TEAM PERFORMANCE OF UNMANNED VEHICLES WITH DIVERSE CAPABILITES

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Introduction

- Applications of Unmanned Vehicles
  - Intelligence
  - Surveillance and Reconnaissance
  - Search
  - Vehicle Tracking
  - Area Patrolling

Teams Of Unmanned Vehicles

- No Free Lunch Theorem
  - Over all search and optimization problems, all agents perform equally well, when no prior knowledge is available to exploit
  - Does not extend to teams of unmanned vehicles

- Problem Statement
  - Build an effective heterogeneous team of unmanned vehicles to search an unknown environment, without any prior knowledge of the search space.

Past Research

- Focused on
  - Multi-vehicle cooperation of predetermined (homogeneous) platoons
  - Communication among heterogeneous teams
  - Building heterogeneous teams to exploit some knowledge of the field (teams with specialized agents).
  - Classified heterogeneous and homogeneous depending on if all the agents were the same or alike

Diversity among Heterogeneous Teams

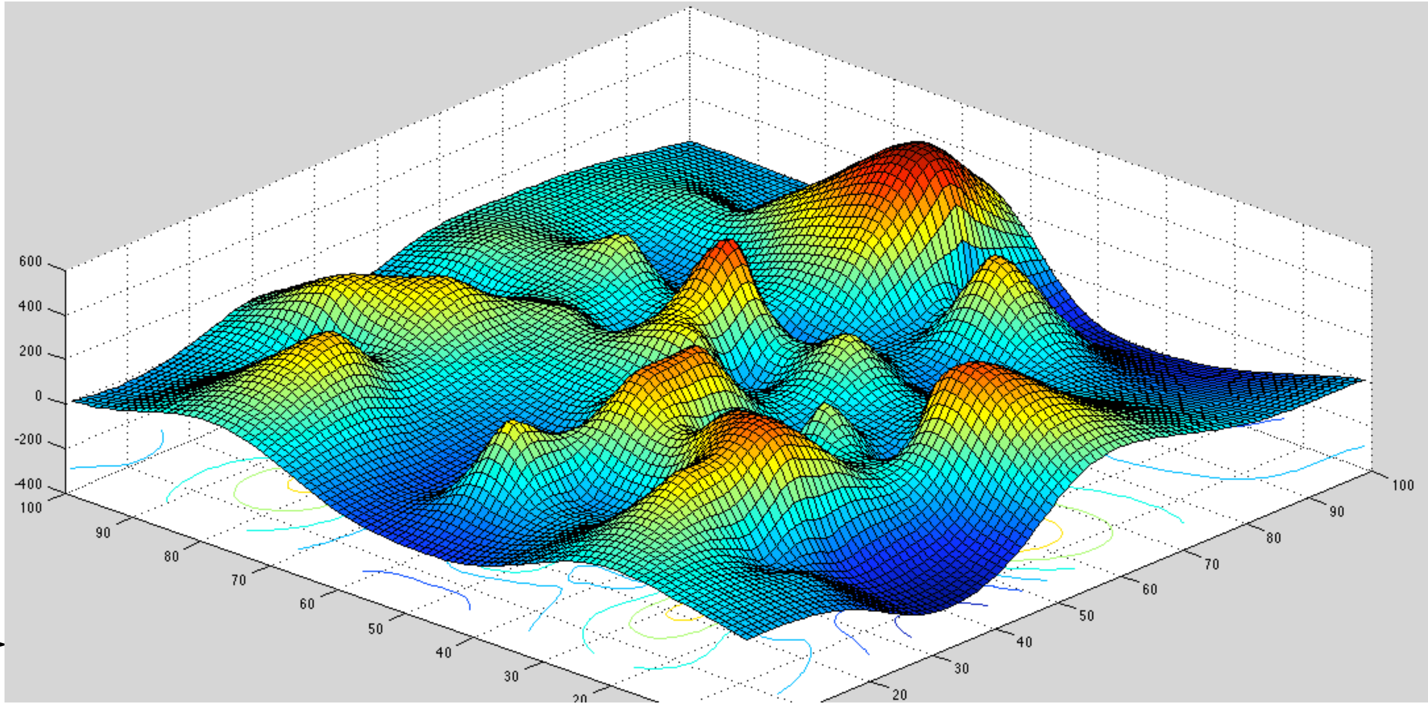
- Past research failed to:
  - Examine the affects of diversity among heterogeneous teams
    - Varying agents on a team
    - No formal qualitative measurement of diversity

Effects of Diversity

- Influences from Social Science (Scott Page)
  - Mathematical Proof & Computational Experiment
    - Diverse teams on average outperform the best suited team
      - Assumptions
        1) A problem is inherently difficult (no single agent can always find the optimum)
        2) There is a great enough diversity among the agents, (when one agent gets stuck, there is always another agent that can find an improvement)
        3) The performance of the best agent is unique

