# COMP SCI 5401 FS2016 Assignment 2c

Robert Jones
rbj2q2@mst.edu

December 7, 2016

## Contents

# 1 Experiment Comparisons

## 1.1 Methodology

For this experiment, both pac controllers and ghost controllers are evolved in competitive co-evolution. All parameters for evolution of both populations are independent and the fitnesses of pac and ghosts are related to the scores in mutual games the pacs get; Where pac score positively affects pac fitness, it negatively affects ghost fitness. Additionally, pac and ghosts are evaluated in a shared game instance. All population members have to be re-evaluated each generation.

For this group of experiments, the mutation rate was experimented on to find the optimal rate. The tested rate are 10the base for all other experiments. It is expected that 50decent, where the other two are potentially destructive.

## 1.2 Experimental Setup

EA parameters were chosen to be as close as possible to the default configuration to minimize changes caused by other forces. In other words, the only variable desired was the variable being tested. The variable parameter was chosen as such to match expectations for the assigned bonus. The random number value was seeded randomly.

In terms of algorithms, this experimentconsisted of vectors of each population that are tested concurrently. Trees are nearly identical in terms of sensors, except that the ghost controllers do not have wall, pill or fruit sensors. Scores for pac controllers scale positively with game score, while ghost controllers scale negatively with pac scores. Ramped Half-and-Half initialization is used. Over-Selection is used for parent selection, sub-tree crossover is used for recombination, and sub-tree mutation is used for mutation. Truncation is used for survival selection and parsimony pressure is used for bloat control. The only termination condition is number of evaluations, which is 2000 per run with 30 runs per experiment.

## 1.3 Results

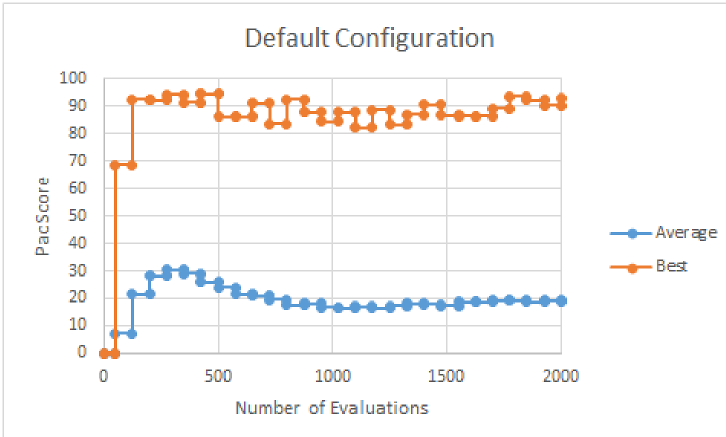


Figure 1: Results of Default Configuration

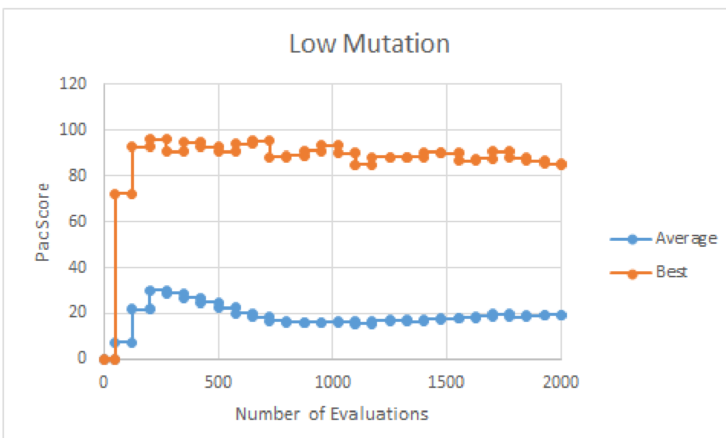


Figure 2: Results of Low Mutation Configuration

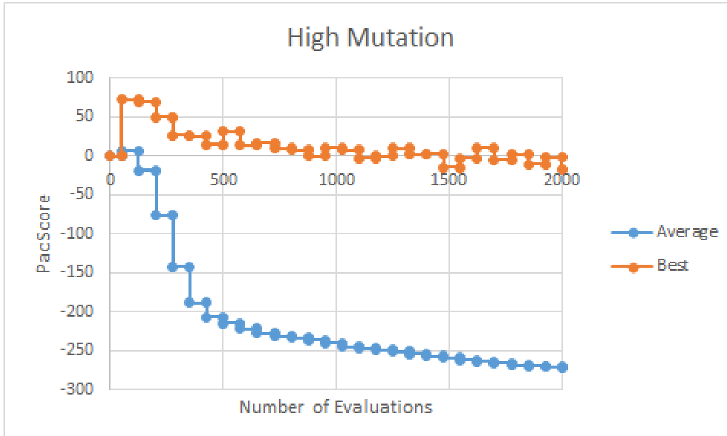


Figure 3: Results of High Mutation Configuration

Default vs Low Mutation

| F-Test Two-Sample for Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 19.803704 | 19.08889 |
| Variance | 21.657635 | 20.83504 |
| Observations | 27 | 27 |
| df | 26 | 26 |
| F | 1.0394812 | |
| P(F<=f) one-tail | 0.4610559 | |
| F Critical one-tail | 1.9292127 | |

| t-Test: Two-Sample Assuming Equal Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 19.8037037 | 19.0888889 |
| Variance | 21.6576353 | 20.8350427 |
| Observations | 27 | 27 |
| Pooled Variance | 21.246339 | |
| Hypothesized Mean Difference | 0 | |
| df | 52 | |
| t Stat | 0.56979466 | |
| P(T<=t) one-tail | 0.28563527 | |
| t Critical one-tail | 1.67468915 | |
| P(T<=t) two-tail | 0.57127055 | |
| t Critical two-tail | 2.00664681 | |

