New Mexico
Supercomputing Challenge

Final Report

April 1, 2015

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Santa Fe High School

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Here they come 'round the final bend! Running up front is Agent #001 with Agent #123 on his heels. They're neck and neck now! It's Agent # 123 in first!
How did he manage to do it?!

Executive Summary

Have you ever wondered if your starting position in a long distance race affected your finishing place? In our simulation, we have recreated the basic characteristics of a long distance race through the coding language Netlogo. Individual programs have been completed to reflect a standard 5K, half marathon (21.1K), and marathon (42.2K). The code addresses physiological conditions that are typically found when competing in a long distance sport; the most important being glucose and oxygen consumption. Agents have also been programmed with the ability to recognize and avoid other runners, as spatial awareness is another key factor in the outcome of a race. To simplify the code, all agents have the same speed and stamina allowing the starting position to be the determining factor. These added elements may seem like small additions, but in reality they make the entire simulation what it is. The results of our experiment have applications for long distance participants and race coordinators. Serious runners will want to position themselves according to our findings if they're hoping for an edge. With slight modifications the code could be applied to other long distance events, such as bicycle racing.

Overview

Does a runner's starting position determine their finishing time? If every runner at the start of a race had the same skill level, but were placed in four different sections (back, front, back middle, and front), who would win? Would those in the back win or would the racers in the front have better odds? A logical conclusion might be that a runner will finish in the position they start in. Our project purpose is to test whether this opinion is correct. The findings will have practical applications for both long distance participants and race coordinators. They also speak directly to a conversation had between Theo and his coach prior to a previous long distance track event.

Image source: http://adventuresintriathlon.com/aitblog/?tag=marathon

In our simulation, agents (runners) with the same potential stamina and speed, are positioned in the front, front middle, back middle, or back in the starting block of threes individual courses—5K, half marathon (21.1K), and marathon (42.2K). These variables of stamina and speed are affected by their individual *Glucose* and *Oxygen* levels which are used to denote muscle fatigue. Spatial awareness was added to represent common etiquette and make the simulation as lifelike as possible. These variables—starting position, glucose and oxygen consumption, and spatial awareness—define the boundaries and results of our project.

Individual agent glucose and oxygen levels will vary as the program runs. Combined, these represent the muscle fatigue present in any long distance activity. Eventually, the body does not receive enough oxygen, slowing down aerobic actions and causing a buildup of lactic acids as the body relies solely on glucose for anaerobic respiration. With more lactic acid present, and a less effective form of cellular respiration, energy drops and the muscles tighten up. The athlete feels this as a "burn" that results in "hitting the wall." No matter the long distance sport, muscles will tense up and slow down the athlete; agent speed will likewise decrease. This will be contingent upon how quickly they run through their stores.

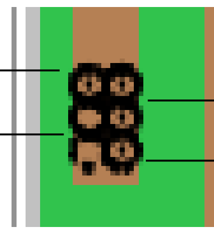
Similar to glucose and oxygen, spatial awareness affects the race results, specifically via the ability of the runners to maneuver through the course. This behavior keeps the agents in their own separate spaces, sometimes restricting their ability to pass others, or others to pass them. This added variable can also have the effect of giving specific agents the advantage in the race, because they will most likely stay in that position. This can happen when the agent in front blocks the agents behind them preventing them from moving up ahead.

We hypothesized that the runners up front will lose speed and have difficulty regaining it as they will deplete their oxygen, relying solely on glucose, before the runners behind them. Those in the middle of the starting order will have larger reserves of energy that allow them to pull ahead once those in front have fallen behind. Those in the back may simply never have enough space to move forward, even though they will have the most oxygen stores. This was only supported in the shorter 5K event. Logic, however, is proven correct in the two longer races.

Description of Project

Clarification of the Variables

The code of our project contains many variables and programs vital to its success. Central to this is the variable of starting position. During the setup agents who are positioned in one of four rows—front, front middle, back middle, and back, as defined below—are randomly selected. Our conclusions reflect the average finishing time for each of these positions.



Two additional variables are the duo of *Glucose* and *Oxygen*. These variables cause the agents to slow down as they run out of oxygen and begin to burn glucose, simulating the physiological process of muscle fatigue. The cells in our muscles need to produce energy in order for them to function. To do this they perform either aerobic or anaerobic respiration. Aerobic respiration is the process of taking oxygen (O_2) and a small amount of glucose ($C_6H_{12}O_6$) to create Adenosine Triphosphate (ATP) and the byproducts carbon dioxide (CO_2) and water (H_2O). On the other hand, anaerobic respiration is the process of taking glucose without oxygen to create ATP with the byproducts water, CO_2, and lactic acid. Lactic acid buildup in muscles causes them to cramp and burn, which slows down the runner affecting their performance negatively. This is known as "hitting the wall". The ATP produced by respiration is used to power the muscles allowing us to run.

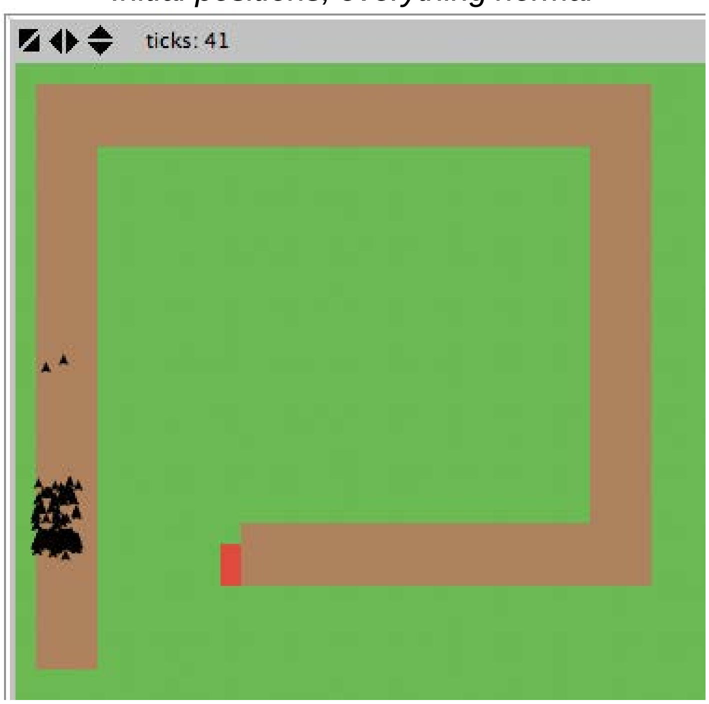
In our simulation, glucose and oxygen are represented as percentages. As the agents move they lose a predetermined amount correlated to their speed. Initially oxygen is the only variable impacted. Until it is expended they continue to perform aerobic respiration, and their speed and glucose are not affected. Once they run out, however, the agents shift to anaerobic respiration resulting in a decrease in glucose and speed. As the agents lose oxygen and glucose at a relatively slow pace, the effects of lactic acid buildup are not seen until they reach the length of a full marathon. This does not mean that they will run unimpeded in the other races, bringing us to spatial awareness.

