant insurance offering (built on our predictive infringement modeling) whereby companies could collaboratively take a stand against malicious entities in the patent market.

Graduate Work

Applying to graduate programs in computer science with my set of interests I was particularly interested in programs with significant focus on interdisciplinary research, which is what brought me to Rutgers University. Collaborations within Dr. Kostas Bekris' robotics group include ongoing work with the Psychology department studying human interpretability of robotic movements, human-robot interaction, and crowd simulation projects. Working with the vision groups of Dr. Ahmed Elgammal and Dr. Dimitris Metaxas, I've had opportunity to collaborate with members of the Center for Cognitive Science (RuCCS) on perception-related studies. The support of these groups and opportunities that they provide have been invaluable to me as a student.

During my first year, our group decided to compete in the Amazon Picking Challenge: a robotics competition with the goal of correctly identifying objects within a warehouse-like shelving unit, grasping a pre-determined but unknown selection of the objects, and placing them securely into an order bin. The project brings together elements of computer vision (perception of objects), motion planning, and mechanical engineering. On the perception task, I worked closely with Dr. Ferreira de Souza, a visiting professor from the Federal University of Espirito Santo. We began with an open-source version of the LINEMOD algorithm for 3D pose estimation and adapted the algorithm to fit the environmentally difficult shelf scenario, where we were able to significantly improve its object detection performance. Additionally, we compiled the largest RGBD database with 6 degree-of-freedom(DoF) ground truth object pose to date which we also freely offered to the community [1].

The challenge provided a unique opportunity to combine research and real-world engineering while building on and learning from the specific expertise of other students. Though the core teams consisted of PhD students in robotic motion planning, manipulation, and perception, the opportunity allowed our team to involve several masters students as well as a handful of undergraduates. All of these students had interest in robotics but no substantial previous experience, and many were able to directly contribute to and take pride in our team's final solution.

In my second year, my interest in complex robotic systems drew me towards a project with my advisor involving tensegrity robots. While our lab had been successful in the past employing efficient sampling-based motion planning algorithms to the high-dimensional challenge in a physics-based simulation, the problem of planning "blind" (i.e., beginning with no prior knowledge) in such a complex system was still very computationally demanding. Having been given the opportunity to spend the summer at NASA ARC, I decided to spend the time working towards more informed solutions to the motion planning problem using Bayesian optimization over previous trajectories. Though the results I was able to achieve were only preliminary, I believe that this direction shows tremendous promise and I was grateful for the opportunity to be able to learn from researchers working on similar problems, and to be able to present my results to them.

References

[1] C. Rennie, R. Shome, K. E. Bekris, and A. F. De Souza, "A dataset for improved rgbd-based object detection and pose estimation for warehouse pick-and-place," *IEEE Robotics and Automation Letters*, vol. 1, no. 2, pp. 1179–1185, 2016.

Coordinated Planning and Control for Tethered Robot Pairs

Motivation: Many important and rewarding science target locations on extra-planetary bodies lie in terrain that is rocky, uneven, or involves traversing steep inclines. Consider the search for ice in underground caves on Mars, or collecting soil samples and images from the bottom of a crater or ravine. These tasks, while very rewarding in terms of scientific value, are not easily achieved by humans nor the current generation of planetary rovers. This shortcoming of current exploratory technology has spurred considerable interest in the development of next generation rover designs featuring a tether that either connects the rover to a static point in the environment [1, 2, 3] or, even more desirably, connects to another rover vehicle of equal capability. A tethered team of space exploration rovers benefits from the stability that a tether can provide while rappelling down difficult terrains. The team is also able to reconfigure to provide maximal stability to the actively descending rover. Furthermore, robots can swap roles between (1) providing stability to their counterparts and (2) traversing the terrain, depending on sensing input. These benefits allow a tethered team to safely traverse difficult terrain well beyond what a single anchored robot could achieve.

Objective: This report proposes viable solutions for two key and related problems for effective tethered robotic teams. Progress in these directions can significantly improve tethered robot technology for planetary exploration: (a) coordinated control for reconfiguring a tether between a pair of rovers to deal with unforeseen terrain challenges, where both robots actively participate in this process, and (b) a planning framework that utilizes the control strategy as a module for coordinated descent or ascent of difficult terrain for a tethered robotic team. These solutions should be general enough to be platform-independent and apply to other space critical applications. For example, a tethered team of Robonauts, Valkyries or other humanoid robots could utilize such solutions during a repair mission of the International Space Station.

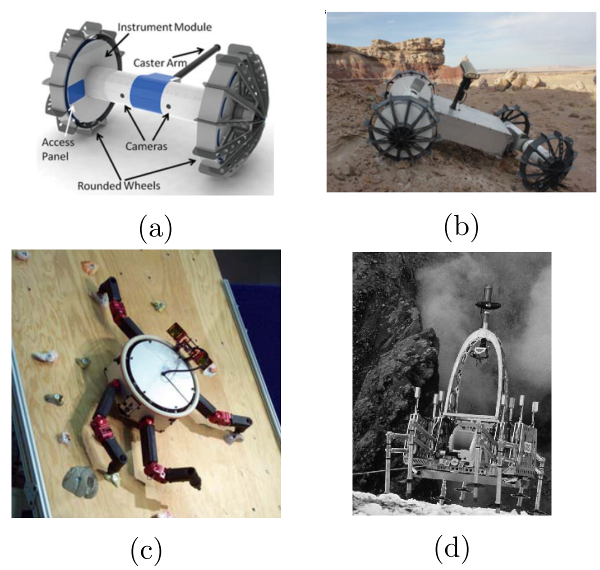
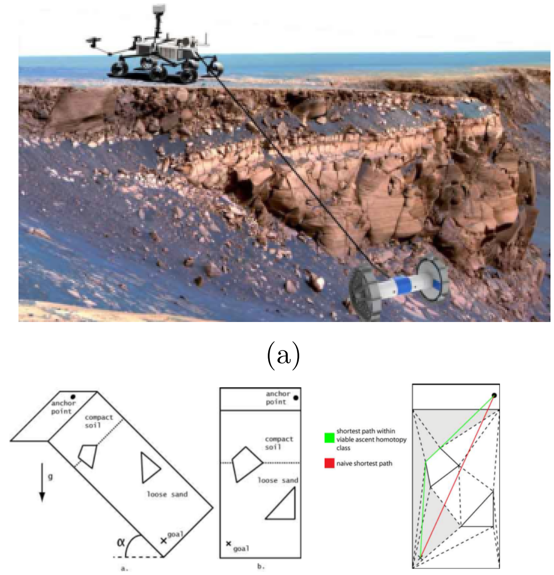