Figure 4: Statistical Analysis of Default Configuratin vs Low Mutation

Default vs High Mutation

| F-Test Two-Sample for Variances | | |
|---|---|---|
| | Variable 1 | Variable 2 |
| Mean | 19.8037037 | -217.409 |
| Variance | 21.65763533 | 5558.675 |
| Observatio | 27 | 27 |
| df | 26 | 26 |
| F | 0.003896186 | |
| P(F<=f) one | 0 | |
| F Critical or | 0.518346169 | |

| t-Test: Two-Sample Assuming Equal Variances | | |
|---|---|---|
| | Variable 1 | Variable 2 |
| Mean | 19.8037 | -217.4086 |
| Variance | 21.65764 | 5558.6753 |
| Observations | 27 | 27 |
| Pooled Variance | 2790.166 | |
| Hypothesized Mean Difference | 0 | |
| df | 52 | |
| t Stat | 16.5002 | |
| P(T<=t) one-tail | 1.29E-22 | |
| t Critical one-tail | 1.674689 | |
| P(T<=t) two-tail | 2.58E-22 | |
| t Critical two-tail | 2.006647 | |

Figure 5: Statistical Analysis of Default Configuratin vs High Mutation

Default vs Low Mutation

| F-Test Two-Sample for Variances | | |
|---|---|---|
| | Variable 1 | Variable 2 |
| Mean | 19.803704 | 19.08889 |
| Variance | 21.657635 | 20.83504 |
| Observations | 27 | 27 |
| df | 26 | 26 |
| F | 1.0394812 | |
| P(F<=f) one-tail | 0.4610559 | |
| F Critical one-tail | 1.9292127 | |

| t-Test: Two-Sample Assuming Equal Variances | | |
|---|---|---|
| | Variable 1 | Variable 2 |
| Mean | 19.8037037 | 19.0888889 |
| Variance | 21.6576353 | 20.8350427 |
| Observations | 27 | 27 |
| Pooled Variance | 21.246339 | |
| Hypothesized Mean Difference | 0 | |
| df | 52 | |
| t Stat | 0.56979466 | |
| P(T<=t) one-tail | 0.28563527 | |
| t Critical one-tail | 1.67468915 | |
| P(T<=t) two-tail | 0.57127055 | |
| t Critical two-tail | 2.00664681 | |

Figure 6: Statistical Analysis of Low Mutation vs High Mutation

## 1.4 Discussion

The mean of the basic configuration is greater than the mean of the low mutation configuration, and F is less than F Critical, so equal variances can be assumed. The absolute value of T stat is less than the absolute value of t critical two-tail, so it can not be determined with 95confidence whether either configuration is better.

The mean of the basic configuration is greater than the mean of the high mutation configuration, and F is less than F Critical, so equal variances can be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95confidence that using the high mutation configuration is less evolutionarily advantageous for pac controllers than the basic configuration.

The mean of the low mutation configuration is greater than the mean of the high mutation configuration , and F is less than F Critical, so equal variances can be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95confidence that using the high mutation configuration is less evolutionarily advantageous for pac controllers than the low mutation configuration.

## 1.5 Conclusion

The high mutation configuration is markedly worse than the base configuration and the low mutation configuration. It is possible that the high mutation rate is more beneficial for a smaller number of terminal options. In this case, the ghost controller would have an advantage, which would explain the behavior of the high mutation graph, where ghost controllers quickly dominate the pac controllers. As such, increasing the mutation rate can be an extremely useful tool when a population with small trees needs to be pushed towards equilibrium with a population with larger trees that are dominant.

# 2 Bonus 1

## 2.1 Methodology

For this experiment, a unique ghost controller was used for each ghost. To do this, a vector of different ghosts is used and passed in until the limit of ghosts is reached. The results are then recorded and compared against a configuration file with the same parameters except it doesn't have unique ghost controllers.

## 2.2 Experimental Setup

EA parameters were chosen to be as close as possible to the default configuration to minimize changes caused by other forces. In other words, the only variable desired was the variable being tested. The variable parameter was chosen as such to match expectations for the assigned bonus. The random number value was seeded randomly.