Spatial awareness is necessary to participate safely in many sports. While running, it is essential to be aware of those around you in order to advance forward and prevent collisions. For our code to be realistic and provide credible results, we needed to work this in. Agents are programmed to look for the closest runner and maintain a set distance from them; however, this often results in moving closer to another agent. As such, continuous shifting occurs, similar to that found in real races. When space allows agents will advance.

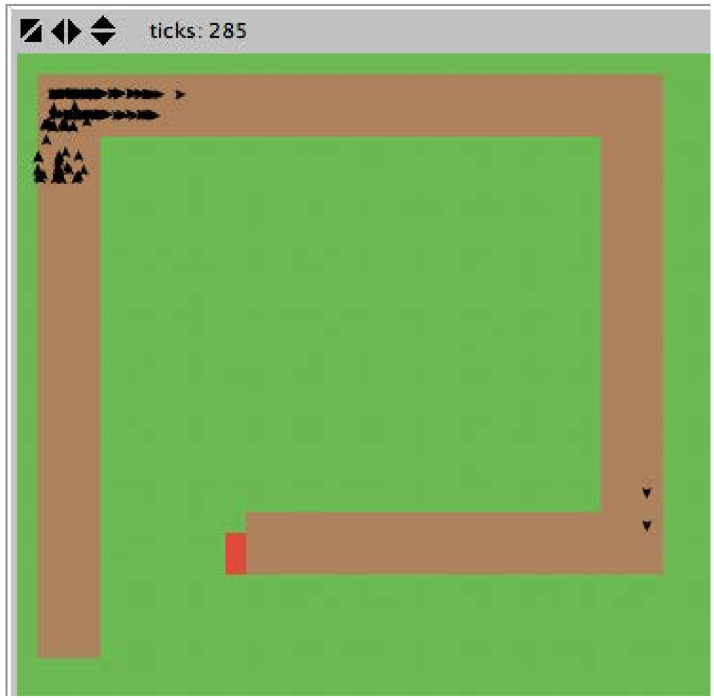
Problems with the Code

We encountered many different problems in the initial phase of our coding. Our first problem was the most occurring problem, but least problematic. While running the program the turtles would run the first segment of the race as intended; however, after rounding the corner they would separate into two separate lines and continue in that fashion through the rest of the course. This problem was an easy fix at first, but as our code grew, its later incarnations became harder and harder to correct. At one point, they even separated into two lines and then began to move backwards. This required an “if” statement to fix.

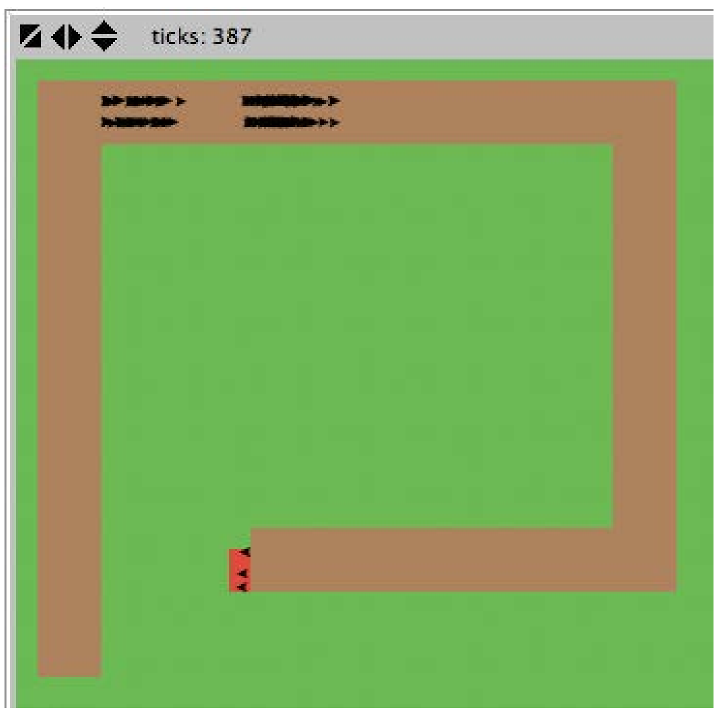
Initial positions; everything normal



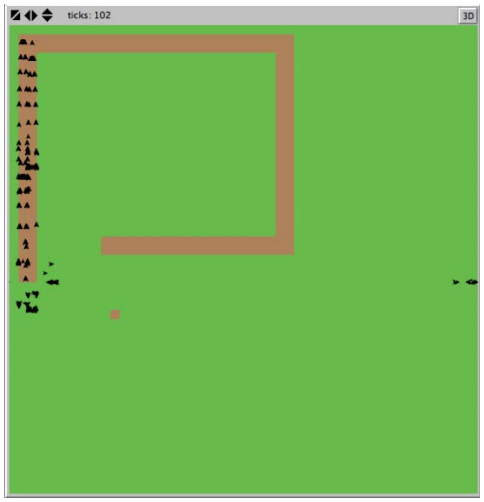
Transition



Problem



Another problem that arose involved runners leaving the course. Typically this occurred right at the beginning of the race (see below). This was extremely difficult to correct and was the only problem to report an error: "GRASS-ON expected input to be a turtle agentset or patch agentset or turtle or patch but got NOBODY instead." Initial attempts at correction resulted in unwanted changes to the way in which the code ran, affecting the end results and decreasing their reliability. The final solution was to delete and rewrite a section of the code that would later become the agents' spatial awareness.



Prior to the rewrite, grass was any green agent detected outside of the path. These agents acted as indicators that the path was not this way. *Grass* agents only spawned in the center of their individual patches, meaning they could be overlooked. The result of this was that runners could look to their side and not see "grass" and assume that the path was that way. *Grass* agents were removed from our final code and runners were programed to look for patch color.

Conclusion

The data below does not necessarily include the fastest or slowest times recorded, but a random sampling of agents selected by the program from each of the four starting positions.

