CALIFORNIA SCIENCE & ENGINEERING FAIR
2019 PROJECT SUMMARY

Name(s)

Pranav Atreya

Project Number

S1401

Project Title

A Novel Analytical Approach to Determining Parameter Derivatives of an Object under Motion Constraints

Abstract

Objectives

When the path of an object is described by the vector equation in the form of r(u,v,w...)=<f(u,v,w...),g(u,v,w...),h(u,v,w...)>, the expression ((d^n)r)/(d(p^n)), where p is a variable that represents one of the parameters u, v, w..., can be used to find the velocity and acceleration of the object with respect to the parameters at any position. However, when this parameterization is unknown, and the object moving along a certain path is subjected to various constraints, a different approach must be employed to find the velocity and acceleration of the object. The objective of this project is to find a generic formula for the acceleration with respect to the parameters of an object in such a situation, and contrast the efficacy of this analytical approach with two existing approaches, curvature and numerical approximation of differential equations.

Methods

The project involved first deriving the new mathematical approach to solve for acceleration, and extending the derivation to three dimensions and to a broader variety of curves and constraints. As such, simply pencils, paper, and a calculator were used. The analytical method was subsequently tested against existing approaches of numerical approximation of acceleration with the use of Euler's Method, and calculation of acceleration using curvature. Comparisons were made based on the metrics of computational efficiency, accuracy, and viability in real world applications. Tests were carried out by implementing these solutions in code using Java and the Apache Commons Math library.

Results

The results of the tests indicated that the new analytical approach fared considerably better than the other approaches on all criteria tested. Its computational efficiency was approximately 22.5% better than that of the curvature approach, and 97.0% better than that of the Euler's Method approach, and produced results of greater accuracy. The analytical approach's algorithmic complexity also proved to be lower than that of the curvature approach, and significantly less than that of the O(n^2) Euler's Method approach.

Conclusions

With faster runtimes and a 100% accuracy, this new approach could have wide applications in flight path planning, space path planning, and autonomous navigation, as it gives the ability to conduct real time calculations on how an object can traverse a certain path under various constraints. The acceleration metrics obtained with the analytical approach can ultimately be converted to engine power and orientation that these objects need to traverse the path. Further work planned includes developing a simulation using this equation for real time flight planning and potentially autonomous driving.

Summary Statement

Derived a new analytical approach to finding acceleration of an object subject to constraints on parameter derivatives and contrasted its viability with current existing methods.

Help Received

I worked on this project individually at home. I referenced a variety of sources for research material.

CALIFORNIA SCIENCE & ENGINEERING FAIR
2019 PROJECT SUMMARY

Name(s)

Maya Basu

Project Number

S1402

Project Title

Creating a Neural Network to Play the Game of Connect Four Using a Genetic Algorithm

Abstract

Objectives

My project explores a genetic algorithm as a method for producing a resultant digital neural network competent at a strategy game, namely Connect Four. I quantify competency as a being able to beat or tie the general population at Connect Four more than 90% of the time. Unsupervised methods have produced successful AI such as AlphaGo Zero. A genetic algorithm is an alternate type of unsupervised learning which is unproven and relatively unstudied.

Methods

I wrote code in the Rust programing language using CLion as my IDE to implement a digital neural network and my genetic algorithm, and validated it using TensorFlow. My code is hosted open source on GitHub for version management. I ran my program several times with different hyperparameters on both a Macintosh and a Linux workstation. I created a logic based Connect Four player to act as a benchmark for measuring progress. I ran my genetic algorithm for 100,000 generations and graphed the ability of the seed of each 500th generation against the benchmark.

Results

During the genetic algorithm, the mutation magnitude used the create each generation diminishes from 1 to a set value. I graphed four separate algorithms with different end mutation magnitudes using performance against the benchmark. Interestingly, the graphs are roughly step shaped, and "step" in order from least to greatest end mutation magnitude. I wondered what would happen if I selected the seed of each generation by using their performance directly against my benchmark, and recorded distinct step shaped graphs which also "step" in order from least to greatest end mutation magnitude.

Conclusions

I played the resultant neural network from every genetic algorithm and won, causing me to deem a study against the general population unnecessary. However, one of the neural networks did exhibit blocking strategies. Given the computing times used to train AlphaGo Zero, I may simply need to run my genetic algorithm for more than 300 times as long to achieve comparable results. However, my data suggests that sharply decreasing the mutation magnitude speeds up the genetic algorithm s performance. This is an important result for genetic algorithms in general, and I will probe how far this trend continues. I also plan to build concurrency into my program to make it faster, and look for gains in performance by using convolutional neural networks.