## 2.3 Results

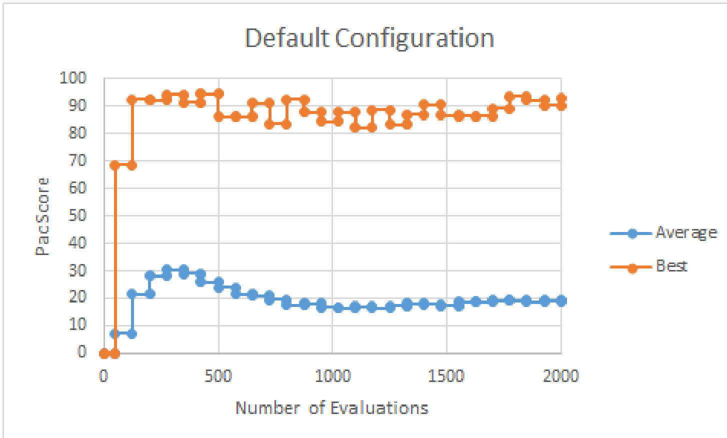


Figure 7: Results of Default Configuration

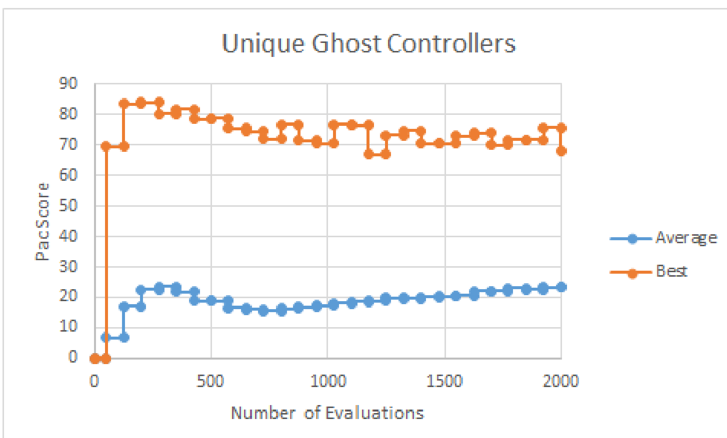


Figure 8: Results of Configuration with Unique Ghost Controller

Default vs Unique Ghosts

| F-Test Two-Sample for Variances | | |
|---|---|---|
| | Variable 1 | Variable 2 |
| Mean | 19.8037037 | 19.319753 |
| Variance | 21.6576353 | 12.577971 |
| Observations | 27 | 27 |
| df | 26 | 26 |
| F | 1.72187037 | |
| P(F<=f) one-tail | 0.08629093 | |
| F Critical one-tail | 1.92921267 | |

| t-Test: Two-Sample Assuming Equal Variances | | |
|---|---|---|
| | Variable 1 | Variable 2 |
| Mean | 19.803704 | 19.319753 |
| Variance | 21.657635 | 12.577971 |
| Observations | 27 | 27 |
| Pooled Variance | 17.117803 | |
| Hypothesized Mean Difference | 0 | |
| df | 52 | |
| t Stat | 0.4297777 | |
| P(T<=t) one-tail | 0.3345665 | |
| t Critical one-tail | 1.6746892 | |
| P(T<=t) two-tail | 0.6691331 | |
| t Critical two-tail | 2.0066468 | |

Figure 9: Statistical Analysis of Default Configuration vs Configuration with Unique Ghost Controllers

### 2.4 Discussion

The mean of the default configuration is less than the mean of the configuration with ghost controllers, and F is less than F Critical, so equal variances can be assumed. The absolute value of T stat is less than the absolute value of t critical two-tail, so it can not be determined with 95either configuration is better.

However, the curve of the unique ghost controller shows a gradual lowering of the best pac controller. However, the average of pac controllers continued to increase for average pac controller fitness. This combination of weakening the most fit individual but allowing an increase in the average could show more successful co-evolution.

### 2.5 Conclusion

In conclusion, both same and unique ghost controllers have strengths and weaknesses that appear to balance each other out. It may be beneficial to use both forms of controller usage. This should be investigated for meta-EAs.

# 3 Bonus 2

## 3.1 Methodology

For this experiment, two pac men were used in conjunction with three ghosts per game. Each game will only end when both pac are killed by a ghost. To improve pac ability to coordinate, a sensor was added in pac controllers that detects the distance to another pac. Experiments without unique controllers, with only unique pac controllers, with only unique ghost controllers, and with both both populations having unique controllers.

## 3.2 Experimental Setup

EA parameters were chosen to be as close as possible to the default configuration to minimize changes caused by other forces in the event that comparison to the default was desired. In other words, the only variables desired were the variables being tested. The variable parameter was chosen as such to match expectations for the assigned bonus. The random number value was seeded randomly.

