Student Checklist (1A)

This form is required for ALL projects.

1. a. Student/Team Leader: Parth Kulkarni Grade: 9

   Email: toparth@gmail.com Phone: 813-716-6039

   b. Team Member: ______ c. Team Member: ______

2. Title of Project:

   Meta-Heuristic Algorithm using Ant Colony Optimization

3. School: Strawberry Crest School Phone: 813-707-7522

   School Address: 4691 Gallagher Road

   Dover, Fl 33527

4. Adult Sponsor: Dianne Schroeder Phone/Email: dianne.schroeder@sdhc.k12.fl.us

5. Does this project need pre-approval? ☐ Yes ☑ No Tentative start date: 11/19/16

6. Is this a continuation/progression from a previous year? ☐ Yes ☑ No

   If Yes:

   a. Attach the previous year's ☐ Abstract **and** ☐ Research Plan

   b. Explain how this project is new and different from previous years on ☐ Continuation/Research Progression Form (7)

7. This year's laboratory experiment/data collection:

   11/19/16 — Actual Start Date: (mm/dd/yy)

   11/20/16 — End Date: (mm/dd/yy)

8. Where will you conduct your experimentation? (check all that apply)

   ☐ Research Institution ☐ School ☐ Field ☑ Home ☐ Other: ______

9. List name and address of all non-school work site(s):

   Name: Home- Parth Kulkarni

   Address: 1802 Raven Manor Dr

   Dover, Fl 33527

   Phone: 813-716-6039

10. **Complete a Research Plan/Project Summary following the Research Plan instructions and attach to this form.**

11. **An abstract is required for all projects after experimentation.**

RESEARCH PLAN

PARTH KULKARNI

I. *Title*

Meta-Heuristic Algorithm using Ant Colony Optimization

II. *Rationale*

As the systems around us get more complex, many shortcomings of a centralized optimization can be seen vividly. This makes companies spend more money, waste the valuable computing and natural resources. To solve this, we must come up with decentralized, individually smart, and collectively intelligent systems. Such systems are easy to manage, reduce risk of failure, and provide practically feasible solutions. Things that can be done with these decentralized systems are: optimize telecom networks by exploiting decentralized SDN (software defined networks), build medicines that can be released only when and where required, predict housing market variations, etc. We will learn from 150 million years of Swarm intelligence developed by ants and use the ways ants live and find food. It's called ACO – Ant Colony Optimization. Per the process of developing algorithms or meta-heuristics, a newly made algorithm or meta-heuristic should be tested against a Test Optimization Function. Thus, I will be testing my meta-heuristic algorithm against a Test Optimization Function known as Sphere Function to see if it is truly optimized.