Summary Statement

My project explores a genetic algorithm as an alternate unsupervised method for producing a digital neural network competent at a strategy game.

Help Received

I wrote all of my code by myself in Rust and receive occasional help with debugging from my father. I obtained a student licence from WebStorm and used CLion as my IDE. I graphed my results using FreeMat. During my project, I discussed my plans with Drs. Basu, Skatter, and Quadri.

CALIFORNIA SCIENCE & ENGINEERING FAIR
2019 PROJECT SUMMARY

Name(s)

Jack Cooper; Eric Reyes

Project Number

S1403

Project Title

Pythagorean Triples Found in the Quadratic Equation

Abstract

Objectives

To fully discover the relationship between the Pythagorean triples and the Quadratic equation.

Methods

The use of Pythagorean triples a long with the application of the Quadratic formula in order to create a quadratic equation that has whole number components.

Results

The Pythagorean triple-related quadratic equations, when graphed, follow a trend along a seemingly invisible line, this line was named the string as it connects the parabolas together through the vertices. There were found to be more than one relation between the Pythagorean triples though, as the areas and circular arc of the parabolas were related as well. In summary, the parabolas are related to each other in a number of ways.

Conclusions

There are a handful of connections between Pythagorean triples, some of which are strings and areas. With this unique new connection of math that has yet to be touched on, based on the research, it can lead to a new discovery in the math community.

Summary Statement

we were able to convert Pythagorean triples into a quadratic equation which yield parabolas in the end.

Help Received

None. We came up with equation on our own and tested it ourselves at home and at school.

CALIFORNIA SCIENCE & ENGINEERING FAIR
2019 PROJECT SUMMARY

Name(s)

Elias Gilbert

Project Number

S1404

Project Title

Defining the Function of a Curve in an Image with Graphical Analysis and Model Selection

Abstract

Objectives

The main objective of this project was to create an algorithm that could take the image of a drawn curve and find a function to model it. This objective can be broken down into three smaller goals. First, obtaining a set of points from the image that represents the curve. Next, finding curves of best fit of various model types for those points. Finally, deciding which model best represents the data.

Methods

I used Python 3 with the Pythonista IDE and its Scene graphics package to write an iPad program that meets all three goals. I first wrote code to select all pixels of a given range of hues within an image, which then allows a user to take an image and select a curve from it based on its color. Next, I wrote separate code to find best-fit curves of various polynomial degrees and to display the best one, superimposed on the actual picture. Then, I explored various ways to select which function was the most representative using statistical analysis. Finally, I combined all the aspects of the program in a concise, user-friendly and elegant format.

Results

In this project, I created an efficient method to capture images and convert them to points that can be analyzed, fitting them with a range of polynomial functions. I used the Akaike Information Criterion (AIC) to choose what fit to use. However, AIC still often chooses fits that are more complicated than necessary, so I have also proposed an alternative way to choose between fits by comparing the effect of decreasing the complexity of the model.

Conclusions

This product could be applied as an aid in learning about how different types of functions are represented mathematically, evaluating the type of model that would best represent a predicted or observed pattern, or turning a handwritten drawing into a vectorized smooth curve. Though AIC may still be the best way to statistically choose between model fits, my proposed method poses an interesting statistical question that may merit further investigation.

Summary Statement

I created a program that takes an image of a drawn curve, rasterizes it, and uses multiple methods to find the best mathematical model to describe the curve.

Help Received

I wrote the program myself. My parents reviewed my presentation.

Name(s)

Mason Holst

Project Number

S1405

Project Title

An Optimized Multigrid Algorithm for Enabling Efficient Physical Simulations on Realistic Geometries

Abstract

Objectives

Partial differential equations (PDEs) are used in physics to mathematically describe the workings of the universe. Using computers to solve these equations allows scientists and engineers of all disciplines to create realistic simulations of real-life phenomena such as the distribution of stress across a support beam in a building to ensure its safety; the diffusion of calcium through a heart cell to improve medical knowledge and save lives; or the Einstein field equations around a black hole to understand how it generates gravitational waves. However, the physics of the real world is very complex, and as a result, when solving such PDEs to accurately represent reality, existing solution methods can exhibit prohibitively long computation times. In this project an improved PDE solver algorithm is developed to enable more efficient creation of physical simulations.