### 3.3 Results

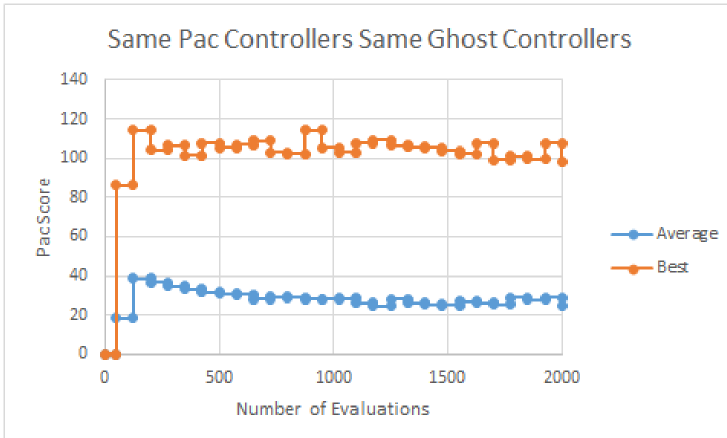


Figure 10: Results of Default Configuration with 2 Pac

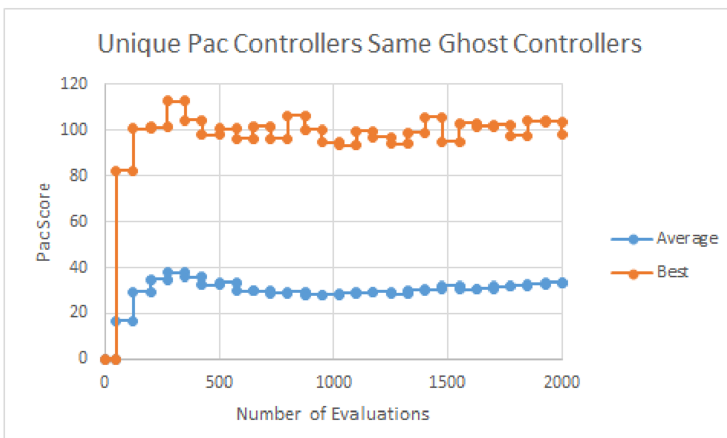


Figure 11: Results of Configuration with 2 Unique Pac Controllers

### 3.4 Results

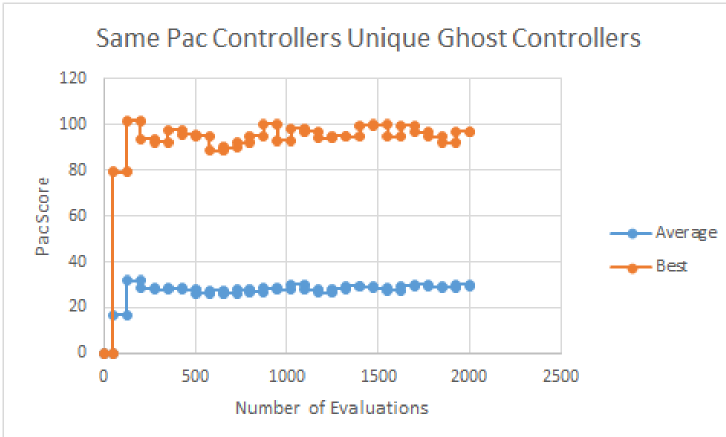


Figure 12: Results of Default Configuration with 2 Pac and Unique Ghost Controllers

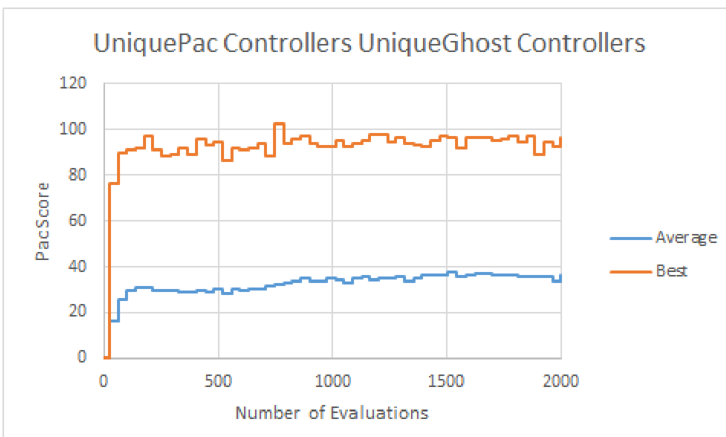


Figure 13: Results of Configuration with 2 Unique Pac Controllers and Unique Ghost Controllers

2 Pac Controllers with Unique Ghost Controllers vs 2 Pac Controllers

| F-Test Two-Sample for Variances | | |
|---|---|---|
| | Variable 1 | Variable 2 |
| Mean | 28.01605 | 28.53704 |
| Variance | 6.862767 | 17.07618 |
| Observations | 27 | 27 |
| df | 26 | 26 |
| F | 0.401891 | |
| P(F<=f) one-tail | 0.011783 | |
| F Critical one-tail | 0.518346 | |

| t-Test: Two-Sample Assuming Unequal Variances | | |
|---|---|---|
| | Variable 1 | Variable 2 |
| Mean | 28.01605 | 28.53704 |
| Variance | 6.862767 | 17.07618 |
| Observations | 27 | 27 |
| Hypothesized Mean Difference | 0 | |
| df | 44 | |
| t Stat | -0.553295 | |
| P(T<=t) one-tail | 0.291431 | |
| t Critical one-tail | 1.68023 | |
| P(T<=t) two-tail | 0.582862 | |
| t Critical two-tail | 2.015368 | |

Figure 14: Statistical Analysis of Unique Ghost Controllers vs Basic

2 Pac Controllers vs Unique Pac Controllers

| F-Test Two-Sample for Variances | | |
|---|---|---|
| | Variable 1 | Variable 2 |
| Mean | 28.537037 | 30.697531 |
| Variance | 17.076182 | 13.901703 |
| Observations | 27 | 27 |
| df | 26 | 26 |
| F | 1.2283518 | |
| P(F<=f) one-tail | 0.3019162 | |
| F Critical one-tail | 1.9292127 | |

| t-Test: Two-Sample Assuming Unequal Variances | | |
|---|---|---|
| | Variable 1 | Variable 2 |
| Mean | 28.537037 | 30.697531 |
| Variance | 17.076182 | 13.901703 |
| Observations | 27 | 27 |
| Hypothesized Mean Difference | 0 | |
| df | 51 | |
| t Stat | -2.017015 | |
| P(T<=t) one-tail | 0.0244864 | |
| t Critical one-tail | 1.675285 | |
| P(T<=t) two-tail | 0.0489729 | |
| t Critical two-tail | 2.0075838 | |

Figure 15: Statistical Analysis of Basic vs Unique Pac Controllers

| 2 Pac Controllers vs Unique Pac Controllers with Unique Ghost Controllers | | | | | | |
|---|---|---|---|---|---|---|
| F-Test Two-Sample for Variances | | | | t-Test: Two-Sample Assuming Unequal Variances | | |
| | | | | | | |
| | *Variable 1* | *Variable 2* | | | *Variable 1* | *Variable 2* |
| Mean | 28.537037 | 32.91761 | | Mean | 28.537037 | 32.91761 |
| Variance | 17.076182 | 14.305966 | | Variance | 17.076182 | 14.305966 |
| Observations | 27 | 53 | | Observations | 27 | 53 |
| df | 26 | 52 | | Hypothesized Mean Difference | 0 | |
| F | 1.1936406 | | | df | 49 | |
| P(F<=f) one-tail | 0.2876382 | | | t Stat | -4.611449 | |
| F Critical one-tail | 1.7096195 | | | P(T<=t) one-tail | 1.445E-05 | |
| | | | | t Critical one-tail | 1.6765509 | |
| | | | | P(T<=t) two-tail | 2.89E-05 | |
| | | | | t Critical two-tail | 2.0095752 | |