Figure 1: (a) The Axel II rover prototype (b) Two Axel II rovers in DuAxel configuration with support structure (c) Lemur IIb autonomous climbing robot (d) Dante II robot exploring a volcanic crater. Images: [4, 5, 2].

Relevant Background on Tethered Rovers

Recent research into robot designs for the traversal of harsh and difficult terrains has featured several different designs with alternative means of locomotion. The Dante II robot design consisted of eight legs for locomotion, an actuated winch used for rappelling down steep and difficult terrain from a static anchor point, and a variety of sensing equipment for data retrieval [3]. In 1994 the system was deployed into Mount Spurr, an active volcanic site, in order to record data for further scientific analysis. During the mission the robot suffered from a failure where the robot incurred a lateral force at its contact point with the tether, fell over, and was not able to correct itself [2]. Apart from this occurrence, however, the 5-day mission was regarded as a success in showing the capabilities of tethered robotic systems to act as "surrogate scientists"; exploring where humans would not otherwise be able.

More recently, NASA's Jet Propulsion Laboratory (JPL) has been working on a two-wheeled differential drive tethered robot, appropriately named "Axel". The Axel II robot design features collapsible, paddled wheels, making the system more appropriate for longer and more remote missions as this design is more robust to issues such as high-centering and failures such as that encountered by Dante II [6]. Two variants of the system are presented: one in which Axel is attached to a stationary anchor point, and a second where two Axel robots are tethered together and deployed via a central support beam ("DuAxel") [4].



(a)

(b) (c)

Figure 2: (a) Conceptualized descent terrain for Axel II mission (b) example projection of terrain to 2D plane (c) example solution: viable controllable regions for ascent (shaded), naive shortest path (red), shortest path within viable homotopy class (green). Images: [1].

A key challenge in either variation was how to plan autonomous descent and corresponding ascent paths for the deployed, tethered Axel robot in rocky extra-planetary terrains. A solution framework was presented which projected this complex problem to a two-dimensional plane. It built on foundational work addressing the tether constraint problem from a computational geometry perspective [7, 8] and extended this approach to produce "controllable" paths by deriving equations of motion arising from the constraints of the Axel robot [1]. The resulting algorithm first plans the more difficult ascent path and then uses the solution to limit its search for viable descent paths lying in the same homotopy class.

While this solution represents substantial progress well-grounded in foundational work, the assumptions and simplifications may limit its applicability. In particular, projecting complex 3D terrain environments in 2D and representing obstacles as simple polygons [Fig. 2b] may be not adequate for many realistic extra-planetary terrains. This strategy also assumes perfect prior knowledge of the environment, frictionless interaction of the tether with the ground plane, and quasi-static motion of the robot. Furthermore, it remains an open question as to how best to plan autonomous motions for the DuAxel configuration where two dynamic robots take turns belaying each other.

Proposed Research

The main goal of this research is to address the problem of planning for tethered teams of exploratory robots, while considering the complexities that arise from realistic three-dimensional terrains. The proposed solution first considers a control strategy for addressing *unforeseen obstacles and failures. It then uses this strategy as a module in planning paths for tethered robotic teams, in which the robots alternate between exploring and providing support to their counterparts.*

The following discussion will focus on the case of a tethered pair of robots but can be generalized to larger teams. The high-level approach is applicable to varying types of tethered rovers provided that they have a means of: (1) actuating the tether at its contact points with each rover, and (2) measuring the forces exerted on each rover at the tether's contact points. The most similar existing system which could utilize such solutions is the DuAxel rover design, which fits these specifications already. Nevertheless, one can also apply this approach to a pair of Lemur IIb robots free-climbing a vertical and jagged cliff face or even a pair of traditional wheeled rovers descending a steep and rocky mountainside. Moreover, exciting future extensions of this work include the extension of this work to larger (either in number of rovers per team, or number of tethered pairs) teams of tethered rovers.

As this proposal is developed with the overall goal of providing more robust and capable algorithms for extra-planetary exploration, we believe it has primary applicability to the technology goals of TABS 4.5.7 (and relatedly, TABS 4.2.6). An inextricable portion of the proposed technology also aims to progress research in multi-agent coordination. As such, we believe there is a strong connection with the technology goals of TABS 4.5.4 as well.

Research Problem 1: Coordinated control of a soft tether

Goal: In presence of imperfect terrain information, we require a strategy for dealing with both unforeseen obstacles and unplanned tether entanglements on rocky terrain elements.

In the following, we consider several potentially difficult situations that are likely to arise when planning for a tethered robotic pair under imperfect information about the terrain. In addressing this problem in the full 3D workspace, a strategy is required which can deal with two important potential failure cases. First, while an exploratory rover is moving along its planned obstacle-free path, the tether comes in contact with and becomes entangled on uneven terrain (the "snagging" case). Second, while performing the exploratory role, a rover encounters an unknown obstacle obstructing its planned path, which we'll call the "reevaluation" case (addressed in the planar case in previous, related work [9]).