Image source: http://photoblog.statesman.com/wp-content/uploads/2013/02/rbz-livestrong-austin-marathon-05.jpg

5K Results Summary

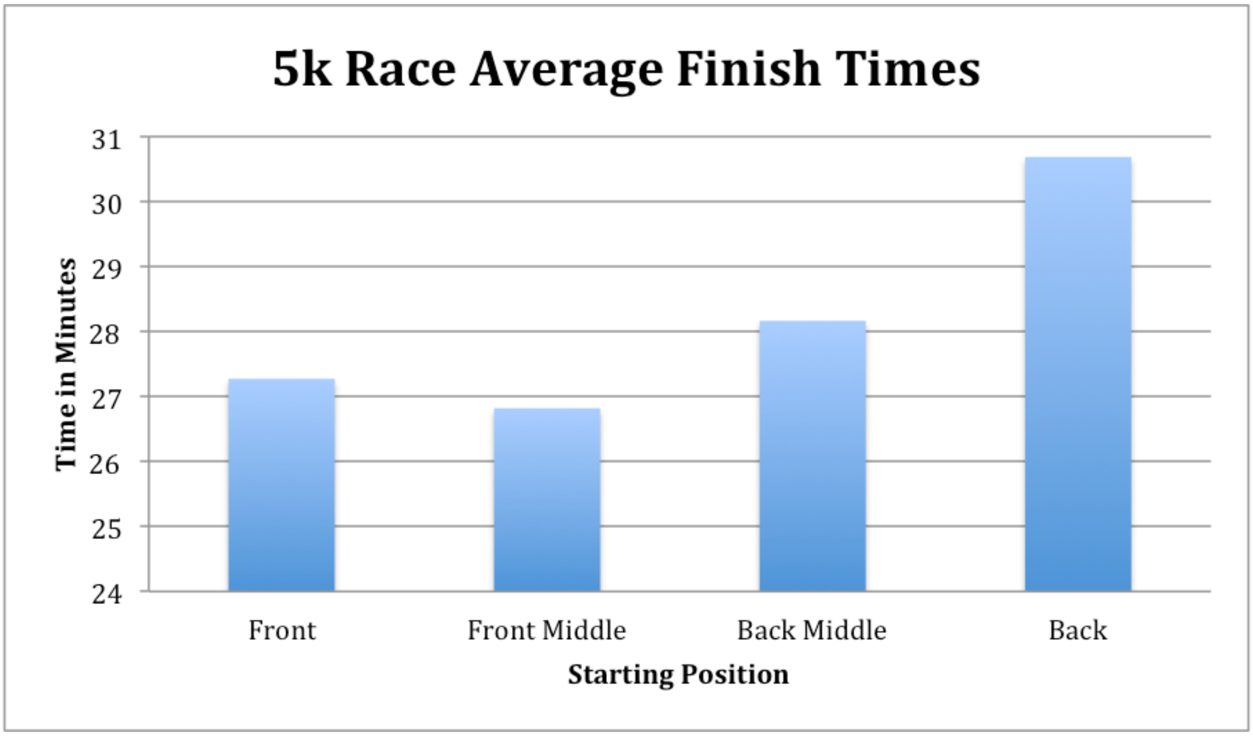
As indicated by the data below and supporting our hypothesis, 50% of the fastest 5K finishing times were recorded by front middle runners, with a an average time of 26.82 minutes. Agents positioned in the back middle placed first 40% of the time. As theorized, runners in the middle appeared able to conserve energy by pacing themselves behind the agents in front of them; when those fell behind, the runners in the middle pulled ahead winning the race. Those in front never placed first, but did record the second fastest average and placed 2nd 50 % of the time. Also of note, was a first place finish by a runner in a back starting position with a finishing time of 26.2 minutes during trial 8. This was an anomaly, as agents placed in the back finished in 3rd or 4th position 80% of the time. We are uncertain as to the cause of this result, but do feel that it reflects the realistic nature of our code; the unexpected is always possible.