Computational Experiment

- Team Search Mission
  - Random Team (presumably more diverse) vs. Best Team
  - Function optimization (differentiable *F*), $F : X \times Y \rightarrow Z; \quad X, Y, Z \in R$
  - Z- target value



Steepest Ascent Method

- Characteristics
  - Function gradient, and gradient constant dependent
  - Converges relatively fast to local extrema for optimal gradient constants
  - Poor convergence for large and small gradient constants
- Example
  - An autonomous underwater vehicle equipped with sensors that measure water temperature and follows the gradient to find the position with the highest temperature

(1)

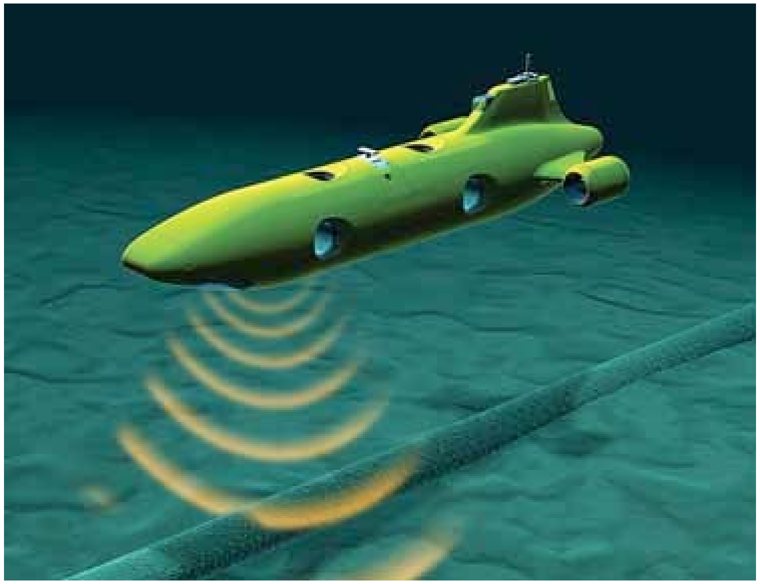
$$\Phi_k = \left\{ k \mid x_{n+1} = \frac{\partial F}{\partial x} + x_n, y_{n+1} = \frac{\partial F}{\partial y} + y_n \right\}$$

$$\Phi_k = \text{heuristic}$$

$$k = \text{gradient constant}$$

$$\frac{\partial F}{\partial x}, \frac{\partial F}{\partial y} = \text{gradient}$$

$$x_n, y_n = \text{coordinates}$$



Step Search Algorithm

- Characteristics
  - Independent of gradient
  - Looks along a radius only in the front of its position
- Example
  - A UAV equipped with cameras as sensors that can see in front of its position

(2) $$\Theta_s = \{ s > 0 \mid x_{n+1} = s + x_n, y_{n+1} = s + y_n \}$$

$$\Theta_s = \text{heuristic}$$

$$s = \text{ step search constant}$$

$$x_n, y_n = \text{coordinates}$$

Expected Performance

- Expected performance value
  - Unity probability distribution of initial conditions
    - Individual agents were allowed to start at every initial condition and apply their heuristic to traverse the search space until $F(x_{n+1},y_{n+1})<F(x_n,y_n)$
  - The higher the expected performance value the better the agent is presumed to be

$$E\left[F;\psi,v\right]=\frac{1}{n^2}\cdot\sum_{x_i=1}^{n}\sum_{y_i=1}^{n}F\left[\psi(x_i,y_i)\right] \quad (3)$$

ψ = heuristic

υ = probability distribution of initial condition

x_i, y_i = initial condition

$F\left[\psi(x_i,y_i)\right]$ = expected performance

Diversity

- Diversity is defined as the standard deviation of the step constant or gradient constant for the members on the team

(4) $$\delta = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(c_i - \bar{c})^2}$$