Figure 16: Statistical Analysis of Basic vs Unique Ghost and Pac Controllers

| 2 Pac Controllers with Unique Ghost Controllers vs Unique Pac Controllers | | | | | | |
|---|---|---|---|---|---|---|
| F-Test Two-Sample for Variances | | | | t-Test: Two-Sample Assuming Unequal Variances | | |
| | | | | | | |
| | *Variable 1* | *Variable 2* | | | *Variable 1* | *Variable 2* |
| Mean | 28.016049 | 30.697531 | | Mean | 28.016049 | 30.697531 |
| Variance | 6.8627667 | 13.901703 | | Variance | 6.8627667 | 13.901703 |
| Observations | 27 | 27 | | Observations | 27 | 27 |
| df | 26 | 26 | | Hypothesized Mean Difference | 0 | |
| F | 0.4936637 | | | df | 47 | |
| P(F<=f) one-tail | 0.0388108 | | | t Stat | -3.05771 | |
| F Critical one-tail | 0.5183462 | | | P(T<=t) one-tail | 0.0018371 | |
| | | | | t Critical one-tail | 1.6779267 | |
| | | | | P(T<=t) two-tail | 0.0036741 | |
| | | | | t Critical two-tail | 2.0117405 | |

Figure 17: Statistical Analysis of Unique Ghost Controllers vs Unique Pac Controllers

2 Pac Controllers with Unique Ghost Controllers vs Unique Pac Controllers with Unique Ghost Controllers

F-Test Two-Sample for Variances

| | *Variable 1* | *Variable 2* |
|---|---|---|
| Mean | 28.016049 | 32.91761 |
| Variance | 6.8627667 | 14.30597 |
| Observations | 27 | 53 |
| df | 26 | 52 |
| F | 0.4797136 | |
| P(F<=f) one-tail | 0.0223086 | |
| F Critical one-tail | 0.5498744 | |

t-Test: Two-Sample Assuming Unequal Variances

| | *Variable 1* | *Variable 2* |
|---|---|---|
| Mean | 28.01605 | 32.91761 |
| Variance | 6.862767 | 14.305966 |
| Observations | 27 | 53 |
| Hypothesized Mean Difference | 0 | |
| df | 71 | |
| t Stat | -6.7706 | |
| P(T<=t) one-tail | 1.54E-09 | |
| t Critical one-tail | 1.6666 | |
| P(T<=t) two-tail | 3.08E-09 | |
| t Critical two-tail | 1.993943 | |

Figure 18: Statistical Analysis of Unique Ghost Controllers vs Unique Ghost and Pac Controllers

Unique Pac Controllers vs Unique Pac Controllers with Unique Ghost Controllers

F-Test Two-Sample for Variances

| | *Variable 1* | *Variable 2* |
|---|---|---|
| Mean | 30.697531 | 32.91761 |
| Variance | 13.901703 | 14.305966 |
| Observations | 27 | 53 |
| df | 26 | 52 |
| F | 0.9717417 | |
| P(F<=f) one-tail | 0.4817379 | |
| F Critical one-tail | 0.5498744 | |

t-Test: Two-Sample Assuming Equal Variances

| | *Variable 1* | *Variable 2* |
|---|---|---|
| Mean | 30.697531 | 32.91761 |
| Variance | 13.901703 | 14.305966 |
| Observations | 27 | 53 |
| Pooled Variance | 14.171212 | |
| Hypothesized Mean Difference | 0 | |
| df | 78 | |
| t Stat | -2.494249 | |
| P(T<=t) one-tail | 0.0073686 | |
| t Critical one-tail | 1.6646246 | |
| P(T<=t) two-tail | 0.0147371 | |
| t Critical two-tail | 1.9908471 | |

Figure 19: Statistical Analysis of Unique Pac Controllers vs Unique Ghost and Pac Controllers

### 3.5 Discussion

The mean of the basic configuration is greater than the mean of the configuration with unique ghost controllers, and F is less than F Critical, so equal variances can be assumed. The absolute value of T stat is less than the absolute value of t critical two-tail, so it can not be determined with 95confidence whether either configuration is better.

The mean of the basic configuration is less than the mean of the configuration with unique pac controllers, and F is less than F Critical, so equal variances cannot be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95confidence that using unique pac controllers gives the pac controllers an evolutionary advantage.

The mean of the basic configuration is less than the mean of the configuration with unique pac controllers, and F is greater than F Critical, so equal variances can be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95confidence that using unique ghost controllers and unique pac controllers gives the pac controllers an evolutionaryy advantage.

The mean of the configuration with unique ghost controllers is less than the mean of the configuration with unique pac controllers, and F is less than F Critical, so equal variances cannot be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95evolutionary advantage to pac controllers that strictly unique ghost controllers does not give.

The mean of the configuration with unique pac controllers is less than the mean of the configuration with unique ghost and pac controllers, and F is greater than F Critical, so equal variances can be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95ghost controllers gives a distinct evolutionary advantage to pac controllers that strictly unique ghost controllers does not give.

The mean of the configuration with unique ghost controllers is less than the mean of the configuration with unique ghost and pac controllers, and F is less than F Critical, so equal variances cannot be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95controllers gives a distinct evolutionary advantage to pac controllers that strictly unique ghost controllers does not give.

### 3.6 Conclusion

This is interesting data that implies that using multiple pac controllers when using multiple pac is always beneficial. Additionally, unique ghost controllers give unique pac even more of an advantage. Unless the pac controllers use the same controller, unique ghost controllers gives an advantage to pac controllers.