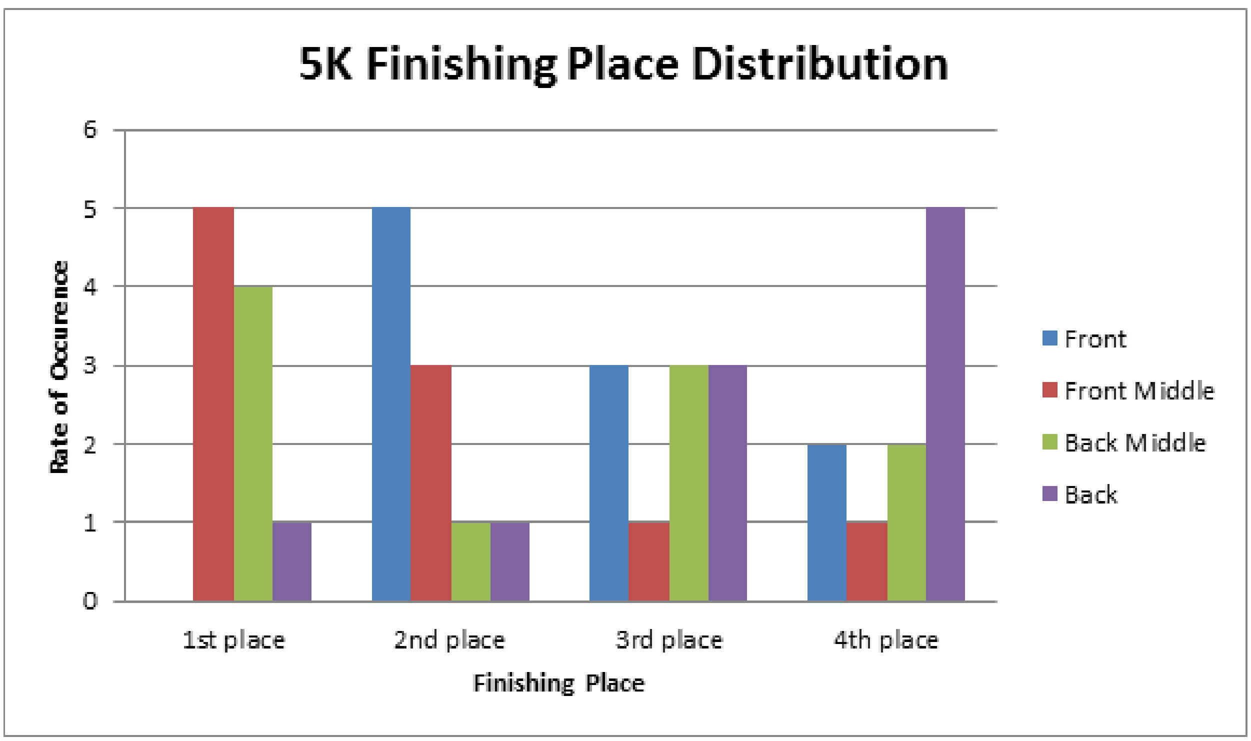
5K Race Times

Trial 1 Front: 27.2m Front Middle: 26.5m Back Middle: 27m Back: 34.4m	Trial 2 Front: 27.3m Front Middle: 27m Back Middle: 33.75m Back: 37m
Trial 3 Front: 26m Front Middle: 25.9m Back Middle: M 29.6m Back: 26.87m	Trial 4 Front: 26.1m Front Middle: M 26.2m Back Middle: 25.9m Back: 27.6m
Trial 5 Front: 28.23m Front Middle: M 25.8m Back Middle: 25.5m Back: 26.2m	Trial 6 Front: 28.3m Front Middle: 26.2m Back Middle: 26m Back: 26.8m
Trial 7 Front: 27.5m Front Middle: 27.3m Back Middle: 29m Back: 38.2m	Trial 8 Front: 28m Front Middle: 27.6m Back Middle: 30.6m Back: 26.2m
Trial 9 Front: 26.6m Front Middle: 29.1m Back Middle: 25.9m Back: 26m	Trial 10 Front: 27.5m Front Middle: 26.6m Back Middle: 28.4m Back: 37.6m

Key

BLUE HIGHLIGHTS: Winner for that trial	YELLOW HIGHLIGHTS: Points of interest


5k Race Average Finish Times
Time in Minutes
31
30
29
28
27
26
25
24
Front
Front Middle
Back Middle
Back
Starting Position


5K Finishing Place Distribution
Rate of Occurence
6
5
4
3
2
1
0
1st place
2nd place
3rd place
4th place
Finishing Place
Front
Front Middle
Back Middle
Back

Half Marathon Results Summary

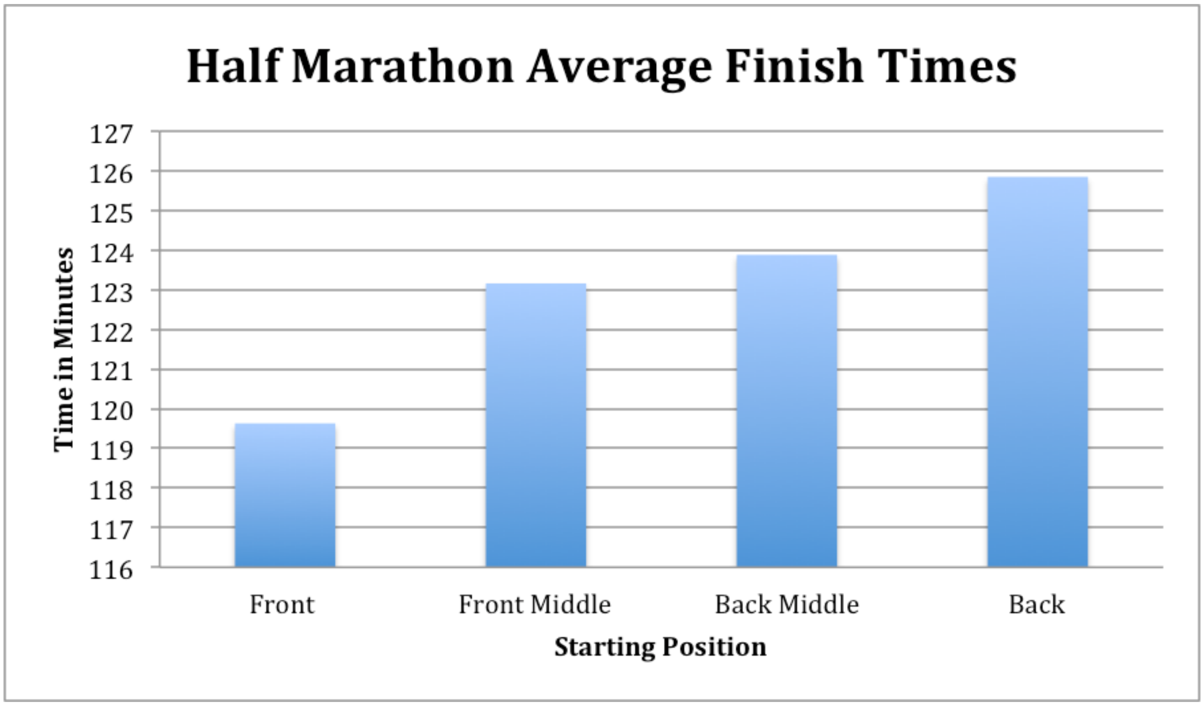
As can be seen in the data below, 40% of the fastest half marathon finishing times were recorded by agents in the front starting position, with an average time of 1 hour 59.63 minutes. This group never placed last. Front middle runners placed first 30% of the time, but also came in last the same percentage. An analysis of the finishing times for the other two positions, show a similar distribution with no significant outliers. There seems to be no clear advantage to being in either the middle or back positions; however, the front starting position does have an advantage over the others.