Methods

In most PDE solver schemes, discretized models of real geometries, referred to as geometric meshes, can be used to approximate physical objects and the equations that govern their behavior. Unlike the best existing methods, which discard information about this underlying geometric mesh, the proposed algorithm creates a hierarchy of multiresolution meshes, retaining geometric information on a multiscale level. This allows for a more faithful and efficient simulation of reality, capable of adapting to differing speed and resolution criteria. The developed algorithm utilizes the GAMer software package to generate the geometric meshes used in simulation, FEniCS software to discretize the PDEs, and the PETSc libraries for essential linear algebra functions.

Results

The computation time of the algorithm was tested against other established PDE solver methods by solving sample PDEs to a target accuracy. Experimental results show that the developed algorithm is faster than most available methods, and is competitive with the fastest of them.

Conclusions

The algorithm here proposed is capable of reaching a solution to the tested PDEs at a rate competitive with the fastest available methods, indicating it is highly computationally efficient. It additionally provides increased flexibility due to its use of an adaptive multilevel approach. This enables faster generation of computer simulations of reality through the solution of physical equations, making it possible to model very large-scale real-world problems.

Summary Statement

A superior numerical algorithm is developed for solving partial differential equations across three-dimensional geometries, better enabling the fast and efficient generation of physical simulations of reality.

Help Received

I developed and tested the software presented independently. I used computational resources provided by the lab of Dr. Rommie Amaro, at the University of California, San Diego. I consulted with, and received advice from, Dr. Christopher Lee at the University of California, San Diego.

CALIFORNIA SCIENCE & ENGINEERING FAIR
2019 PROJECT SUMMARY

Name(s)

Alex Levine

Project Number

S1406

Project Title

Efficiently Identifying High-Centrality Nodes in Modular Networks

Abstract

Objectives

Identifying high-centrality nodes in large networks can be computationally inefficient, given that the most efficient exact algorithm runs in O(MN) time. A number of randomized approximations have been proposed based on sampling. We aim to identify more efficient ways to compute centrality based on the properties of real-world networks. We are also interested in understanding the dynamics of networked systems, such as social network behavior.

Methods

We initially conjecture that the highest centrality nodes in a network lie on the border between two communities.

Using the NetworkX library in Python, we test our conjecture on various network models, namely the Erdos-Renyi Model (ER) and the Barabasi-Albert (BA) Model and some real-world models. For each trial, we generate two communities using the Stochastic Block Model. To verify our results, we use the K-Means clustering algorithm and the Louvain Community Detection Method.

Results

Our conjecture holds 100% of the time on the ER Model. We initially do not yield the same results on the BA Model, however, as we increase the number of nodes and the average degree, the probability of our conjecture tends towards 100%. On the graphs where are conjecture seemingly doesn t hold, we apply the Louvain Method and reveal a very different community structure than we originally defined and find that our conjecture does in fact hold true. We obtain similar results when applying the Louvain method to real-world networks.

We provide theoretical evidence for two structured cases: complete graphs and star graphs. We find that our conjecture does not hold on the star graph when one community is larger than the other, however, we conjecture that there are more natural community structures than initially imposed, which may explain some of our results for the BA model.

Conclusions

Our findings have the potential to significantly speed up the computation of betweenness centrality. Rather than computing the betweenness centrality of every node in the network, one can uncover a community structure using the efficient Louvain Method and only compute the centrality of the inter-community nodes. In addition, our results can be used to better understand the dynamics of many social and biological networks.

Summary Statement

We find a very strong correlation between high-centrality nodes and inter-community nodes and demonstrate the implications of this result.

Help Received

Dr. Behrouz Touri of UCSD provided the research idea and supported me throughout the research process. He most notably helped with the theoretical evidence.

CALIFORNIA SCIENCE & ENGINEERING FAIR
2019 PROJECT SUMMARY

Name(s)

Daniel Liu

Project Number

S1407

Project Title

Extending Adversarial Attacks and Defenses to Deep 3D Point Cloud Classifiers

Abstract

Objectives

Testing 3D point cloud neural networks to see if they are susceptible to adversarial attacks like previous results on 2D images, proposing new algorithms for both attacking and defending 3D point clouds, and explaining the effectiveness of the attacks and defenses to better understand the nature of 3D point cloud classifiers.