# 4 Bonus 3

## 4.1 Methodology

For this experiment, a speed ratio was implemented and tested. The previously defined defauly configuration was used. Additionally, four speeds were tested, with ranges of .3, .5, 1.5, 2.5. Values were chosen to compare both slow and fast speeds of pac controllers against each other.

## 4.2 Experimental Setup

Specific implementation utilized a float set to 0. Each game round, the speed ratio is added to the float. While the speed ratio variable is greater than or equal to 1, the float variable is decremented by 1 and each pac makes a move. This is a simple method for implementing a controlled speed ratio.

## 4.3 Results

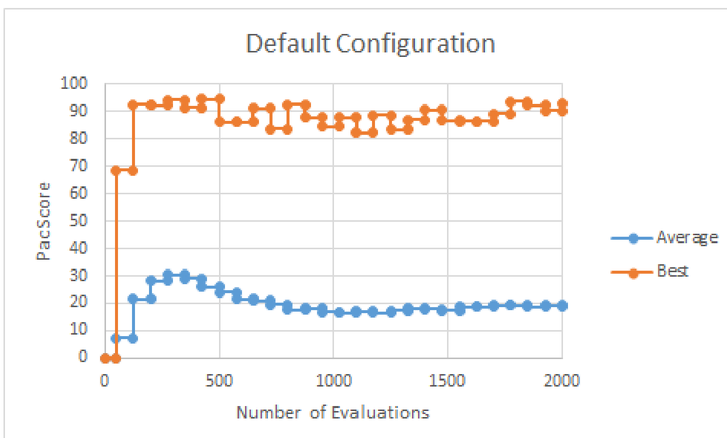


Figure 20: Results of Default Configuration

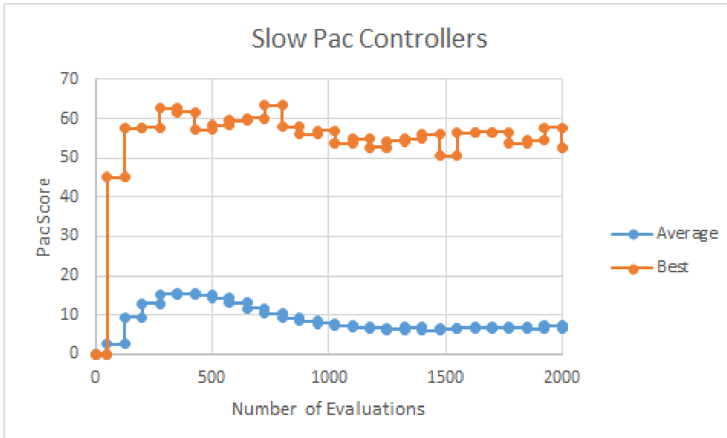


Figure 21: Results of Slow Pac Controllers

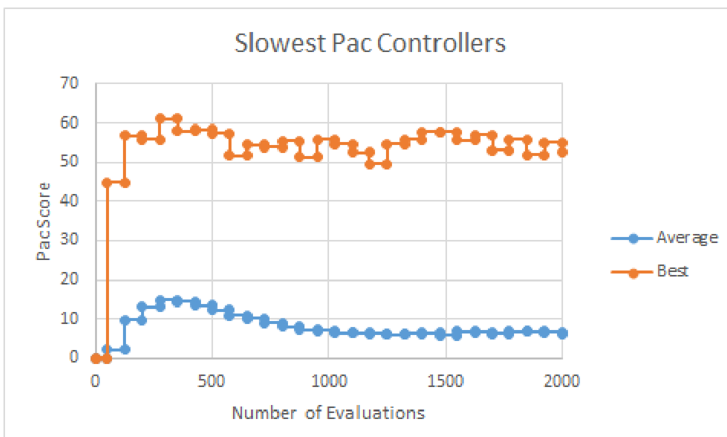


Figure 22: Results of Slowest Pac Controllers

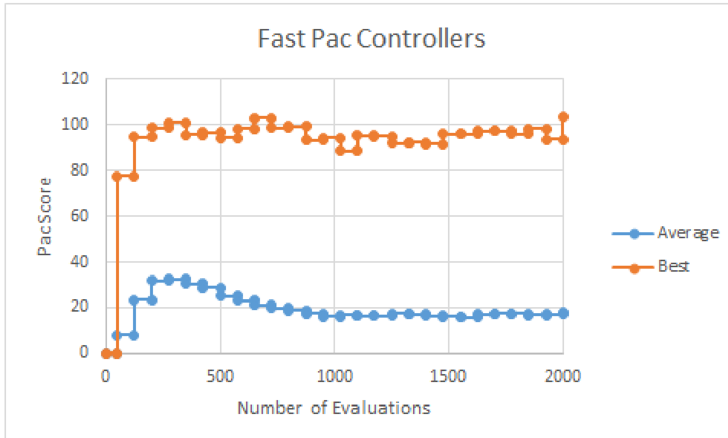


Figure 23: Results of Fast Pac Controllers

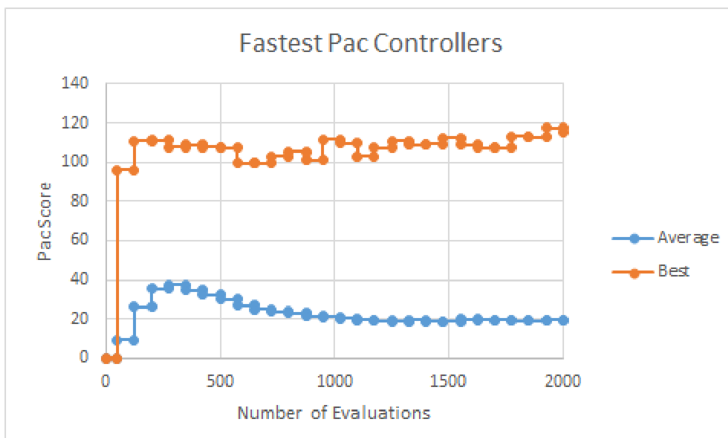


Figure 24: Results of Fastest Pac Controllers

| Default vs Fast Pac Controller | | | | | | |
|---|---|---|---|---|---|---|
| F-Test Two-Sample for Variances | | | | t-Test: Two-Sample Assuming Unequal Variances | | |
| | | | | | | |
| | Variable 1 | Variable 2 | | | Variable 1 | Variable 2 |
| Mean | 19.8037 | 19.691358 | | Mean | 19.803704 | 19.691358 |
| Variance | 21.65764 | 32.336888 | | Variance | 21.657635 | 32.336888 |
| Observations | 27 | 27 | | Observations | 27 | 27 |
| df | 26 | 26 | | Hypothesized Mean Difference | 0 | |
| F | 0.66975 | | | df | 50 | |
| P(F<=f) one-tail | 0.156518 | | | t Stat | 0.0794444 | |
| F Critical one-tail | 0.518346 | | | P(T<=t) one-tail | 0.4684981 | |
| | | | | t Critical one-tail | 1.675905 | |
| | | | | P(T<=t) two-tail | 0.9369963 | |
| | | | | t Critical two-tail | 2.0085591 | |

Figure 25: Results of Default Configuration vs Fast Pac Controllers

| Default vs Fastest Pac Controller | | | | | | |
|---|---|---|---|---|---|---|
| F-Test Two-Sample for Variances | | | | t-Test: Two-Sample Assuming Equal Variances | | |
| | | | | | | |
| | Variable 1 | Variable 2 | | | Variable 1 | Variable 2 |
| Mean | 19.803704 | 22.911111 | | Mean | 19.803704 | 22.911111 |
| Variance | 21.657635 | 39.777265 | | Variance | 21.657635 | 39.777265 |
| Observations | 27 | 27 | | Observations | 27 | 27 |
| df | 26 | 26 | | Pooled Variance | 30.71745 | |
| F | 0.5444727 | | | Hypothesized Mean Difference | 0 | |
| P(F<=f) one-tail | 0.0637985 | | | df | 52 | |
| F Critical one-tail | 0.5183462 | | | t Stat | -2.060025 | |