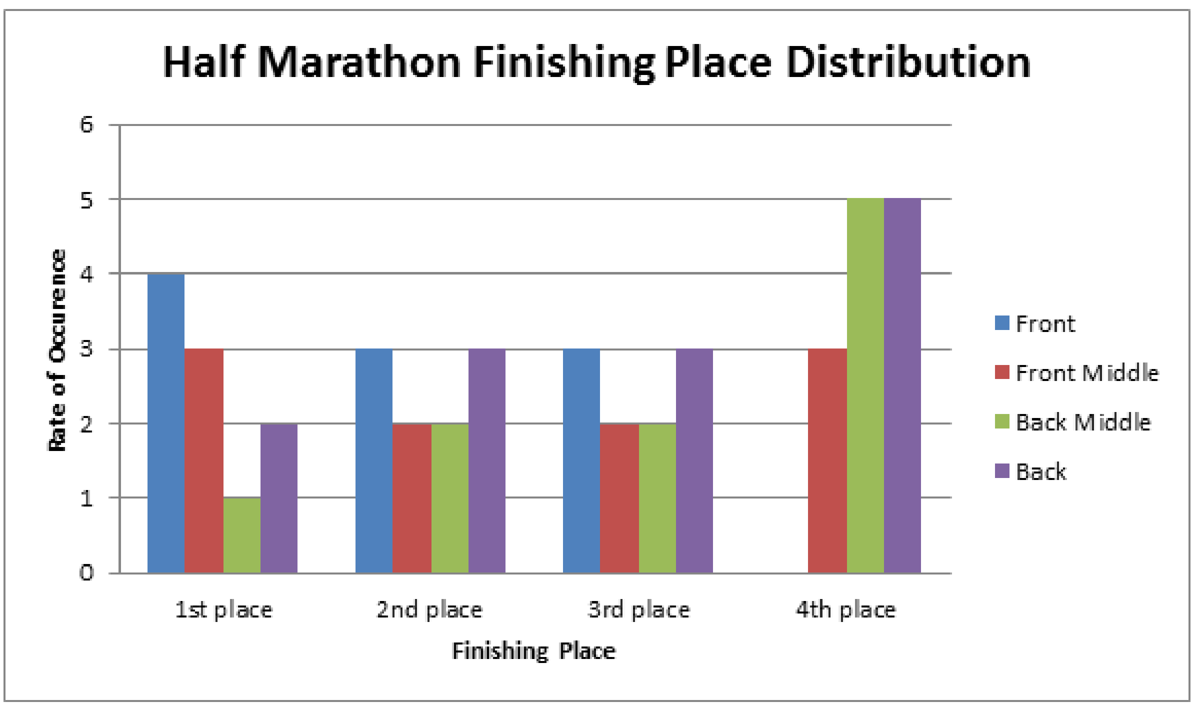
Half Marathon Times

Trial 1 Front: 1h 59.7m Front Middle: 1h 58.04m Back Middle: 2h 22.2m Back: 2h 20.15m	Trial 2 Front: 1h 55.23m Front Middle: 2h 5.4m Back Middle: 2h 6.4m Back: 1h 57.1m
Trial 3 Front: 1h 52.03m Front Middle: 1h 52.65m Back Middle: 1h 58.28m Back: 1h 56.25m	Trial 4 Front: 1h 55m Front Middle: 2h 21.4m Back Middle: 1h 55.46 Back: 2h 10.15m
Trial 5 Front: 1h 54.29m Front Middle: 1h 54m Back Middle: 2h 2.57m Back: 2h 15.54m	Trial 6 Front: 2h 4.7m Front Middle: 1h 55.07 Back Middle: 2h 4.76m Back: 1h 51.4m
Trial 7 Front: 2h .23m Front Middle: 2h 14.14m Back Middle: 2h 19.14m Back: 2h 11.95m	Trial 8 Front: 2h 2.1m Front Middle: 2h 2.8m Back Middle: 1h 53.2 m Back: 1h 56.64m
Trial 9 Front: 2h 20.15m Front Middle: 2h 1.64m Back Middle: 2h 3.2m Back: 2h 26.64m	Trial 10 Front: 1h 52.89m Front Middle: 2h 6.27 Back Middle: 1h 53.6m Back: 1h 52.65m

Key

BLUE HIGHLIGHTS: Winner for that trial	YELLOW HIGHLIGHTS: Points of interest


Half Marathon Average Finish Times
Time in Minutes
127
126
125
124
123
122
121
120
119
118
117
116
Front
Front Middle
Back Middle
Back
Starting Position


Half Marathon Finishing Place Distribution
Rate of Occurence
6
5
4
3
2
1
0
1st place
2nd place
3rd place
4th place
Finishing Place
Front
Front Middle
Back Middle
Back

Marathon Results Summary

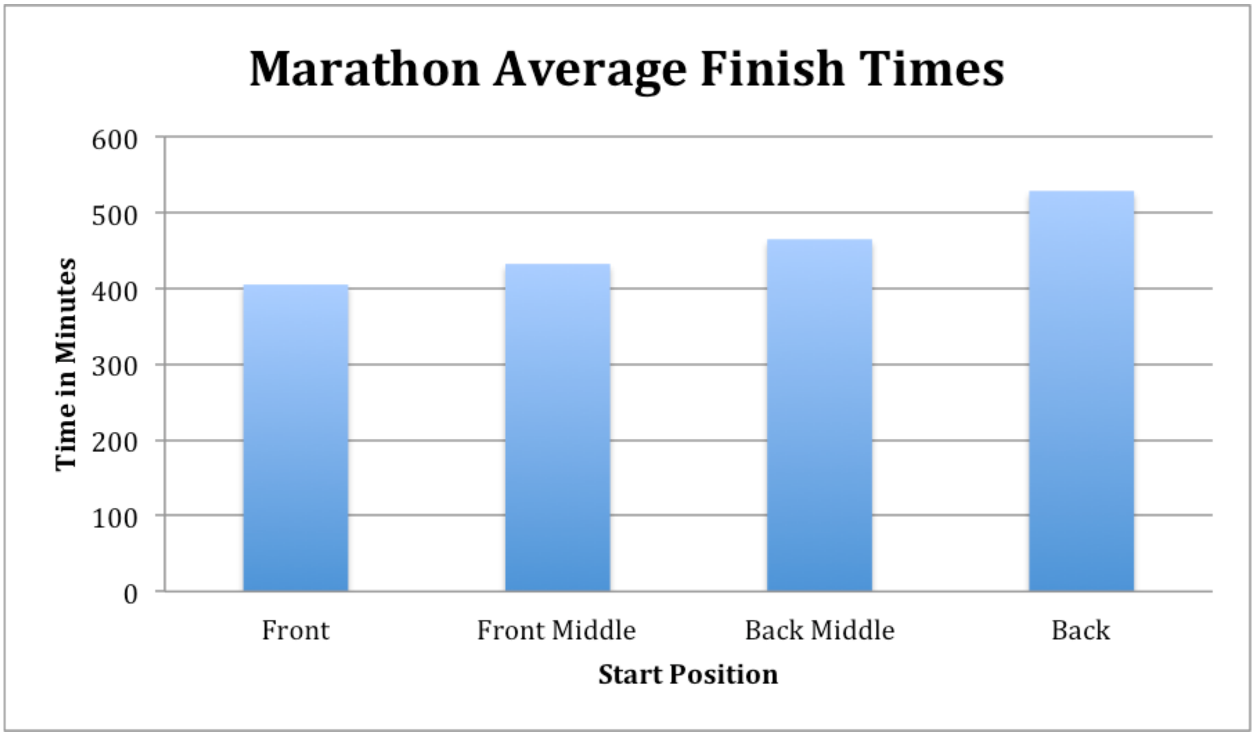
In the marathon, the distinction between the frequency of each starting position's 1st place finish was less pronounced with front and back middle each placing 1st 30% of the time, and the other two positions doing so 20% of the time. That being said, agents in the front finished in 6 hours 44.82 minutes on average and those in the back finished in 8 hours 48.34 minutes. This is a range of 2 hours 4.48 minutes, which would indicate that there is an advantage to being in the front. This discrepancy is due to significant outliers; in trials 3 and 5 the back row finishers selected by the program completed the marathon in roughly 14 hours. Additionally, those in the front starting position only placed 4th 20% of the time, while the back did so 50% of the time.