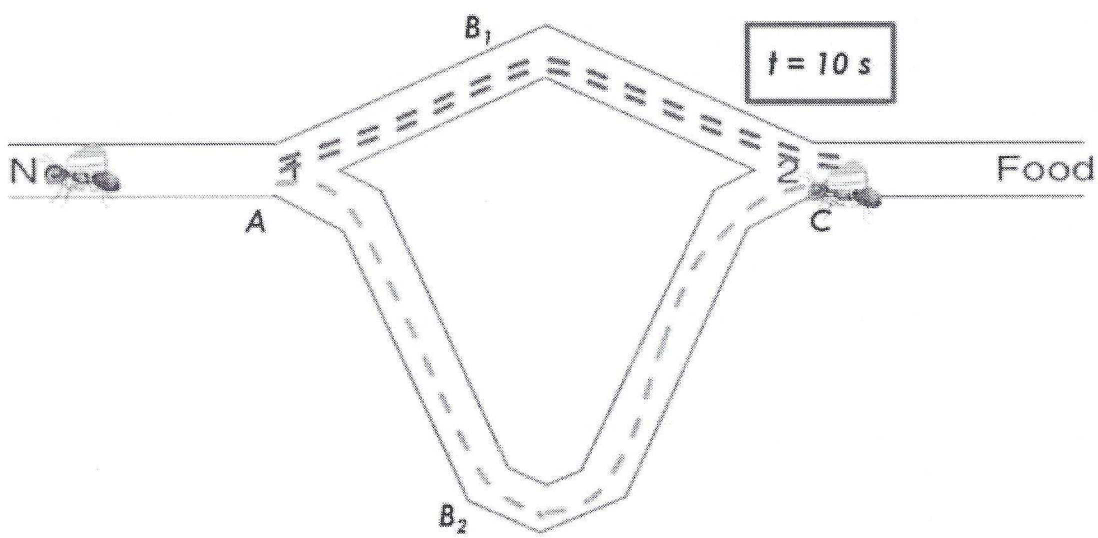
Question

Can ACO meta-heuristics algorithm be used to reach a minimum value of Sphere Test Optimization Function and hence solve it?

Research

- Ants are mostly blind, deaf, and dumb. There are 1-2 queens who reproduce, rest all female ants. 25% of ants work outside.
- They switch tasks sometimes. If there is more food, then more ants will switch work and come to collect food. 50% ants are in reserve; they generally do nothing.
- Ants start deep inside colony, as they grow, they come out and become food hunters.
- Ant lives about a year; queen lives about 15 years.
- Each ant has hydro-carbon grease on them, which builds with growing in the colony, it has specific smell for a given colony. They touch each other with 2 antennas to test if an ant is from same colony and same team.
- After a few years, a female reproductive (one with wings) and exits with male and starts another colony.
- ACO studies the behavior of ants and uses it to solve real world optimization problems
- Autocatalytic behavior - the more ants that follow the trail the more attractive it becomes to follow
- ACO algorithm is inspired by - ants being able to finding the shortest path from nest to food

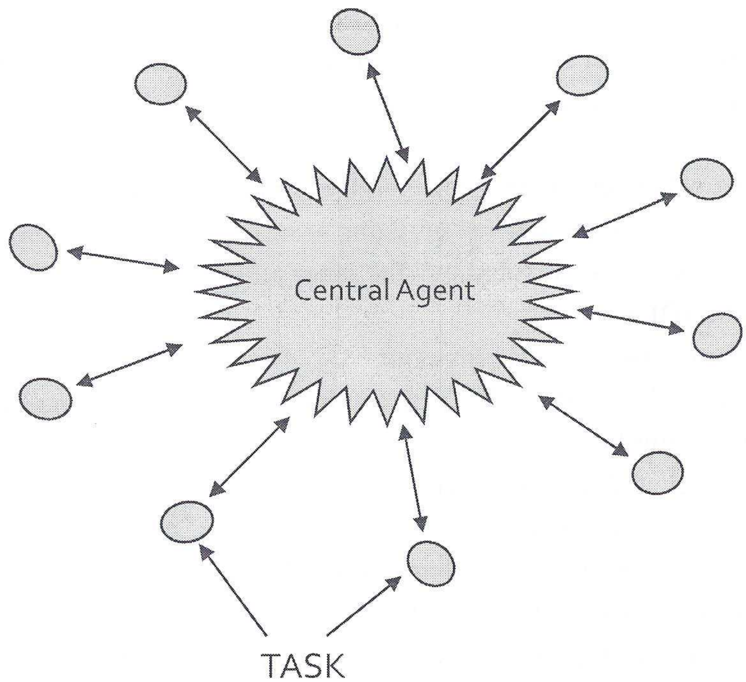
- Stigmergy - indirect communication via interaction with the environment
- Ants choose what trail to take based on the strength of the pheromone. If they had a choice between a trail going N and a trail going NE and the N trail was stronger, there will be a HIGHER PROBABILITY that the ant will go N.
- SWARM Intelligence
    - The discipline that deals with natural and artificial system composed of individuals that coordinate using decentralized control and self-organization.
    - Also it is collective behavior of a decentralized system with self-organizing elements or systems.
- Double Bridge Experiment can show ants behavior - There first time going to the food source, they reach a for in the road. One is longer than the other, but the ants don't know this. There is a 50/50 chance on which path they will take. They take different paths. Ant A who took the shorter path got the food faster, and is already heading home. His path will have two layers of pheromone. Ant B just got to the food. When he returns, he meets the point where the two roads met and made one. The trail Ant A took will have a greater value of pheromone that the path he just took. So now there is a greater probability that Ant B will