In the "snagging" case [Fig. 3], we propose to develop a low-level control law capable of inducing a traveling wave in the tether by employing an oscillatory control policy at the actuated tether contact of the rover closest to the tether snag location. This approach is similar to the strategy used by humans when they encounter the same situation while mountain climbing. The challenge in this strategy, however, is that once the tether is free, it's likely to impart a substantial force on the robot's stabilizing counterpart, potentially resulting in dangerous jerking in a partially known environment. A promising solution to this problem would be to induce in response a counteracting wave from the stabilizing rover's actuated tether contact. To this end, the first direction to explore involves building a model (potentially analytically) of the expected forces exerted by the induced wave on the counterpart robot. We would then use this model in the context of a model predictive control approach, where the low-level control policy optimizes its current control with respect to counteracting the incurred force over a finite time horizon of future predictions. The second direction involves exploring model-free approaches (e.g., designing an admittance controller), as it's possible that reacting to forces incurred is a more feasible solution than accurately predicting them ahead of time.

In the "reevaluation" case of encountering an unmodeled obstacle in our path, what we must first decide is whether or not we can configure our tether such that we are able to place the tether in an arbitrary configuration on either side of the obstacle once we have moved past it. The reason being that while the unmodeled obstacle may not cause significant problems for our current rover's descent, planning the current stabilizing rover's traversal of the same slope is much more constrained as it does not have a stabilizing tether. Being able to place the tether on either side of the obstacle would then allow us to first plan the descent of the current stabilizing rover (incorporating this new obstacle), and then use the traversing rover to place the tether on the side of the obstacle that is easiest for the stabilizing rover to traverse.

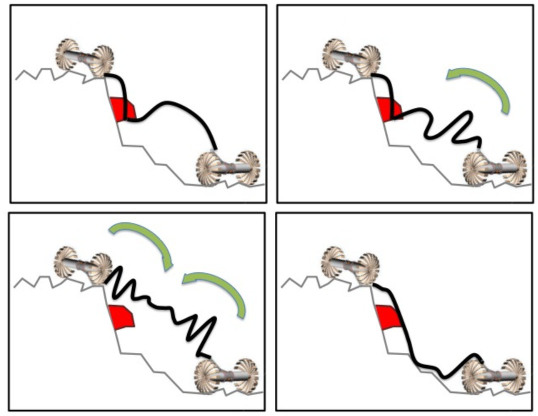


Figure 3: During a coordinated descent down a rocky extra-planetary surface, the tethered rover pair encounters an unplanned snag of the tether with a rock in the terrain (red). The situation is resolved by using the coordinated wave-inducing control strategy (green arrows indicate controls applied) to free the tether.

There are two tools available to determine whether this new obstacle is surmountable. By considering the height of the obstacle, we can search for configurations of the tethered pair which raise the tether above the obstacle. Alternatively, it is possible to extend the snagging strategy outlined above – simulating the effects of various parameterizations of our wave-inducing control policies to find one that would be able to surmount the obstacle. If such a policy is found, then it can be combined with a motion plan to move the exploratory rover to the desired side of the new obstacle, terminating the control policy once it has successfully reached the target state.

Research Problem 2: Motion planning for dynamic tethered rover pairs

Goal: Develop a robust motion planning framework for a tethered team of rovers by integrating the control strategy outlined above as a subroutine in cases of environmental obstacles and tether entanglements. This framework can plan the coordinated traversal of difficult terrain while the rovers alternate exploratory and stabilizing roles.

Given incomplete knowledge of the environment, the proposed strategy is to first select a set of maximally stable waypoints throughout the terrain. It is then possible to proceed iteratively and in an alternating fashion, first planning the descent of one of the rover pair to the first stable waypoint, then the other to some next stable waypoint closer to the goal. The waypoints can then be thought of as "role reversal" locations. When unforeseen obstacles (or snags) are encountered, the planning strategy can call upon the control strategy as a module and then re-plan. Importantly, re-planning under this strategy only requires re-computing the path between the current set of waypoints, as opposed to the trajectory of the entire traversal.

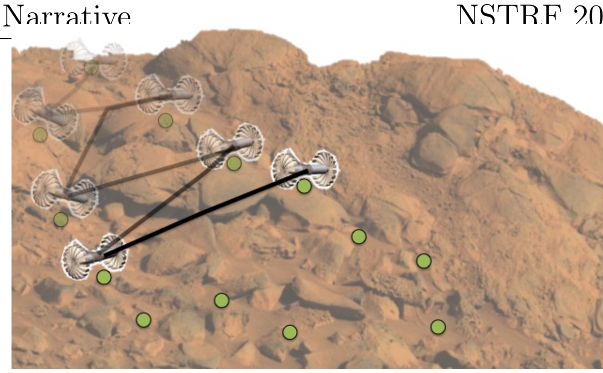


Figure 4: Conceptualized time lapse of coordinated descent of a tethered robot pair. Tether shown in black, computed waypoints in green.

Planning between two waypoints in the full 3D workspace and taking into account the dynamics of the tethered systems can be addressed by using a variety of trajectory-based methods. One promising solution corresponds to sampling-based motion planners, which have been successfully applied to solve similarly high-dimensional problems with complex kinematic and dynamic constraints [10]. A typical limitation with these methods, however, is the relatively high computation requirements to sample enough states to converge to a high-quality solution. Considering that the objective is to dynamically replan so as to respond to sensing input, an objective of this work is to decrease the amount of time required to find solutions while still addressing this problem in the full state space of the underlying robotic system.

Several techniques can be drawn upon for this purpose. The first set of approaches involve biasing the sampling of states in ways that utilize key aspects of this specific challenge. For example, by computing the "most stable" support position of the stabilizing rover (i.e., perpendicular to the current position of the exploratory rover) and biasing the sampling process toward the subset of the state space with this property.