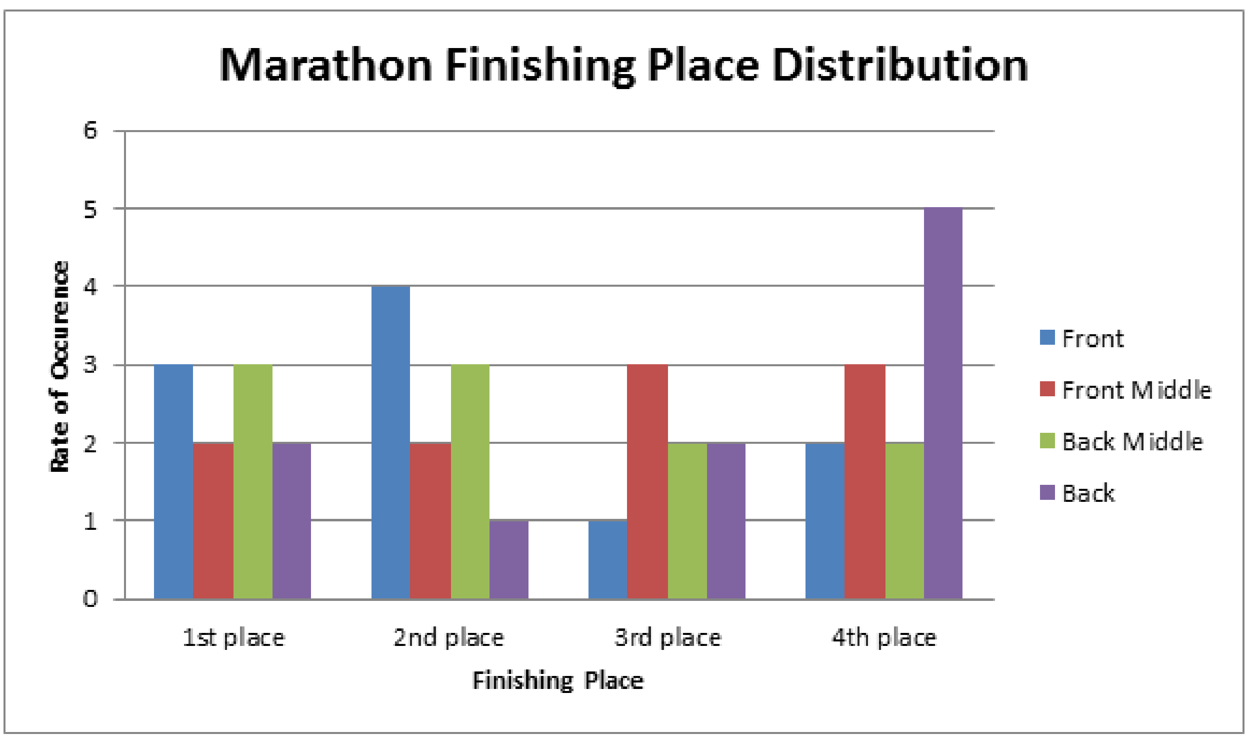
Marathon Race Times

Trial 1 Front: 9h 14.14m Front Middle: 7h 15.15m Back Middle: 8h 35.07 Back: 6h 16.09	Trial 2 Front: 7h 7.26m Front Middle: 6h 19.68m Back Middle: 6h 9.6m Back: 6h 47.89m
Trial 3 Front: 5h 58.51 Front Middle: 7h 9.92m Back Middle: 6h 28.75m Back: 14h 42.18m	Trial 4 Front: 6h 55.15 Front Middle; 5h 52.34m Back Middle: 6h 29.06m Back:9h 7.34m
Trial 5 Front: 6h 54.14m Front Middle: 6h 58.67m Back Middle: 6h 15.7m Back: 13h 32.73m	Trial 6 Front: 6h 6.56m Front Middle: 8h 24.92m Back Middle: 7h 59.45m Back: 8h 39.53m
Trial 7 Front: 6h 35.46m Front Middle: 8h 27.81m Back Middle: 6h 23.75m Back: 8h 36.09m	Trial 8 Front: 6h 41.32m Front Middle: 8h 43.67m Back Middle: 8h 11.79m Back: 6h 39.29m
Trial 9 Front: 6h 13.9m Front Middle: 6h 8.04m Back Middle: 11h 25.15m Back: 7h 36.25m	Trial 10 Front: 5h 41.75m Front Middle: 6h 40.39 Back Middle: 9h 17.8m Back: 6h 6.01m

Key

BLUE HIGHLIGHTS: Winner for that trial	YELLOW HIGHLIGHTS: Points of interest


Marathon Average Finish Times
600
500
400
300
200
100
0
Time in Minutes
Front
Front Middle
Back Middle
Back
Start Position


Marathon Finishing Place Distribution
6
5
4
3
2
1
0
Rate of Occurence
1st place
2nd place
3rd place
4th place
Finishing Place
Front
Front Middle
Back Middle
Back

Results Summary

Our results show that the ideal starting position depends on what length race you are running. If you are participating in a shorter race, like a 5K, then positioning yourself towards the front middle of the pack would increase the likelihood of a first place finish. This position appears to have the advantage of allowing the runner to start slow, but then outpace those in front as their energy is depleted. In longer races, such as the half marathon and marathon, positioning yourself closer to the front is most advantageous. This contradicts our hypothesis. In both of these the average time echoes the agent's starting position. This justifies the inclination of some race coordinators to have their racer's start in waves based on ability with faster runners up front, so that they are not impeded by slower participants.

Citations

Davis, John. "Running Writings: The Different Types of Fatigue." *Running Writings: The Different Types of Fatigue*. 11 Aug. 2011. Web. 6 Dec. 2014. <http://www.runningwritings.com/2011/08/types-of-fatigue.html>.

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Rosenbaum, Mike. "Four Minutes and Beyond: The Fastest Miles Ever Run." *About*. About.com, 1 Jan. 2014. Web. 6 Dec. 2014. <http://trackandfield.about.com/od/middledistance/p/Fastest-Mile-Times-The-Mens-Mile-World-Records.htm>.

Acknowledgements

- **Mohit Dubey:** Mohit, a former competitor of the Supercomputing challenge, contacted our group saying that he was interested in helping our group with our code. When we received this email, we were more than happy to have him guide us. He was extremely helpful. It was great having someone who could point the code in the right direction, and help make it the simulation we have today. Thank you, Mohit, for helping us get our code back on its feet when we hit a rough patch. Have fun at Odin!