take the path of Ant A. Picture of the paths:
- If the route is complicated, an ant can get stuck in a loop, getting nowhere.
- By using artificial ants, we will not be solving simple problems that ants face as mentioned above. We will use their methods to create a heuristic for difficult problems.
- To prevent loops in a program, you need to give the individual ants a limited memory
- They will remember how to get to the food.
- They will only apply pheromone on the trip back to the nest. This prevents any loops. They will use their memory to find their way home. If they use pheromone on the way to the food, they can get caught in a loop.
- "Two roads diverged in a wood, and I – I took the one less traveled by, and that has made all the difference." – Robert Frost

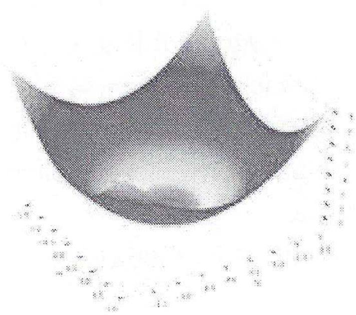
- This quote is used to explain the Robert Frost Ant
- There are ants that will take the path with less pheromone. This is because there isn't a 100% chance that an ant takes the path with the most pheromone, it is just a higher probability.
- In a program, you need to add accelerated evaporation of the pheromone trail. This allows newer, and sometimes better, paths to be explored, and to be used. If an ant does take the road "less traveled by" the other ants can follow that path.

- TWO WORKING MODES
  - Forward – Probabilistic Searching Ants
    - It will find its path to the food without leaving pheromone (it will find the path randomly)
    - It will remember its path to the food
  - Backward – Solution Construction
    - Before starting back, implement loop elimination in program
    - Retrace steps back to the nest (using the limited memory given)
    - On the return trip, it will leave pheromone (this will give the best path to itself and other ants, so no one gets caught in a loop).
    - The shorter the path, the pheromone will be dropped.
      - Some real ant species leave a thicker trail when it has found a rich food source.
- Probability Collectives – Book – pg. 1-13 – Anand Jayant Kulkarni, Kang Tai, Ajith Abraham
  - For humans, optimization is to minimize or maximize something to achieve the most favorable or the best outcome for a given situation.
  - It is difficult to understand the whole, say ACO, by studying the individual parts since any move by one individual effects the moves of all the other individuals.
  - Previously, systems were centralized as they were not as complex. As systems grew more complex, it became necessary to create a more decentralized and distributed approach.
  - The problem with a centralized agent is that it needs enormous knowledge, storage space, needs to do required computation, etc. Although this is possible, it is not effective. Centralized system:


Central Agent
TASK

  - Such a decentralized and distributed Multi-Agent System (MAS) is intended for open ended problems where there is no well-defined solution available.
  - A decentralized solution requires the right to share information among the agents. This can happen in a centralized solution too, but by the time it has happened in the centralized solution, the environment has already changed.
  - There are many benefits to the decentralized and distributed MAS
    - It reduced the dependency on the centralized system, this reducing the chance of failure
    - Reduces communication delay between agents since they now communicate directly with each other, not through the centralized system.
    - If the agents are sharing confidential information through the centralized system, security breaches may occur and third parties can gain access to the information being transferred. On the other hand, transferring information directly (agent to agent) reduces the chance of security issues, making it much safer for companies.
    - It reduces the complexity of the communication problem, making it cheaper and more effective at the same time.
  - Meta-heuristics is the field where several agents interchange information while searching for an optimal solution
    - In the case of a centralized system, the exchange of information is done though the central system. This can lead in a system overload. When you have a decentralized system, the agents can decide themselves when, where, and how to exchange information. This makes the process much more effective and reduces the chances of an overload.
- Let's solve real world problem by learning from Ants. After all - they have perfected harmonized, organized & sustained living for 150m years.
- They follow simple rules in repeated manner. They use Strigmergy (change in environment) to communicate.
- We will be using Heuristics = common sense = Use practical & not theoretical approach = Used where getting optimized solution is practically impossible = It's not completely organized method.
- Start, adjust iteratively, reach promising position.
- 5! is 120, 10! is more than 3.5m, & 15! is more than 1T. That would mean a company like Fedex would have to run 1T lines of code (takes a very long time) to find the best route possible
- It's not practical for say Fedex to compare thousands of delivery routes each day, by comparing trillions of route combinations, even if they have super computers. Plus conditions of routes change each hour depending on weather etc. And that is where we use ACO.
- It should be noted that we might expect a path to take N hours, but only after traversing it, will we know that it takes N hours or less or more. That is again where ACO can help