This work will explore whether or not it is effective to project the problem from the full state space, which may be very high-dimensional, depending on the degrees of freedom of the involved robots, to appropriate lower-dimensional task space projections. For example, the problem may potentially be dissected into multiple subproblem manifolds, where it may be possible to achieve reliable solutions much faster than in the full state space. In certain cases, this has been achieved through use of machine learning techniques, where it is possible to train a model to learn the important sub-manifolds of a particular system's state space while also learning to predict which static configurations for other state dimensions would be most effective for solving the complete problem [11].

Visiting Technologist Experience

In making progress toward the stated objectives of this research, hands-on experience with NASA engineers at a NASA research center would be invaluable. Observing and interacting with the most promising rover prototypes currently in development would allow my efforts in modeling these systems to be as accurate and share as many traits as possible. Working with the mechanical engineers building these systems would allow me crucial insight into the capabilities and limitations of current prototypes and would promote faster dissemination of inter-disciplinary ideas. Beyond benefits directly to the research, these experiences would be tremendously beneficial to my own education as a scientist.

Many of the systems (Axel II, DuAxel, Lemur IIb) mentioned in this paper were developed and tested at NASA JPL, which would make this location an ideal candidate for visiting experience. However, as the ideas presented here are largely independent of the platform, I believe it could also be beneficial to work with systems and engineers at NASA Ames (Tensegrity robots, KRex) or Johnson Space Center (Robonaut 2).

References

[1] P. Abad-Manterola, I. A. D. Nesnas, and J. W. Burdick, "Motion planning on steep terrain for the tethered axel rover," *Proceedings - IEEE International Conference on Robotics and Automation*, pp. 4188–4195, 2011.

[2] J. E. Bares, "Dante II: Technical Description, Results, and Lessons Learned," *The International Journal of Robotics Research*, vol. 18, no. 7, pp. 621–649, 1999.

[3] M. Krishna, J. Bares, and E. Mutschler, "Tethering System Design for Dante II," *Proceedings of the IEEE*, pp. 1100–1105, 1997.

[4] M. Bibuli, M. Caccia, and L. Lapierre, "Path-following algorithms and experiments for an autonomous surface vehicle," *IFAC Proceedings Volumes (IFAC-PapersOnline)*, vol. 7, no. PART 1, pp. 81–86, 2007.

[5] T. Bretl, "Motion Planning of Multi-Limbed Robots Subject to Equilibrium Constraints: The Free-Climbing Robot Problem," *The International Journal of Robotics Research*, vol. 25, no. 4, pp. 317–342, 2006.

[6] I. A. D. Nesnas, P. Abad-Manterola, J. A. Edlund, and J. W. Burdick, "Axel mobility platform for steep terrain excursions and sampling on planetary surfaces," *IEEE Aerospace Conference Proceedings*, 2008.

[7] S. Hert and V. Lumelsky, "The ties that bind: Motion planning for multiple tethered robots," *Robotics and Autonomous Systems*, vol. 17, no. 3, pp. 187–215, 1996.

[8] J. Hershberger and J. Snoeyink, "Computing minimum length paths of a given homotopy class," *Computational geometry*, vol. 4, no. 2, pp. 63–97, 1994.

[9] M. M. Tanner, J. W. Burdick, and I. A. D. Nesnas, "Online motion planning for tethered robots in extreme terrain," in *ICRA*, 2013.

[10] Y. Li, Z. Littlefield, and K. E. Bekris, "Asymptotically optimal sampling-based kinodynamic planning," *International Journal of Robotics Research (IJRR)*, vol. 35, pp. 528–564, 04/2016 2016.

[11] J. Rowekamper, G. D. Tipaldi, and W. Burgard, "Learning to guide random tree planners in high dimensional spaces," *IEEE International Conference on Intelligent Robots and Systems*, pp. 1752–1757, 2013.

Semester	Tasks & Milestones
Fall 2017	• Software Development: Design and modeling of variety of prototype systems which would benefit from tethered motions to use in simulation • Exploration of ways to best model cable interactions on rough terrain in variety of gravities
Spring 2018	• Software development: Finalize prototype systems and physics simulation • Investigate efficiency of sampling-based motion planners on variety of systems with different complexities
Fall 2018	• Design and testing of several control policies for efficacy in maneuvering tether
Spring 2019	• Publish results of low-level control policies for physically-realistic tethered systems • Explore planning in low dimensional state space projections
Fall 2019	• Investigate machine learning approaches for dimensionality reduction in planning • Publish initial low dimensional state space results
Spring 2020	• Analyze results; Finalize low dimensional strategy • Software development: integrate appropriate low level control policies with rudimentary sensing data in simulation • Closing the loop: Integrating all parts of the coordinated solution
Fall 2020	• Simulating and analyzing benefits on variety of systems. • Writing dissertation
Spring 2021	• Finish dissertation

Colin M. Rennie

115 N 4th Avenue
Highland Park, NJ 08904
+1 805 440 9589
colin.rennie@cs.rutgers.edu
www.pracsyslab.org/colin.rennie

EDUCATION

PhD, Department of Computer Science Fall 2014 - Present
Rutgers University, Piscataway, NJ
Graduate research and coursework focusing on robotics, control systems, motion planning, and machine learning.

Bachelor of Science Fall 2006 - Spring 2011
Sonoma State University, Rohnert Park, CA
Major in Finance, minor in Computer Science (Cum Laude)
Concentration on computational finance.

RESEARCH AND TEACHING EXPERIENCE

Graduate Research Assistant - PRACSYS Lab Fall 2016 - Present
Rutgers University - Piscataway, NJ
Supervisor: Dr. Kostas Bekris
Focus on development of motion primitives for informed motion planning and control for complex Tensegrity robots. Implementation of CPG systems, iLQR trajectory optimization, and physics engine integration.