- **Danny Adams:** Our (original) mentor was the push that got our group on our feet. He suggested articles to help our research which in turn helped the coding. Danny was also extremely helpful with recommending what we should do and getting up to focus on our Interim report. Thank you, Danny, for being the boost we needed to start.

- **Hope Cahill:** Hope was extremely helpful throughout the entire project. It seemed that she was always there. Thank you, Hope, for helping us to brainstorm improvements to the code, pointing out areas in our text that could benefit from additions or simplifications, and encouraging us to take a closer look at our conclusions.

Appendix A

Source Code

```
breed [runners runner]
breed [rar]
breed [grass]
runners-own [oxygen glucose speed p-speed time times loss done? n-runners n-runner o-heading n-
heading dist]
globals [time-list time-list2 p-time f-time s-time sort-times b-runner bm-runner fm-runner f-runner selected-
times]

to setup
  ca reset-ticks create-runners Runner-num
  ask runners [set shape "Person" set size .5 set color black  setxy (-39 + (random 2)) (14.5 - (random
2.5))
    if any? other runners-here [ifelse random 10 < 5 [left random 45] [right random 45] back .5]
    if pcolor = green [lt 90 ifelse [pcolor] of patch-ahead 1 [rt 180 fd .5 lt 90] [fd .5 rt 90]] set heading 0

    set speed .25 set oxygen 100 set glucose 100 set loss 0.05 set time 0 set time-list [] set selected-times
[] set done? false] ;set loss 0.0390625

  ask turtle 3 [
    ask one-of runners-on patch -39 15 [set f-runner who]
    ask one-of runners-on patch -39 14 [set fm-runner who]
    while [fm-runner = f-runner]
      [
        ask one-of runners-on patch -39 14 [set fm-runner who]
      ]
    ask one-of runners-on patch -39 13 [set bm-runner who]
    while [bm-runner = fm-runner]
      [
        ask one-of runners-on patch -39 13 [set bm-runner who]
      ]
    ask one-of runners-on patch -39 12 [set b-runner who]
    while [bm-runner = b-runner]
      [
        ask one-of runners-on patch -39 12 [set b-runner who]
```

```
    ]
   ]

  if course = 1 [ask patches
   [ask patch (-39 + (random 2)) (16 + (random 24)) [set pcolor brown]
    ask patch (-39 + (random 33)) (39 + (random 2)) [set pcolor brown]
    ask patch (-8 + (random 2)) (39 - (random 24)) [set pcolor brown]
    ask patch (-8 - (random 26)) (16 + (random 2)) [set pcolor brown]
    ask patch (-39 + (random 2)) (15 - (random 4)) [set pcolor brown]
    if pcolor = black [set pcolor green] if pcolor = green [sprout 1 [set breed grass set color green ]]]]

  if course = 1 [ask patch -34 16 [set pcolor red] ask patch -34 17 [set pcolor red]
   ask grass [if pcolor = brown or pcolor = red [die]]]
  if course = 2 [ask patches [ask patch (-39 + (random 2)) (16 + (random 24)) [set pcolor brown] ask patch
(-39 + (random 78)) (39 - (random 2)) [set pcolor brown]
   ask patch (39 - (random 2)) (39 - (random 78)) [set pcolor brown] ask patch (38 - (random 72)) (-38 +
(random 2)) [set pcolor brown]
   ask patch (-35 + (random 2)) (-38 + (random 73)) [set pcolor brown] ask patch (-35 + (random 70)) (35
- (random 2)) [set pcolor brown]
   ask patch (35 - (random 2)) (35 - (random 27)) [set pcolor brown] ask patch (-39 + (random 2)) (15 -
(random 4)) [set pcolor brown]
   if pcolor = black [set pcolor green] ask patch (34 + (random 2)) 8 [set pcolor red]
   ask grass [if pcolor = brown or pcolor = red [die]]]]

  if course = 3 [ask patches [ask patch (-39 + (random 2)) (16 + (random 24)) [set pcolor brown] ask patch
(-39 + (random 78)) (39 - (random 2)) [set pcolor brown]
   ask patch (39 - (random 2)) (39 - (random 78)) [set pcolor brown] ask patch (38 - (random 72)) (-38 +
(random 2)) [set pcolor brown]
   ask patch (-35 + (random 2)) (-38 + (random 73)) [set pcolor brown] ask patch (-35 + (random 70)) (35
- (random 2)) [set pcolor brown]
   ask patch (35 - (random 2)) (35 - (random 70)) [set pcolor brown] ask patch (33 - (random 65)) (-34 +
(random 2)) [set pcolor brown]
   ask patch (-31 + (random 2)) (-32 + (random 63)) [set pcolor brown] ask patch (-31 + (random 63)) (31
- (random 2)) [set pcolor brown]
   ask patch (31 - (random 2)) (30 - (random 61)) [set pcolor brown] ask patch (29 - (random 57)) (-30 +
(random 2)) [set pcolor brown]
```

```
    ask patch (-27 + (random 2)) (-28 + (random 56)) [set pcolor brown] ask patch (-25 + (random 3)) (27 -
(random 2)) [set pcolor brown]
    ask patch (-39 + (random 2)) (15 - (random 4)) [set pcolor brown] ask patch -22 (27 - (random 2)) [set
pcolor red]
    if pcolor = black [set pcolor green]
    ask grass [if pcolor = brown or pcolor = red [die]]]]
end
to go
  ask runners [ifelse pcolor = red [stop]
    [if pcolor != red [set time time + 1]]
  spacial
  path-finding
  ]

  ask runners [if pcolor = red [while [done? = false] [set p-time time set time-list fput p-time time-list set
done? true]]]
  if count runners with [done? = true] = runner-num [print "Times without duplicates:" set sort-times sort
remove-duplicates time-list print sort-times set time-list2 time-list
    repeat (runner-num - 1) [set time-list2 sort time-list2 set time-list2 but-first time-list2]
    repeat (runner-num - 1) [set time-list sort time-list set time-list but-last time-list]
    print "Fastest Time(s) in ticks:" set f-time time-list print time-list
    print "Slowest Time(s) in ticks:" set s-time time-list2 print time-list2
    ;write "Fastest Time(s) in minutes:" write ((time-list * 4.6875) / 60)
    ask turtle f-runner [set time ((time * 4.6875) / 60) write "Front Finishing time: " print time]
    ask turtle fm-runner [set time ((time * 4.6875) / 60) write "Front Middle Finishing time: " print time]
    ask turtle bm-runner [set time ((time * 4.6875) / 60) write "Back Middle Finishing time: " print time]
    ask turtle b-runner [set time ((time * 4.6875) / 60) write "Back Finishing time: " print time]
    ask turtle b-runner [set selected-times fput time selected-times]
    ask turtle bm-runner [set selected-times fput time selected-times]
    ask turtle fm-runner [set selected-times fput time selected-times]
    ask turtle f-runner [set selected-times fput time selected-times]
    stop]
end
to move
  ifelse any? runners-on patch-ahead .25 and speed >= .1

    [lt 90 ifelse any? runners-on patch-ahead .98
```