- A regular Algorithm provides optimal solution in finite time, however the time increases exponentially with complexity. That is where Heuristics comes into picture. It may not deliver the optimal solution, but delivers practically optimal solution in finite-limited time.
- Heuristics is problem-dependent approach.
- Meta-heuristics (ex: ACO) is problem independent approach. In order to better explore solution space, it can temporarily go into wrong direction too. Unlike Heuristics, it does not generally get trapped into local minimum.
- Sphere's optimization function graph is depicted below:



III. ***Research Goals***

Hypothesis: If we raise the number of moves to around 40 and keep the amount of ants that explore at 30%, then all the ants will reach the destination (0.01 from coordinates of zero) because:

- If they are given more moves, they are given more time to use each other and be able to follow each other to reach the destination.
- When more ants are exploring, an ant could find a better route, which other ants will be able to follow. Say a really low percentage (10%), of the ants were exploring, then there will be less ants that explore, which causes following problem: After the initial random moves, there will be an ant that will be followed by all the other ants, then the ant colony is not reaching its potential. By having more ants exploring, we can have ants that might find a better route, taking the ants to the destination more effectively. If there are too many exploring, too many of the ants would be going all over the place, not being effective since not many are following. I believe 30% is the perfect amount to explore.

Goals: If we make a meta-heuristic algorithm then we could make telecom networks much more optimized, make medicines that only affect the area needed, and predict housing networks, because we will have created a decentralized but collectively smart solution giving us the fastest and most effective solution. I want to develop a meta-heuristic algorithm based on SWARM intelligence and ACO that is optimized and tested on the Sphere's Test Optimization function. [In the program I will develop, I will know the program is optimized if all the ants reach VERY close to the coordinate (0,0,0)]

Data Analysis: I will run my meta-heuristic algorithm on the Sphere's optimization function and see if it is truly optimized.

Discussion of Results and Conclusions: According to the data, the amount of moves needed for all the ant to reach the destination is 55. When we give the ants 55 moves, we let it make 3 random moves. After that, it starts following the ant with the most pheromone, or explore. Giving the ant 55 moves, we let them explore a little to find the best route, and then use each other to find and collectively reach the destination. If we give them more moves it would not make it any faster, since once an ant has reached its destination, it will not make any moves. We may not have the FASTEST way, but we have the practically fastest and effective way. Moving on to exploration, "0.45" was the best number of ants to explore. When the amount of ants was exploring was too low there was one huge problem. The ants could not find the BEST path available since very few of the ants were exploring. When I tested the ants at 75% and above, it was too much, and the ants were not making any LOGICAL moves; Just random moves. In conclusion, 55 moves with 25% exploring allows the ants to collectively reach the destination. Also, letting 45% of the ants explore, the ants can reach the destination within 25 to 43 moves. Previously I had my destination set as 0.1 (distance from zero). The ants successfully reached the destination. To see if it was truly optimized, I made the destination 0.01. This made the destination much harder to get to, but the ants were not stopped. Using each other, and a little more moves, the ants could successfully reach the destination.