Graduate Summer Intern - Pirate Lab Summer 2016
NASA Ames Research Center - Mountain View, CA
Supervisor: Vytas Sunspiral
Summer research collaboration centered on Bayesian optimization for dynamic movement primitive/maneuver generation in a snake-like system.

Teaching Assistant - CS674: Seminar in Robotic Learning Spring 2016
Rutgers University - Piscataway, NJ
Professor: Dr. Abdeslam Boularias
Topics covered: Classical robotics, Optimal control, Kinematics, Dynamics, Reinforcement learning, Learning from demonstration, Model learning, Grasping, and Manipulation.

Teaching Assistant - CS520: Intro to Artificial Intelligence Fall 2015
Rutgers University - Piscataway, NJ
Professor: Dr. Abdeslam Boularias
Topics covered: Heuristic search, Adversarial search, Constraint satisfaction problems, Bayesian networks, Hidden markov models, Kalman and Particle filters, Markov decision processes, Linear models, Neural networks, Kernel methods, Gaussian processes, Reinforcement learning.

Research Asst. - Center for Adaptive Behavior & Cognition Spring 2009
Max-Planck Institute for Human Development - Berlin, Germany
Supervisor: Dr. Henry Brighton
Research project using large health questionnaire response dataset, focused on reducing length while retaining predictive capabilities of responses in terms of future health risk. Side-by-side analysis of various machine learning algorithms.

PROFESSIONAL EXPERIENCE

Senior Analyst - Corporate Development Group August 2012 - August 2013
RPX Corporation - San Francisco, CA
Development of patent valuation estimation tools based on litigation, ownership, and market data. These insights were used as primary decision-making tools for the company - one of the largest purchasers of domestic Intellectual Property assets.

Analyst - Data Science Group July 2011 - August 2012
RPX Corporation - San Francisco, CA
Design of relational databases, external data source Input/Output protocol, and maintenance mechanisms for patent ownership, licensing, and litigation data.

PUBLICATIONS

"A Dataset for Improved RGBD-based Object Detection and Pose Estimation for Warehouse Pick-and-Place." **Rennie, Colin**, Rahul Shome, Kostas E. Bekris, and Alberto F. De Souza. IEEE Robotics and Automation Letters 1, no. 2: 1179-1185. (2016) [Journal version - around 33% acceptance]

PRESENTATIONS

A Dataset for Improved RGBD-based Object Detection and Pose Estimation for Warehouse Pick-and-Place
First Annual Workshop on Recovering 6D Object Pose - International Conference on Computer Vision (ICCV), 2015 [Poster]

A Dataset for Improved RGBD-based Object Detection and Pose Estimation for Warehouse Pick-and-Place
IEEE International Conference on Robotics and Automation (ICRA), 2016 [Oral/Poster]

AWARDS

GAANN Fellowship - Rutgers University *Fall 2014 - Spring 2015*
Tribal Scholarship - Citizen Potawatomi Nation *Fall 2014*
Dean's List - Sonoma State University (6 semesters) *Fall 2006 - Spring 2011*

STUDENT NAME: RENNIE,COLIN MATTHEW
STUDENT ID NO: [redacted]
BIRTH MO/DAY: 01/06
ALTERNATE ID NO: ***-**-1167
DATE ISSUED: 12/12/2013

UNDERGRADUATE RECORD

DEGREE CONFERRED:
BACHELOR OF SCIENCE
CUM LAUDE
MAJOR:
BUSINESS ADMINISTRATION [FINANCE]
MINOR:
COMPUTER SCIENCE
DATE CONFERRED: AUGUST 19, 2011

WRITTEN ENGLISH PROFICIENCY TEST PASSED DECEMBER 4, 2010
MEETS CSU GRADUATION WRITING ASSESSMENT REQUIREMENT

PRIOR SCHOOLS ATTENDED
UNIV. OF CALIF L A EXTENDED UNIV
CUESTA COLLEGE
SANTA ROSA JUNIOR COLLEGE

TRANSFER TOTALS	UG	UE	GP	GPA
CREDIT ALLOWED	21.3	21.3	67.8	(3.17)

FALL SEMESTER 2006			UA	UG	UE	GP	GR	REF
BIOL	115	Introduction to Biology	3.0	3.0	3.0	12.0	A	B2
CS	115	Programming I	4.0	4.0	4.0	16.0	A	B3
ENSP	200	Global Environmental Issues	3.0	3.0	3.0	12.0	A	D5
KIN	101	Ultimate Frisbee	1.0	0.0	0.0	0.0	W	
PHIL	101	Critical Thinking	3.0	3.0	3.0	11.1	A-	A3
PSY	250	Introduction to Psychology	3.0	3.0	3.0	12.0	A	D1
			17.0	16.0	16.0	63.1	(3.94)	
		DEAN'S LIST						

WINTER SESSION 2007			UA	UG	UE	GP	GR	REF
PSY	306	History of Modern Psychology	3.0	3.0	3.0	12.0	A	
			3.0	3.0	3.0	12.0	(4.00)	

SPRING SEMESTER 2007			UA	UG	UE	GP	GR	REF
ARTH	199	Readings In Art History 211	1.0	0.0	1.0	0.0	CR	
ARTH	211	Intro to Art History	4.0	4.0	4.0	16.0	A	C1
FL	214	French Literature and Film	4.0	4.0	4.0	16.0	A	C2
GEOG	203	Cultural Geography	3.0	3.0	3.0	12.0	A	D2
MATH	161	Calculus I	4.0	4.0	4.0	16.0	A	B4
PHYS	100	Descriptive Physics	3.0	3.0	3.0	12.0	A	B1
PHYS	102	Descriptive Physics Lab	1.0	1.0	1.0	4.0	A	B1
			20.0	19.0	20.0	76.0	(4.00)	
		DEAN'S LIST						