$\delta =$ diversity

$n =$ number of agents on a team

$c =$ s (step constant) for step search

$c = k$ (gradient constant) for steepest ascent method

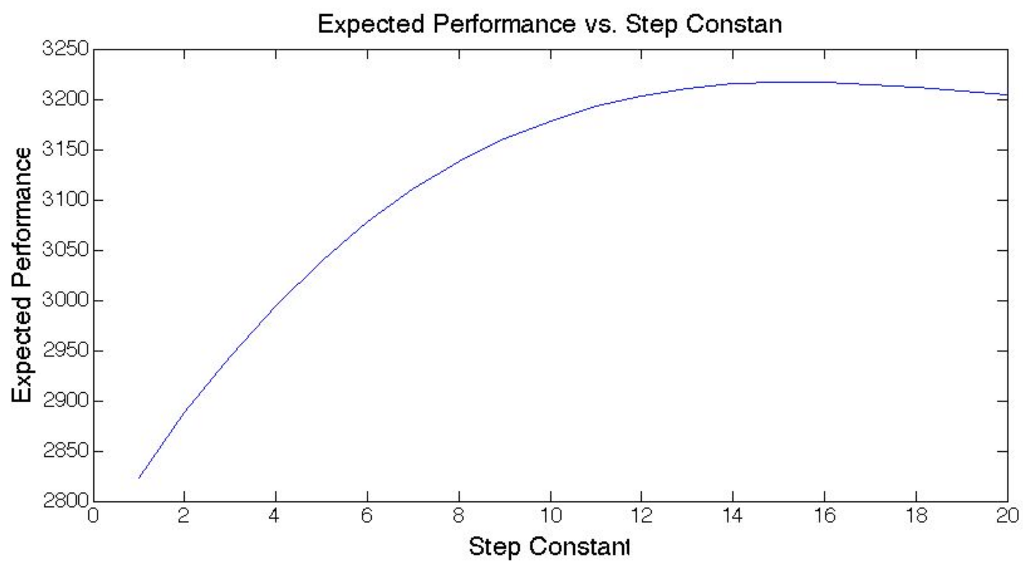
Computational Experiment

- Teams of 5
  - 5 best agents (highest expectance performance) vs. 5 random agents
  - Teams worked sequentially, the following agent started at the optimal point of the previous agent
  - Each agent attempted to optimize function 3 times
- Results are shown for
  - 5000 initial conditions per a functions/ per team
  - 2000 optimization functions

Step Search Results

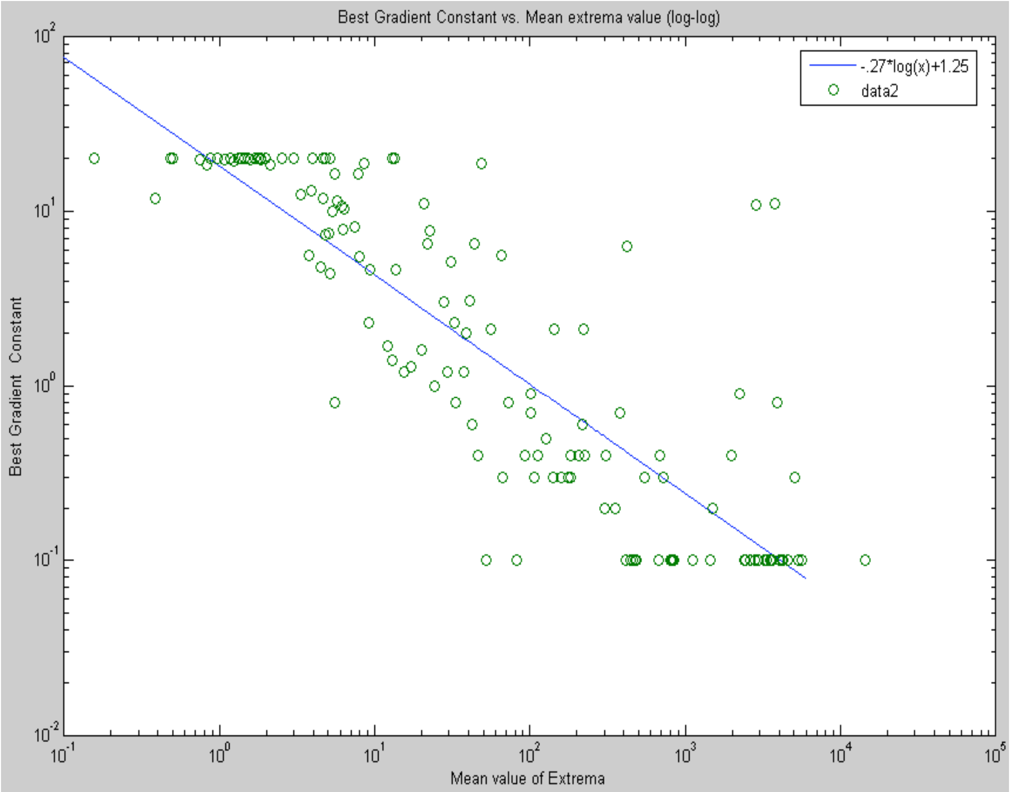
- Random team outperformed the best team by 9%
- Random team expected performance is 6% lower than the best team
- Random team outperformed its expected value by16%
  - Greater ability to become unstuck on local minimums
- Best team outperformed its expected value by 3%

	Best Team	Random Team
Average Maximum	$6.3x10^3$	
Average Expected Value	$3.3x10^3$	$3.1x10^3$
Average Diversity	2.9 (29%)	5.7 (57%)
Average Performance	$3.4x10^3$	$3.7x10^3$