| | | | | P(T<=t) one-tail | 0.0222085 | |
| | | | | t Critical one-tail | 1.6746892 | |
| | | | | P(T<=t) two-tail | 0.0444169 | |
| | | | | t Critical two-tail | 2.0066468 | |

Figure 26: Results of Default Configuration vs Fastest Pac Controllers

Default vs Slow Pac Controller

| F-Test Two-Sample for Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 19.803704 | 8.8481481 |
| Variance | 21.657635 | 11.659943 |
| Observations | 27 | 27 |
| df | 26 | 26 |
| F | 1.8574392 | |
| P(F<=f) one-tail | 0.0603978 | |
| F Critical one-tail | 1.9292127 | |

| t-Test: Two-Sample Assuming Equal Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 19.803704 | 8.8481481 |
| Variance | 21.657635 | 11.659943 |
| Observations | 27 | 27 |
| Pooled Variance | 16.658789 | |
| Hypothesized Mean Difference | 0 | |
| df | 52 | |
| t Stat | 9.862331 | |
| P(T<=t) one-tail | 8.371E-14 | |
| t Critical one-tail | 1.6746892 | |
| P(T<=t) two-tail | 1.674E-13 | |
| t Critical two-tail | 2.0066468 | |

Figure 27: Results of Default Configuration vs Slow Pac Controllers

Default vs Slowest Pac Controller

| F-Test Two-Sample for Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 19.803704 | 8.2382716 |
| Variance | 21.657635 | 9.5952738 |
| Observations | 27 | 27 |
| df | 26 | 26 |
| F | 2.2571149 | |
| P(F<=f) one-tail | 0.0212514 | |
| F Critical one-tail | 1.9292127 | |

| t-Test: Two-Sample Assuming Unequal Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 19.803704 | 8.2382716 |
| Variance | 21.657635 | 9.5952738 |
| Observations | 27 | 27 |
| Hypothesized Mean Difference | 0 | |
| df | 45 | |
| t Stat | 10.749754 | |
| P(T<=t) one-tail | 2.573E-14 | |
| t Critical one-tail | 1.6794274 | |
| P(T<=t) two-tail | 5.145E-14 | |
| t Critical two-tail | 2.0141034 | |

Figure 28: Results of Default Configuration vs Slowest Pac Controllers

Fast Pac Controller vs Fastest Pac Controller

| F-Test Two-Sample for Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 19.69136 | 22.91111 |
| Variance | 32.33689 | 39.77726 |
| Observations | 27 | 27 |
| df | 26 | 26 |
| F | 0.812949 | |
| P(F<=f) one-tail | 0.300676 | |
| F Critical one-tail | 0.518346 | |

| t-Test: Two-Sample Assuming Equal Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 19.691358 | 22.911111 |
| Variance | 32.336888 | 39.777265 |
| Observations | 27 | 27 |
| Pooled Variance | 36.057077 | |
| Hypothesized Mean Difference | 0 | |
| df | 52 | |
| t Stat | -1.970127 | |
| P(T<=t) one-tail | 0.0270799 | |
| t Critical one-tail | 1.6746892 | |
| P(T<=t) two-tail | 0.0541598 | |
| t Critical two-tail | 2.0066468 | |