FALL SEMESTER 2007			UA	UG	UE	GP	GR	REF
CS	110	Introduction to Unix	1.0	1.0	1.0	4.0	A	
CS	215	Programming II	4.0	4.0	4.0	13.2	B+	
CS	390	Computer Science Colloquim	1.0	0.0	1.0	0.0	CR	
MATH	211	Calculus II	4.0	4.0	4.0	16.0	A	
MATH	211W	Calculus II Workshop	1.0	0.0	1.0	0.0	CR	
MATH	222	Elem Applied Linear Algebra	3.0	3.0	3.0	11.1	A-	
POLS	200	American Political System	3.0	3.0	3.0	9.0	B	D4
			17.0	15.0	17.0	53.3	(3.55)	

WINTER SESSION 2008			UA	UG	UE	GP	GR	REF
MUS	343	Studies in Musical Genres	3.0	3.0	3.0	12.0	A	
			3.0	3.0	3.0	12.0	(4.00)	

SPRING SEMESTER 2008			UA	UG	UE	GP	GR	REF
CS	252	Intro to Computer Organization	4.0	4.0	4.0	16.0	A	
CS	355	Database Mgt System Design	4.0	4.0	4.0	16.0	A	
GER	101	Elementary German-1st Semester	4.0	4.0	4.0	12.0	B	
		Per GE Pattern,course satisfies area C4.						
GER	101L	Language Laboratory	1.0	0.0	1.0	0.0	CR	
			13.0	12.0	13.0	44.0	(3.66)	
		DEAN'S LIST						

SUMMER SESSION 2008			UA	UG	UE	GP	GR	REF
IP	200	Intermediate German B	3.0	3.0	3.0	12.0	A	
IP	200	Intermediate German A	3.0	3.0	3.0	12.0	A	
			6.0	6.0	6.0	24.0	(4.00)	

******** CONTINUED ON PAGE 2 ********

Colin Rennie
[redacted]

Lisa Noto, University Registrar

STUDENT NAME: RENNIE,COLIN MATTHEW
STUDENT ID NO: [redacted]
BIRTH MO/DAY: 01/06

ALTERNATE ID NO: ***-**-1167
DATE ISSUED: 12/12/2013
PAGE NUMBER: 2 OF 2

FALL SEMESTER 2008			UA	UG	UE	GP	GR	REF
IP	200	German Aural Compreh/GER	2.0	0.0	2.0	0.0	CR	
IP	300	German Lit II/GER	3.0	3.0	3.0	8.1	B-	
IP	300	Contemp German Civilizat/GER	3.0	3.0	3.0	9.0	B	
IP	300	Adv German: Gramm & Comp/GER	4.0	4.0	4.0	16.0	A	
IP	300	Adv German/GER	4.0	4.0	4.0	16.0	A	
IP	300	Intercult Communication/COMS	3.0	3.0	3.0	9.0	B	
IP	300	German Film/GER	1.0	1.0	1.0	3.7	A-	
			20.0	18.0	20.0	61.8	(3.43)	

SPRING SEMESTER 2009			UA	UG	UE	GP	GR	REF
		Withdrew : 10-MAR-09						
IP	100F	International Study Abroad	12.0	0.0	0.0	0.0	W	
			12.0	0.0	0.0	0.0	(0.00)	

FALL SEMESTER 2009			UA	UG	UE	GP	GR	REF
BUS	230A	Financial Accounting	4.0	4.0	4.0	16.0	A	
CS	242	Discrete Structures for CS	4.0	0.0	0.0	0.0	W	
CS	315	Data Structures	4.0	4.0	4.0	16.0	A	
CS	351	Computer Architecture	4.0	0.0	0.0	0.0	W	
CS	390	Computer Science Colloquim	1.0	0.0	1.0	0.0	CR	
ECON	205	Intro to Microeconomics	4.0	4.0	4.0	12.0	B	
			21.0	12.0	13.0	44.0	(3.66)	

DEAN'S LIST

WINTER SESSION 2010			UA	UG	UE	GP	GR	REF
MATH	165	Elementary Applied Statistics	4.0	4.0	4.0	13.2	B+	B4
			4.0	4.0	4.0	13.2	(3.30)	

SPRING SEMESTER 2010			UA	UG	UE	GP	GR	REF
BUS	316	Production Operations Mgt	4.0	4.0	4.0	8.0	C	
BUS	319	Intro to MIS	4.0	4.0	4.0	12.0	B	
BUS	360	Intro to Marketing	4.0	0.0	0.0	0.0	W	
BUS	370	Intro Managerial Finance	4.0	4.0	4.0	16.0	A	
			16.0	12.0	12.0	36.0	(3.00)	

FALL SEMESTER 2010			UA	UG	UE	GP	GR	REF
BUS	360	Intro to Marketing	4.0	4.0	4.0	13.2	B+	
BUS	472	Investments	4.0	4.0	4.0	16.0	A	
BUS	474	Computer Apps in Finance	4.0	4.0	4.0	14.8	A-	
ECON	375	Money and Banking	4.0	4.0	4.0	16.0	A	
			16.0	16.0	16.0	60.0	(3.75)	

DEAN'S LIST

WINTER SESSION 2011			UA	UG	UE	GP	GR	REF
NAMS	346	Philosophic Sys&Sacred Mvmnts	3.0	0.0	3.0	0.0	CR	C3
			3.0	0.0	3.0	0.0	(0.00)	