Methods

Two well-known networks were evaluated: PointNet and PointNet++. They were trained and tested with the ModelNet-40 and smaller ModelNet-Unique dataset. Previously proposed adversarial attacks and defenses were implemented and tested. Also, new algorithms for attacking networks using methods that make use of intrinsic properties of 3D space and the 3D network architectures are proposed.

Results

3D point cloud neural networks were found to be similarly susceptible against adversarial attacks compared to 2D image classifiers, and human-imperceptible perturbations can be generated for 3D point clouds. The defense algorithms that I proposed were also effective. 3D point cloud networks were found to exhibit a new "gradient hiding" phenomenon, which allows the correct shape of objects to be hidden from adversarial attacks that require gradients.

Conclusions

Though 3D point cloud classifying neural networks are weak against adversarial attacks, gradient hiding and other intrinsic properties of 3D point clouds and the network architectures allow 3D point cloud classifiers to be more easily defensible than 2D image classifiers. This means that 3D point cloud classifiers should be favored over 2D image classifiers in tasks that require visual data, like autonomous driving. Also, the gradient hiding theory leads to a better understanding of how 3D neural networks behave against adversarial perturbations.

Summary Statement

Examining the behavior of 3D point cloud classifiers against adversarial attacks and attempting to defend them.

Help Received

Ronald Yu and Hao Su (both from Department of CSE, UCSD) provided the topic for me to work on, and GPUs for running experiments. I also conversed with Ronald Yu on the general designs of the project. All code were written by me. Almost all algorithm ideas were designed by me.

CALIFORNIA SCIENCE & ENGINEERING FAIR
2019 PROJECT SUMMARY

Name(s)

Andrei Mandelshtam

Project Number

S1408

Project Title

Dynamics of the Tangent Map

Abstract

Objectives

Analyze the distribution of the iterations of the tangent map for most starting values, both measure-theoretically and topologically. Characterize sets of starting values whose trajectories avoid certain intervals.

Results

I proved that almost all points, in both measure-theoretic and topological senses, have dense orbits under iterations of tan(x). The next theorem proved that any pattern of behavior is possible and happens for exactly one point. Furthermore, the set of starting points whose trajectory avoids a given set of intervals is a Cantor set.

Conclusions

I developed a new method to analyze expanding maps with indifferent fixed points. The methods I used are simpler than what exists in the literature and could be used in a broader class of maps with indifferent fixed points. My project provides a relatively simple approach to a complicated problem studied extensively today. This approach can be used to study models with intermittent chaos, a topic of particular interest in physics, computer science, and certain areas of mathematics.

Summary Statement

I found a new method to study expanding maps with indifferent fixed points and applied it to prove four theorems regarding the density and patterns of the iterations of the tangent map.

Help Received

I discovered and proved all the theorems myself. After I completed my project, Prof. A. Gorodetski from UCI showed me prior research done on this topic and commented on my paper.

Name(s)

Tejas Narayanan; Ashish Rao; Bidipta Sarkar

Project Number

S1409

Project Title

Novel Reinforcement Learning Methods in Collaborative Environments

Abstract

Objectives

Reinforcement learning (RL) is an emerging field with numerous applications in a wide variety of domains, such as robotics, supply chain and network optimization, marketing, and more. Our research focuses on developing improved RL algorithms and applying them to domains involving complex interactions between multiple intelligent systems.

Methods

We propose a novel algorithm which employs a Bayesian method of parameter space exploration to solve reinforcement learning problems. We parameterize policies as neural networks, and a Gaussian process is used to learn the expected return of a policy given the parameters. The system is trained by updating the parameters in the directions suggested by the Gaussian Process to maximize the expected return and explore important new states.

Results

Our method is applied to three challenging robotic simulations where we achieve gains of 8%, 20%, and 33% over current methods. We also observe good performance in cooperative and competitive environments that require communication between multiple intelligent systems.

Conclusions

The improved performance of our methods will enable the development of intelligent systems that tackle significantly more complex problems in robotics and other fields. Our novel method of Bayesian parameter space exploration can be theoretically shown to result in less conservative updates towards better policies.

Summary Statement

We develop a novel method of Bayesian parameter space exploration inspired by Policy Gradient methods to solve Reinforcement Learning Problems.

Help Received

We designed, developed, and implemented our algorithm by ourselves, but received some help. In particular, we emailed Dr. Yi Wu (UC Berkeley) and Dr. Ryan Lowe (McGill University) to clarify some questions we had on their papers.