IV. ***Bibliography***

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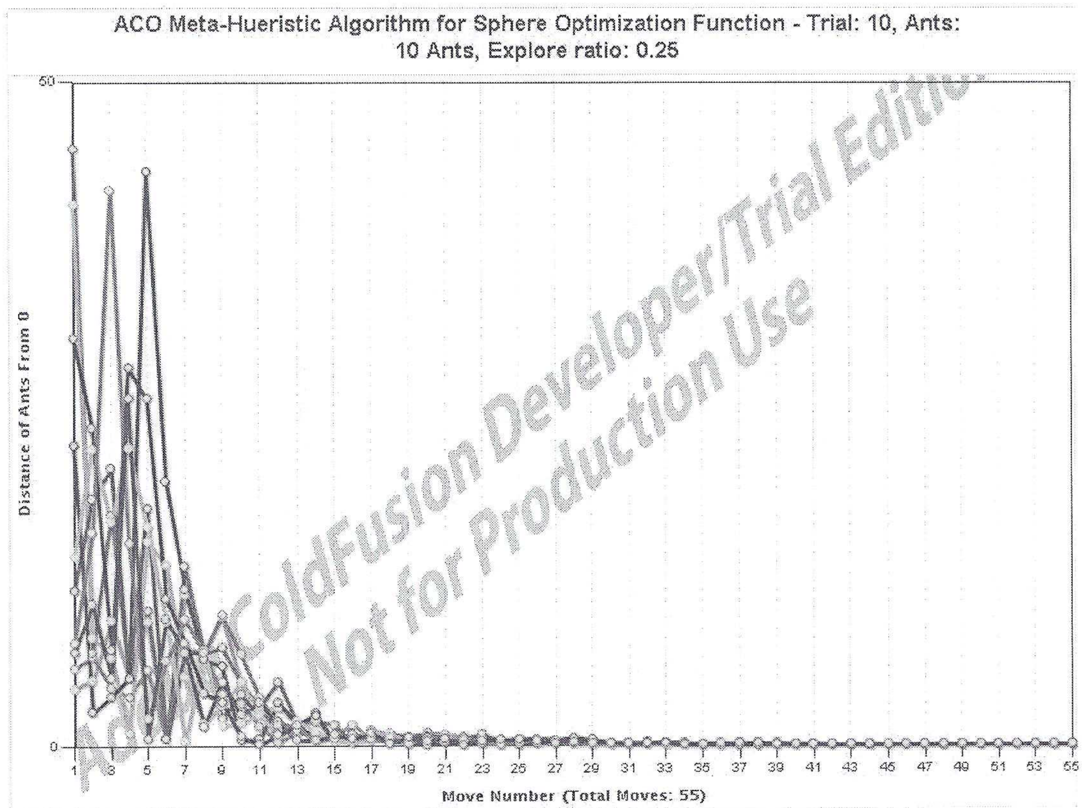
V. ***Test Data***