SPRING SEMESTER 2011			UA	UG	UE	GP	GR	REF
BUS	330A	Intermediate Accounting	4.0	4.0	4.0	6.8	C-	
BUS	344	Organizational Behavior	4.0	4.0	4.0	9.2	C+	
BUS	470	Managerial Finance	4.0	4.0	4.0	12.0	B	
HIST	252	History U.S. Since 1865	3.0	0.0	3.0	0.0	CR	D3
			15.0	12.0	15.0	28.0	(2.33)	

SUMMER SESSION 2011			UA	UG	UE	GP	GR	REF
BUS	491	Seminar Mgmt Strategy & Policy	4.0	4.0	4.0	10.8	B-	
NURS	480	Health, Sexuality, and Society	3.0	3.0	3.0	12.0	A	E
			7.0	7.0	7.0	22.8	(3.25)	

CUMULATIVE TOTALS	UA	UG	UE	GP	GPA
CAMPUS	193.0	155.0	168.0	550.2	(3.54)
TRANSFER		21.3	21.3	67.8	(3.17)
TOTAL		176.3	189.3	618.0	(3.50)

******** END OF ACADEMIC RECORD ********

Colin Rennie
[redacted]

Lisa Noto, University Registrar

RECORD OF: COLIN MATTHEW RENNIE

STUDENT NUMBER: 160003328

RECORD DATE: 11/03/16 PAGE: 1

Fall 2014 GRADUATE SCHOOL-NEW BRUNSWICK

PROGRAM: COMPUTER SCIENCE
Degree Sought: DOCTORAL PRE-QUALIFYING

TITLE	SCH	DEPT	CRS	SUP	SEC	CRED	PR	GRADE
DSGN&ANAL DS&ALGOR I	16	198	513		01	3.0		A
PATTERN RECOGNITION	16	198	535		01	3.0		A
RESEARCH COMP SC	16	198	701		E1	3.0		
GRADUATE FELLOWSHIP	16	198	811		01	0.0		

TOTAL CREDITS ATTEMPTED: 9.0

DEGREE CREDITS EARNED: 6.0 TERM AVG: 4.000 CUMULATIVE AVG: 4.000

Spring 2015 GRADUATE SCHOOL-NEW BRUNSWICK

PROGRAM: COMPUTER SCIENCE
Degree Sought: DOCTORAL PRE-QUALIFYING

TITLE	SCH	DEPT	CRS	SUP	SEC	CRED	PR	GRADE
COMPUTER VISION	16	198	534		01	3.0		B+
SEMINAR COMPUTER SCI	16	198	672		01	3.0		A
SUB TOPIC: SEMINAR IN COMPUTER SCIENCE								
GRADUATE FELLOWSHIP	16	198	811		01	0.0		

TOTAL CREDITS ATTEMPTED: 6.0

DEGREE CREDITS EARNED: 12.0 TERM AVG: 3.750 CUMULATIVE AVG: 3.875

Fall 2015 GRADUATE SCHOOL-NEW BRUNSWICK

PROGRAM: COMPUTER SCIENCE
Degree Sought: DOCTORAL PRE-QUALIFYING

TITLE	SCH	DEPT	CRS	SUP	SEC	CRED	PR	GRADE
TOPICS IN A I	16	198	598		01	3.0		A
RESEARCH COMP SC	16	198	701		B4	3.0		A
FULL TA APPOINTMENT	16	198	877		01	6.0	E	

TOTAL CREDITS ATTEMPTED: 12.0

DEGREE CREDITS EARNED: 18.0 TERM AVG: 4.000 CUMULATIVE AVG: 3.917

Spring 2016 GRADUATE SCHOOL-NEW BRUNSWICK

PROGRAM: COMPUTER SCIENCE
Degree Sought: DOCTORAL PRE-QUALIFYING

TITLE	SCH	DEPT	CRS	SUP	SEC	CRED	PR	GRADE
SEM COG SCI II	16	185	601		01	3.0		B+
SUB TOPIC: CONCEPTS & CATEGORIES								
SEL PROB COMP SCI	16	198	602		B4	6.0		A
FULL TA APPOINTMENT	16	198	877		01	6.0	E	

TOTAL CREDITS ATTEMPTED: 15.0

DEGREE CREDITS EARNED: 27.0 TERM AVG: 3.833 CUMULATIVE AVG: 3.889

**** CONTINUED ON NEXT PAGE ****

RECORD OF: COLIN MATTHEW RENNIE

STUDENT NUMBER: 160003328

RECORD DATE: 11/03/16 PAGE: 2

TITLE	SCH	DEPT	CRS	SUP	SEC	CRED	PR	GRADE

Fall 2016 GRADUATE SCHOOL-NEW BRUNSWICK

PROGRAM: COMPUTER SCIENCE
Degree Sought: DOCTORAL PRE-QUALIFYING

TITLE	SCH	DEPT	CRS	SUP	SEC	CRED	PR	GRADE
FULL GA APPOINTMENT	16	198	866		01	6.0		E
APPLIED CONTROLS	16	332	506		01	3.0		

TOTAL CREDITS ATTEMPTED: 9.0

DEGREE CREDITS EARNED: TERM AVG: CUMULATIVE AVG:

Last Term Information

LAST TERM CREDIT HOURS: 15.0
LAST TERM CREDITS IN GPA: 9.0
LAST TERM POINTS IN GPA: 34.5
LAST TERM CUMULATIVE CREDITS IN GPA: 27.0
LAST TERM CUMULATIVE POINTS IN GPA: 105.0

***** END OF TRANSCRIPT *****

ETS GRE

TEST TAKER SCORE REPORT

Note: This report is not valid for transmission of scores to an institution.