CALIFORNIA SCIENCE & ENGINEERING FAIR
2019 PROJECT SUMMARY

Name(s)

Raj Palleti; Suhas Prasad

Project Number

S1410

Project Title

Dimensional Isomorphisms of the Eulerian Sequence: A Computer Inspired Analysis

Abstract

Objectives

In his monograph "Solutio facilis problematum quorumdam geometricorum difficillimorum," the Swiss mathematician Leonhard Euler first publicized the concept of the Euler Line, which connects the circumcenter, centroid, and orthocenter of any triangle. Curious to explore this line in other geometrical configurations, we began with the Eulerian Sequence, a subset of polygons postulated to contain the Euler Line. Inductive and extensive reasoning yielded several isomorphisms between this sequence and three-dimensional figures. Our project focuses on generalizing this sequence to describe a set of polyhedrons that contain the Euler Line in addition to exploring their properties.

Methods

We utilize multiple computer simulations to gather observations and make conjectures, primarily using Java and MATLAB software to plot the special points and the set of polyhedrons with the Euler Line. Inspired by our simulations, we proved our conjectures of Eulerian Polyhedrons through various multivariate techniques.

Results

Using a proof by induction, we were able to develop explicit and recursive descriptions for the number of faces, edges, and vertices for any Eulerian Polyhedron. Through topological and analytical techniques, we located the centroid, Monge point, and circumcenter of a general Eulerian Polyhedron, and using differential geometry to express the volume and surface area of each Eulerian Polyhedron. Lastly, examining the end behavior of our formulas showed that Eulerian Polyhedrons would converge not to a sphere but to a Steinmetz solid.

Conclusions

In our project, we define the criteria for any Eulerian Polyhedron while also validating its algebraic and geometric properties. We also explore and develop barycentric descriptions of Eulerian Polyhedrons. Ultimately, our computer simulations remain a critical inspiration for our analyses and applications, and we hope to use our computer simulations in the future to approach problems in other fields that may benefit from computer inspiration.

Summary Statement

Our project focuses on generalizing the Eulerian Sequence to describe a subset of polyhedrons that contain the Euler Line in addition to exploring their properties.

Help Received

None. While we have received no outside help, we plan on contacting a professor in the near future and publishing our results.

Name(s)

Jian Park

Project Number

S1411

Project Title

DT-DBSCAN: Density-Based Spatial Clustering in Linear Expected Time Using Delaunay Triangulation

Abstract

Objectives

DBSCAN is an unsupervised learning algorithm that connects locally dense regions of data to form data clusters. This algorithm is frequently used for medical, engineering, and financial applications, and it is also used to train machine learning algorithms. However, the fastest iteration of DBSCAN runs in quasi-linear time, which makes the algorithm unusable for larger sets of data. Therefore, the goal of this project was to develop a DBSCAN algorithm that has a linear expected run-time.

Methods

To determine locally dense regions, current DBSCAN iterations use R - trees and hashing methods to check for points within a locality, which takes O(log n) time for each point. DT-DBSCAN, or Delaunay triangulated DBSCAN, conducts the locality check by tree-searching along the edges of the Delaunay triangulation of the initial data set. Given that the maximum density of a cluster is bounded by a finite constant, I prove that this process takes provably constant time for each point. After classifying locally dense points, DT-DBSCAN connects locally dense points to form clusters in linear time by exploiting the linearity of the edges of a planar graph. After mathematically proving the run-time of DT-DBSCAN, an experiment was conducted to verify this claim. Procedurally generated data-sets were created with varying sizes, and the run-times between DT-DBSCAN and conventional DBSCAN algorithms were compared.

Results

After testing a total of 3,750 datasets with varying sizes, the run-time test showed that DT-DBSCAN heavily outperformed DBSCAN for data sets with more than 15,000 points. In addition, DT-DBSCAN displayed a linear growth in run-time as the data size increased, which affirmed the mathematical proofs on the run-time.

Conclusions

The proofs and the experiment both demonstrated the advantages of DT-DBSCAN over conventional DBSCAN iterations. DT-DBSCAN generates the exact same cluster results as DBSCAN, but has a linear expected run-time. This provides a unique solution for practically computing density-based clusters from larger sets of data.

Summary Statement

I developed DT-DBSCAN, an algorithm that classifies density-based data clusters faster than currently existing methods.

Help Received

I developed the run-time proofs and the DT-DBSCAN algorithm independently. My math teacher reviewed my project.