Optimal Gradient Constant

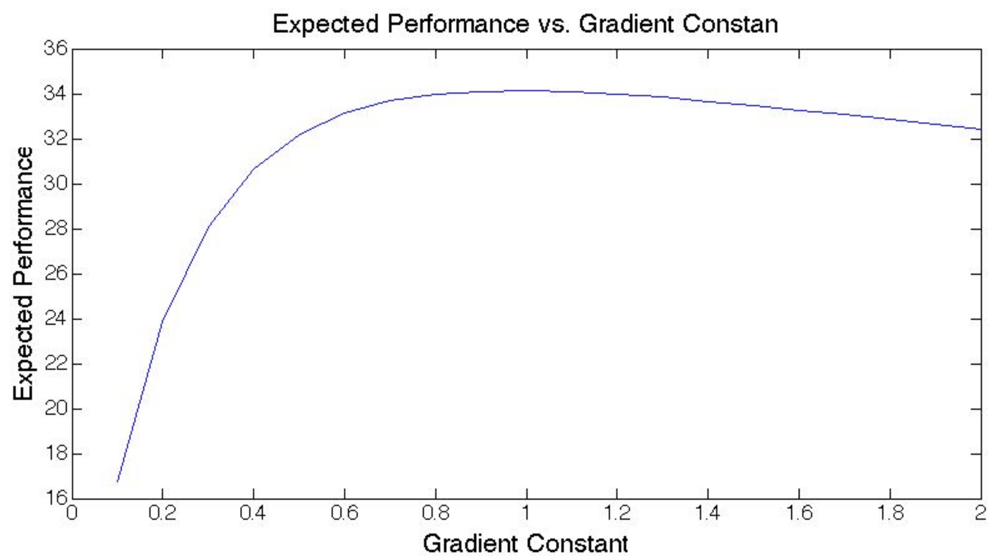
- Optimal Gradient Constant vs. Mean Extrema
  - Find range of optimal gradient constants



Steepest Ascent Results

- Random team outperformed the best team by 3%
- Random team expected performance is 12% lower than the best team
- Random team outperformed its expected value by 19%
  - Greater ability to become unstuck on local minimums
- Best team outperformed its expected value by 6%

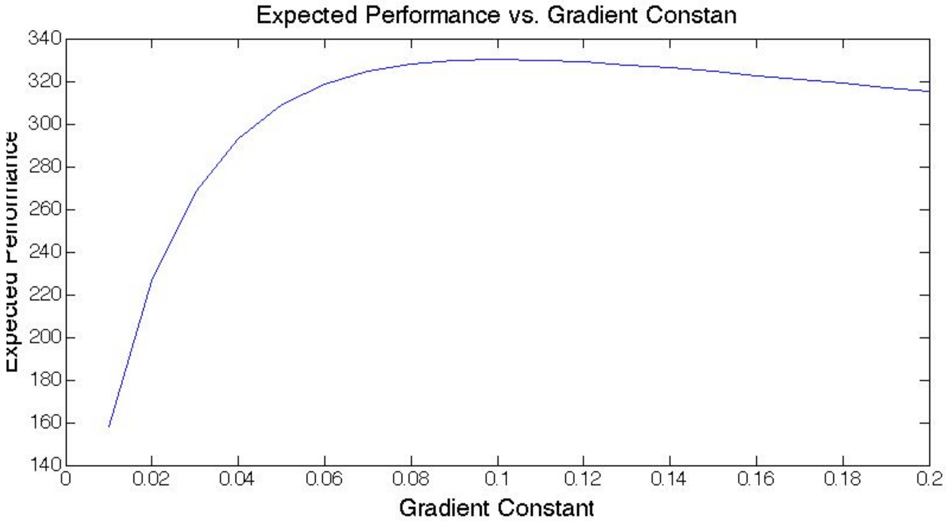
	Best Team	Random Team
Average Maximum	64.3	
Average Expected Value	36.0	31.8
Average Diversity	.16 (16%)	.53 (56%)
Average Performance	38.2	39.3



Steepest Ascent Results

- Random team outperformed the best team by 3%
- Random team expected performance is 14% lower than the best team
- Random team outperformed its expected value by 24%
  - Greater ability to become unstuck on local minimums
- Best team outperformed its expected value by 6%

	Best Team	Random Team
Average Maximum	625.4	
Average Expected Value	347.7	304.9
Average Diversity	.016 (16%)	.053 (53%)
Average Performance	368.4	379.5



Conclusion

- Diverse teams of UAV on average outperform the best-suited, with the goal being to search an unknown field for the highest value target.

Publications

- Submitted: ASME Dynamic Systems and Control Conference (DSCC)-2008