

The Hunting Strategy of the Velociraptor

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ABSTRACT

There are many problems that computers could solve if the appropriate software existed. Flight control systems for aircraft, automated manufacturing systems, and sophisticated avionics systems all present difficult, nonlinear control problems. It is often useful to develop mathematical models for hypothetical situations that are related to more challenging real-world problems. This paper presents an algorithm that models the hunting strategy of *Velociraptor mongoliensis*.

INTRODUCTION

The *Velociraptor* was a predatory dinosaur that lived during the late Cretaceous period, approximately 75 million years ago. Paleontologists think that it was a very tenacious hunter, and may have hunted in pairs or in larger packs. Unfortunately, there is no way to observe an analog of hunting strategies in the wild as with modern mammalian predators. An average adult *Velociraptor* was 3 meters long with a hip height of 0.5 meters and an approximate mass of 45 kg. It is estimated that the animal could run extremely fast, at the speed of 60 km/hr, for about 15 seconds. After the initial burst of speed, the animal needed to stop and recover from a buildup of lactic acid in its muscles. The *Velociraptor* preyed on *Thescelosaurus neglectus*, a herbivorous biped approximately the same size as the *Velociraptor*. A biomedical analysis of a fossilized *Thescelosaurus* indicates that it could run at 50 km/hr for a long period of time. Assuming the *Velociraptor* is a solitary hunter, we will design a mathematical model that describes a hunting strategy for a single *Velociraptor* stalking and chasing a single *Thescelosaurus*, as well as the evasive strategy of the prey. We will assume the *Thescelosaurus* can always detect the *Velociraptor* when it is within 15 meters, but may detect the predator at even greater distances (up to 50 meters), depending on the habitat and weather conditions. Additionally, due to physical structure and strength, the *Velociraptor* has a limited turning radius when turning at a full speed. This radius is estimated to be three times the animal height. On the other hand, the *Thescelosaurus* is extremely agile and has a turning radius of 0.5 meters.¹

¹Consortium for Mathematics and Its Applications (COMAP), Mathematical Contest in Modeling 1997.

MODEL

We modeled the chase between the *Velociraptor* and the *Thescelosaurus* incorporating some mathematical ideas and the concepts of Reinforcement Learning System. A reinforcement learning system generally consists of three parts: agent, environment and simulation.² The agent in this case is the *Velociraptor*. The environment includes the behavior of the *Thescelosaurus*, and the habitat. The simulation refers to the interaction between the agent and the environment (Figure 1).

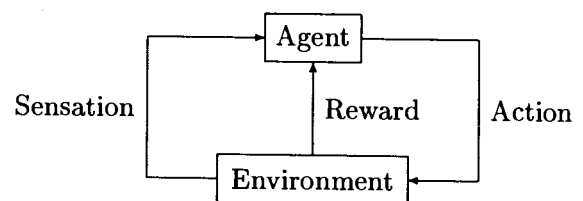


FIGURE 1. Agent and Environment Interaction

A mathematical model of an agent generally consists of three basic components: a policy function, a reward function, and a value function. Figure 2 illustrates the relationship between these three functions.

The policy function is the decision-making component of the agent which specifies what action it takes in each of the situations that it might encounter. Thus, policy determines the agent's behavior and performance.

The reward function defines the goal of the agent. It maps the state of the environment to a single number, a reward, indicating the intrinsic desirability of the state. The agent's objective is to maximize the total reward it receives in the long run. The reward function thus defines the good and the bad events for

²Online Tutorial on Reinforcement Learning. 21 May 1998.
<<http://www.arw.cs.umass.edu/~mharmon/rltutorial/frames.html>>

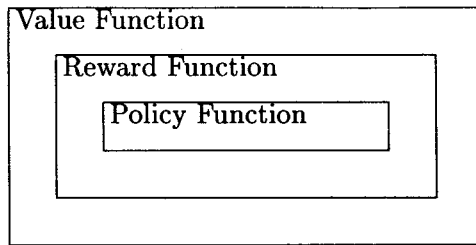


FIGURE 2. Relationship between the Value, Reward, and the Policy functions

an agent. The reward function is necessarily fixed.³ It may, however, be used as a basis for changing the policy. For example, if an action selected by the policy results in a low reward then the policy for that situation may change.

Whereas the reward function indicates what is good in an immediate sense, the value function determines what is good in the long run. Roughly speaking, the value of a state is the total amount of reward the agent expects to accumulate in the future. A state might always yield a low immediate reward, but still have a high value reward, or the reverse could be true.

MODELING ASSUMPTIONS

This model is based on the concept of Reinforcement Learning and uses geometric, trigonometric and related mathematical concepts. The model is also based on the following assumptions:

1. The *Velociraptor* is young and inexperienced in hunting and therefore we would expect more negative rewards in the initial stages of the chase.
2. The chase starts when the distance between the dinosaurs is 50 meters.
3. Biological reports say that the *Velociraptor* normally takes two to three weeks to recover from the build up of lactic acid from the chase. However, for simplicity of the program we ignore this fact and let the process continue till the *Velociraptor* gets its prey.
4. The *Thescelosaurus* will not turn more than 90 degrees at a time.
5. There is no loss of speed during the turns.
6. Both dinosaurs run at constant speeds.
7. The *Velociraptor* will get its prey if it is within 5 meters of its prey.