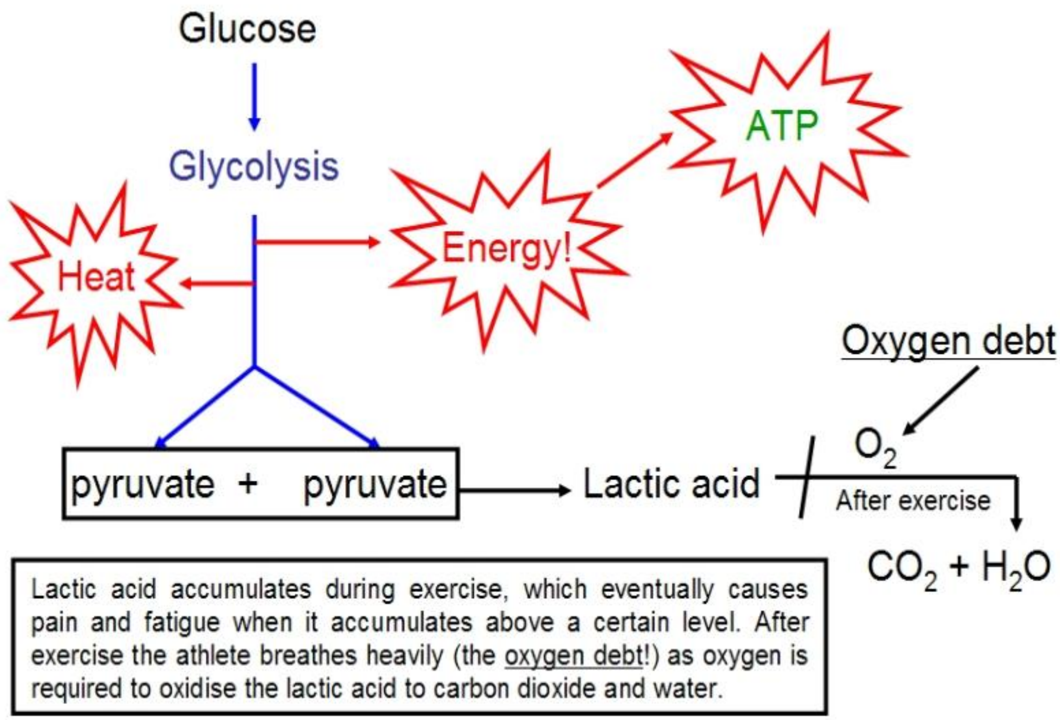
```
    [rt 180 ifelse any? runners-on patch-ahead .98

     [lt 90 ifelse any? runners-on patch-ahead .75

      [if speed >= .15 [set p-speed speed set speed speed - .02  fd speed set speed p-speed]
       ifelse oxygen <= 1.5 [ set glucose glucose - loss]
       [set oxygen oxygen - loss]
       decrease]
     [ifelse oxygen <= 1.5 [ set glucose glucose - loss]
      [decrease fd speed]]]

     [lt 45 fd speed lt 45 fd speed ifelse oxygen <= 1.5 [set glucose glucose - loss]
      [set oxygen oxygen - loss]
     decrease]]

    [rt 45 fd speed rt 45 fd speed ifelse oxygen <= 1.5 [set glucose glucose - (loss * 2)]
     [set oxygen oxygen - (loss * 2)]
    decrease]]

   [fd speed ifelse oxygen <= 1.5 [set glucose glucose - loss]
    [set oxygen oxygen - loss]
   decrease]
end
to path-finding
 if pcolor = green [lt 90 fd .25 ifelse pcolor = green [rt 180 fd .5 lt 90][rt 90]]
 ifelse [pcolor] of patch-ahead .75 = green [
 rt 90 ifelse [pcolor] of patch-ahead 2.25 = green [
  lt 180
    fd speed ifelse oxygen <= 1.5 [set glucose glucose - loss]
     [set oxygen oxygen - loss]
    decrease]

   [fd speed ifelse oxygen <= 1.5 [set glucose glucose - loss]
    [set oxygen oxygen - loss]
   decrease]

 ][fd speed ifelse oxygen <= 1.5 [set glucose glucose - loss]
```

```
        [set oxygen oxygen - loss]
      decrease];<------
end
to Spacial
  if any? other runners in-radius .25[
    set n-runners other runners in-radius .25 set n-runner min-one-of n-runners [distance myself] set dist
(.2 - (distance n-runner))
    set o-heading heading face n-runner set n-heading heading set heading o-heading
    ifelse n-heading = o-heading [if speed >= .15 [set p-speed speed set speed speed - .025] fd speed]
  [
    if n-heading > o-heading [if n-heading - 90 <= o-heading [set heading o-heading left 90 fd dist rt 90 fd
speed]]
    if n-heading < o-heading [if n-heading + 90 >= o-heading [set heading o-heading right 90 fd dist lt 90 fd
speed]]
  ]]
end
to decrease
  ifelse glucose > 95 [set speed .225]
      [ifelse glucose > 90 [set speed .2]
        [ifelse glucose > 85 [set speed .175]
          [ifelse glucose > 80 [set speed .15]
            [ifelse glucose > 75 [set speed .125]
              [ifelse glucose > 70 [set speed .1]
                [ifelse glucose > 65 [set speed .075]
                  [ifelse glucose > 60 [set speed .05]
                    [if glucose > 55 [set speed .025]]]]]]]]
      ifelse speed >= .225 [set loss .045]
      [ifelse speed >= .2 [set loss .0425]
        [ifelse speed >= .175 [set loss .04]
          [ifelse speed >= .15 [set loss .0375]
            [ifelse speed >= .125 [set loss .035]
              [ifelse speed >= .1 [set loss .0325]
                [ifelse speed >= .075 [set loss .03]
                  [ifelse speed >= .05 [set loss .0275]
                    [if speed >= .025 [set loss .025]]]]]]]]
end
```

Appendix B

Anaerobic Visual

Image source: http://cronodon.com/BioTech/Respiration.html



Appendix C

Aerobic Visual

Image source: http://cronodon.com/BioTech/Respiration.html