Figure 29: Results of Fast Pac Controllers vs Fastest Pac Controllers

Slowest Pac Controller vs Fast Pac Controller

| F-Test Two-Sample for Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 8.238272 | 19.691358 |
| Variance | 9.595274 | 32.336888 |
| Observations | 27 | 27 |
| df | 26 | 26 |
| F | 0.296728 | |
| P(F<=f) one-tail | 0.001434 | |
| F Critical one-tail | 0.518346 | |

| t-Test: Two-Sample Assuming Unequal Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 8.2382716 | 19.691358 |
| Variance | 9.5952738 | 32.336888 |
| Observations | 27 | 27 |
| Hypothesized Mean Difference | 0 | |
| df | 40 | |
| t Stat | -9.190323 | |
| P(T<=t) one-tail | 1.04E-11 | |
| t Critical one-tail | 1.683851 | |
| P(T<=t) two-tail | 2.08E-11 | |
| t Critical two-tail | 2.0210754 | |

Figure 30: Results of Slowest Pac Controllers vs Fast Pac Controllers

Slow Pac Controller vs Fast Pac Controller

| F-Test Two-Sample for Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 8.8481481 | 19.69136 |
| Variance | 11.659943 | 32.33689 |
| Observations | 27 | 27 |
| df | 26 | 26 |
| F | 0.3605772 | |
| P(F<=f) one-tail | 0.0058101 | |
| F Critical one-tail | 0.5183462 | |

| t-Test: Two-Sample Assuming Unequal Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 8.8481481 | 19.691358 |
| Variance | 11.659943 | 32.336888 |
| Observations | 27 | 27 |
| Hypothesized Mean Difference | 0 | |
| df | 43 | |
| t Stat | -8.494328 | |
| P(T<=t) one-tail | 4.783E-11 | |
| t Critical one-tail | 1.6810707 | |
| P(T<=t) two-tail | 9.566E-11 | |
| t Critical two-tail | 2.0166922 | |

Figure 31: Results of Slow Pac Controllers vs Fast Pac Controllers

Slow Pac Controller vs Slowest Pac Controller

| F-Test Two-Sample for Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 8.8481481 | 8.2382716 |
| Variance | 11.659943 | 9.5952738 |
| Observations | 27 | 27 |
| df | 26 | 26 |
| F | 1.2151756 | |
| P(F<=f) one-tail | 0.3114544 | |
| F Critical one-tail | 1.9292127 | |

| t-Test: Two-Sample Assuming Equal Variances | | |
|---|---|---|
| | *Variable 1* | *Variable 2* |
| Mean | 8.8481481 | 8.2382716 |
| Variance | 11.659943 | 9.5952738 |
| Observations | 27 | 27 |
| Pooled Variance | 10.627608 | |
| Hypothesized Mean Difference | 0 | |
| df | 52 | |
| t Stat | 0.6873707 | |
| P(T<=t) one-tail | 0.2474518 | |
| t Critical one-tail | 1.6746892 | |
| P(T<=t) two-tail | 0.4949036 | |
| t Critical two-tail | 2.0066468 | |

Figure 32: Results of Slow Pac Controllers vs Slowest Pac Controllers

## 4.4 Discussion

The mean of the basic configuration is less than the mean of the fast configuration, and F is greater than F Critical, so equal variances can be assumed. The absolute value of T stat is less than the absolute value of t critical two-tail, so it can not be determined with 95confidence whether either configuration is better.

The mean of the basic configuration is less than the mean of the fastest configuration, and F is greater than F Critical, so equal variances can be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95confidence that using the fastest controllers gives the pac controllers an evolutionary advantage compared to the basic configuration.

The mean of the basic configuration is greater than the mean of the slow configuration , and F is less than F Critical, so equal variances can be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95confidence that using slow configurations is an evolutionary disadvantage for pac controllers compared to the basic configuration.

The mean of the basic configuration is greater than the mean of the slowest configuration, and F is greater than F Critical, so equal variances cannot be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95disadvantage for pac controllers compared to the basic configuration.

The mean of the fast configuration is less than the mean of the fastest configuration, and F is greater than F Critical, so equal variances can be assumed. The absolute value of T stat is less than the absolute value of t critical two-tail, so it can not be determined with 95confidence whether either configuration is better.

The mean of the slowest configuration is less than the mean of the fast configuration, and F is less than F Critical, so equal variances cannot be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95controllers gives a distinct evolutionary advantage to pac controllers that the slowest pac controllers do not have.

The mean of the slowest configuration is less than the mean of the fastest configuration, and F is less than F Critical, so equal variances cannot be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95evolutionary disadvantage compared to the fastest pac controllers.

The mean of the slow configuration is less than the mean of the fast configuration, and F is less than F Critical, so equal variances cannot be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95controllers an evolutinary advantage over slow configurations.

The mean of the slow configuration is less than the mean of the fastest configuration, and F is less than F Critical, so equal variances cannot be assumed. The absolute value of T stat is greater than the absolute value of t critical two-tail, so it can be stated with 95controllers an evolutionary advantage over pac controllers that use the slow configuration.

The mean of the slow configuration is greater than the mean of the slowest configuration, and F is less than F Critical, so equal variances can be assumed. The absolute value of T stat is less than the absolute value of t critical two-tail, so it cannot be stated with 95

## 4.5 Conclusion

Generally, any configuration is not worse than any slower configuration. The larger the speed gap, the greater the chance that the faster configuration is better. If co-evolution has stagnated, then changing speed is an easy way to push up or down a given population.