COLIN M RENNIE

Most Recent Test Date: December 4, 2013

Address: [redacted]

Registration Number: 5587036
Print Date: October 31, 2016

Email: COLINMATTHEW@GMAIL.COM
Phone: 1-8054409589
Date of Birth: [redacted]
Social Security Number (Last Four Digits): 1167
Gender: Male
Intended Graduate Major: Computer Science (0402)

Your Scores for the General Test Taken on December 4, 2013

Verbal Reasoning	Quantitative Reasoning	Analytical Writing
Your Scaled Score: 159 (130–170)	Your Scaled Score: 170 (130–170)	Your Score: 3.5 (0–6)
82nd Percentile	97th Percentile	42nd Percentile

Your Test Score History

General Test Scores

	Verbal Reasoning		Quantitative Reasoning		Analytical Writing	
Test Date	**Scaled Score**	**Percentile**	**Scaled Score**	**Percentile**	**Score**	**Percentile**
December 4, 2013	159	82	170	97	3.5	42

Subject Test Scores

You do not have reportable test scores at this time.

Your Score Recipient(s)

Undergraduate Institution

Report Date	Institution (Code)	Department (Code)	Test Title	Test Date
Not Reported	SONOMA ST U (4723)	BUSINESS ADMIN & MGMT (4201)	General Test	December 4, 2013

COLIN M RENNIE

Most Recent Test Date: December 4, 2013

Date of Birth: January 6, 1988

Registration Number: 5587036
Print Date: October 31, 2016

Designated Score Recipient(s)

Report Date	Score Recipient (Code)	Department (Code)	Test Title	Test Date
January 8, 2014	NORTHEASTERN U GRAD COMP SCI (3679)	COMPUTER SCIENCE (0402)	General Test	December 4, 2013
January 8, 2014	OHIO ST UNIV (1592)	UNDECIDED (0000)	General Test	December 4, 2013
January 8, 2014	TUFTS U MEDFORD (3901)	UNDECIDED (0000)	General Test	December 4, 2013
January 8, 2014	VIRGINIA POLYTECH & ST UNIV. (5859)	UNDECIDED (0000)	General Test	December 4, 2013
December 25, 2013	RUTGERS GRADUATE NEW BRUNSWICK (2790)	ANY DEPARTMENT NOT LISTED (5199)	General Test	December 4, 2013
December 25, 2013	YALE U (3987)	UNDECIDED (0000)	General Test	December 4, 2013
December 13, 2013	MCGILL UNIVERSITY (0935)	COMPUTER SCIENCE (0402)	General Test	December 4, 2013
December 13, 2013	NYU POLYTECHNIC SCHL ENGRNG (2668)	COMPUTER SCIENCE (0402)	General Test	December 4, 2013
December 13, 2013	UNIV CHICAGO (1832)	COMPUTER SCIENCE (0402)	General Test	December 4, 2013
December 13, 2013	UNIVERSITY TORONTO (0982)	COMPUTER SCIENCE (0402)	General Test	December 4, 2013

• **Not Reported** - Institution does not accept GRE scores.

About Your *GRE*® Score Report

Score Reporting Policies

With the *ScoreSelect*® option, you can decide which test scores to send to the institutions you designate. There are three options to choose from:

- Most Recent option – Send your scores from your most recent test administration
- All option – Send your scores from all administrations in the last five years
- Any option – Send your scores from one OR as many test administrations in the last five years (this option is not available on test day when you select up to four FREE score reports)

Scores for a test administration must be reported in their entirety. Institutions will receive score reports that show only the scores that you selected to send to them. There will be no special indication if you have taken additional GRE tests. See the *GRE® Information Bulletin* for details. The policies and procedures explained in the Bulletin for the current testing year supersede previous policies and procedures in previous bulletins.

Scores will be sent to designated score recipients approximately 10-15 days after a computer-delivered test and 5 weeks after a paper-delivered test. If your scores are not available for any reason, you will see "Not Available" in Your Test Score History.

GRE test scores are reportable according to the following policies:

- For tests taken prior to July 1, 2016, scores are reportable for five (5) years following the testing year in which you tested (July 1 – June 30). For example, scores for a test taken on May 15, 2015, are reportable through June 30, 2020. GRE scores earned prior to August 2011 are no longer reportable.
- For tests taken on or after July 1, 2016, scores are reportable for five (5) years following your test date. For example, scores for a test taken on July 3, 2016, are reportable through July 2, 2021.

Note: Score recipients will only receive scores from test administrations that you have selected to send to them.

Percentile Rank (% Below)

A percentile rank for a test score indicates the percentage of test takers who took that test and received a lower score. Regardless of when the reported scores were earned, the percentile ranks for General Test and Subject Test scores are based on the scores of all test takers who tested within the most recent three-year period.

Retaking a GRE Test

You can take the *GRE*® General Test *once every 21 days*, up to *five times* within any continuous rolling 12-month period (365 days). This applies even if you canceled your scores on a test taken previously. You can take the paper-delivered GRE General Test and *GRE*® Subject Tests as often as they are offered.

Note: This policy will be enforced even if a violation is not immediately identified (e.g., inconsistent registration information) and test scores have been reported. In such cases, the invalid scores will be canceled and score recipients will be notified of the cancellation. Test fees will be forfeited.

For More Information

For information about interpreting your scores, see *Interpreting Your GRE Scores* at **www.ets.org/gre/understand.**

For detailed information about your performance on the Verbal Reasoning and Quantitative Reasoning sections of the computer-delivered GRE General Test, access the free GRE Diagnostic Service from your ETS account. This service includes a description of the types of questions you answered right and wrong, the difficulty level of each question, and the time spent on each question. This service is available approximately 15 days after your test administration and for six months following your test administration.

If you have any questions concerning your score report, email GRE Services at **gre-info@ets.org** or call 1-609-771-7670 or 1-866-473-4373 (toll free for test takers in the U.S., U.S. Territories and Canada) between 8 a.m. and 7:45 p.m. (New York Time).