CHANGING MOVES

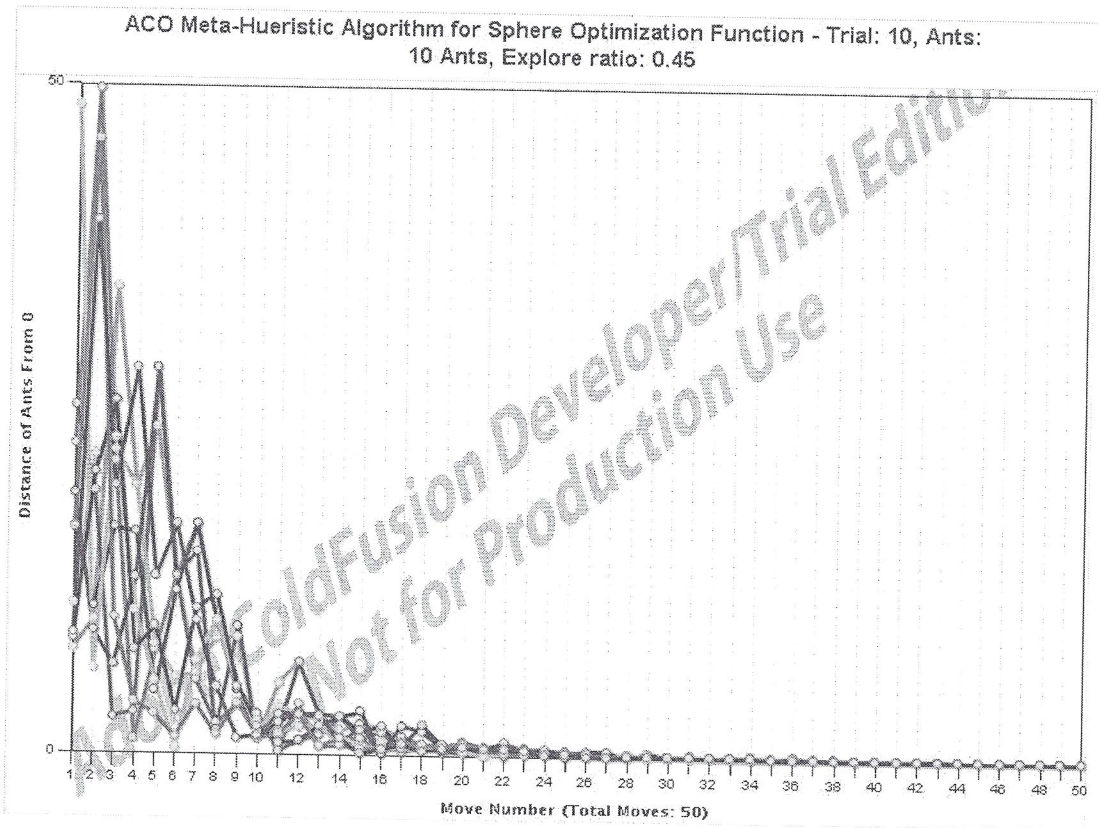
At first I tested how many moves it takes for ants to use each other and reach to the destination. I ran 10 trials with 30, 35, 40, 50, 55, 60, and 70 moves. I kept the exploration percentage at 25%. Initially I ran 70 trials for the destination as 0.1 and later ran the tests for the destination as 0.01.



As the graph shows, a minimum of 55 moves are needed for the ants to reach the destination. When I tested it with 50 moves, not all the ants would always reach the destination. Moves 55 and above allow all ants to reach the destination.

CHANGING EXPLORATION PERCENTAGE

This time I tested how much of the ants should explore and how many of the ants should exploit (follow). I tested it with 0%, 15%, 25%, 35%, 45%, 75%, 100% of the ants exploring. I kept the amount of moves at 50. Initially I ran 70 trials for the destination as 0.1 and later ran the tests for the destination as 0.01.



As the graph shows, around 45% should explore to reach the destination. Anything from 45% to 75% is fine. As you pass 75%, the ants stop reaching the destination. If there are enough moves given, they could reach it. Given a limited amount of moves, too much exploration is bad since no one is following the fastest route. If too less are exploring, the fastest route possible cannot be found in the limited amount of time. 45% to 75% is the right amount of ants that should explore.

VI. ***Abstract***

As the systems around us get more complex, many shortcomings of a centralized optimization can be seen vividly. To solve this, we must come up with decentralized, individually smart, and collectively intelligent systems. To achieve this, I have created a meta-heuristic algorithm that is successfully tested against Sphere's Test Optimization Function. I have named it as "EEE ACO Meta-Heuristics Algorithm." In my algorithm, I used ants that must reach the destination. I tested how many moves it takes for an ant to reach the destination and how many ants should explore instead of follow. In this algorithm, the ants use each other to reach the destination. Initially they make three random moves. Afterwards, a set amount of ants explore (make another random move), and the other set follows the ant with the most pheromone. Pheromone is given to an ant when it makes a move approaching the destination, is being followed, and taken away when it makes a move going away from the destination. According to my data, it took 10 ants around 55 moves to reach the destination when 25% of them explored and only 25-43 moves when 45% of them explored. This shows that when around 45% are exploring the best convergence is achieved. If too many ants are exploring there is less exploitation, and if too less are exploring, the ants could possibly not be using the fastest paths possible. This shows how my meta-heuristic algorithm is optimized and could be applied to real world challenges.