³ Performance Of Reinforcement Learning Methods. 10 August 1998. <<http://www.cmu.edu/afs/cs/usr/skoenig/www/sven/projects/markov.html>>

A DETAILED DESCRIPTION OF THE MODEL

The *Velociraptor*, V , is initially positioned at the origin $(0,0)$ and the *Thescelosaurus*, T , is positioned 50 meters away from the *Velociraptor* at $(0, 50)$, as shown in Figure 3.

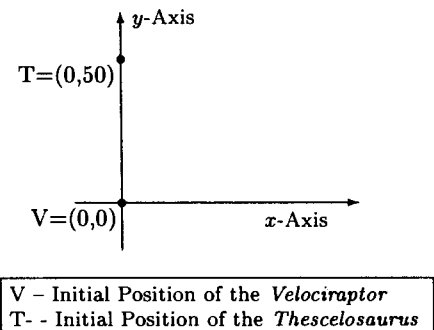


FIGURE 3. Initial Positions of Agents

The initial difficulty that was encountered while designing the model was that as the two dinosaurs move, the *Velociraptor* needs to know where the *Thescelosaurus* is located so that it knows how the current situation compares with previously encountered states. To solve this problem, the model adjusts the *Velociraptor*'s reference axes after each 'move.' When the *Velociraptor* moves to a new point $V = (a, b)$ and the *Thescelosaurus* moves to point $T = (c, d)$, then the axes of reference for the *Velociraptor* change to x' and y' as shown in Figure 4. The model always assigns the new y' axis to be in the direction of the vector joining the positions of the *Velociraptor* V' and *Thescelosaurus* T' . The new x' -axis is then perpendicular to this axis (Figure 5).

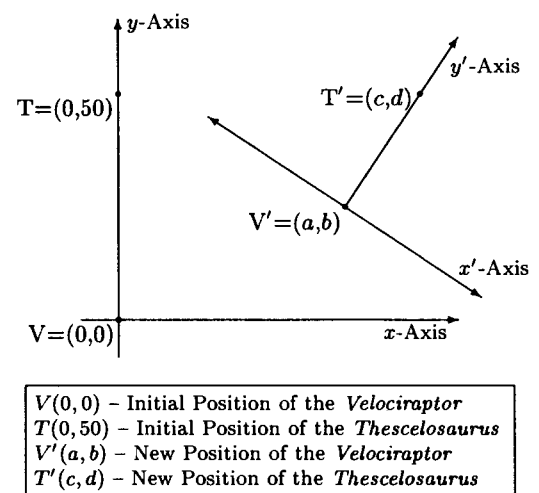


FIGURE 4. The New Axes

It is impossible for an animal to make sharp turns. Animals always turn in circles and their turning radius depends on their size, height and weight. The turning radius for the *Velociraptor* was determined to be 1.5 meters and that of the *Thescelosaurus* to be 0.5

meters. We calculated the distance that each of the animals can cover in one time step using the formula:

$$\text{DistancePerTimeStep} = \text{MAX_TIME} \cdot \text{speed} \cdot \frac{\text{ConversionFactor}}{\text{TIME_STEPS}}$$

where MAX_TIME = 15 seconds is the time duration of the chase, and DistancePerTimeStep is the maximum distance that each of the animals can cover in one time step.

$$\begin{aligned} \text{Velociraptor speed} &= 60 \frac{\text{km}}{\text{hr}} \\ \text{Thescelosaurus speed} &= 50 \frac{\text{km}}{\text{hr}} \\ \text{CONVERSIONFACTOR} &= \frac{5}{18} \\ \text{TIME_STEPS} &= 105 \end{aligned}$$

CONVERSIONFACTOR converts units from $\frac{\text{km}}{\text{hr}}$ to $\frac{\text{m}}{\text{s}}$

A random angle is generated using the random number generator. Angles are generated from 0 to 180 degrees with respect to the new axis. The Velociraptor takes off on the circle of turning radius 1.5 meters on the circle shown in the Figure 6 and covers a part of the DistancePerTimeStep on the circle. The temporary position on the circle (point B) can be calculated using the formula:

$$\begin{aligned} \text{Old_X_Pos} &= x_2 = r(1 - \sin(\alpha - \theta)) \\ \text{Old_Y_Pos} &= y_2 = r(1 - \cos(\alpha - \theta)) \end{aligned}$$

Where r is the turning radius and θ is the angle between the relative axis and the x -axis.

The distance traveled on the circle is calculated using the formula for the arc length given by the formula: ArcLength = $r \cdot \delta$ where r is the turning radius for the agents and δ is the angle $\angle CVQ$ in the Figure 6.

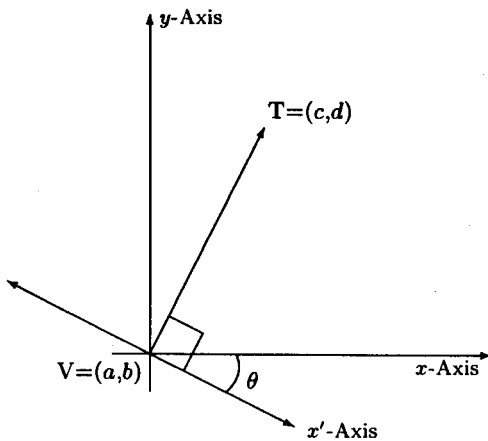


FIGURE 5. The Relative Axes (x' -Axis)

Old_X_Pos and Old_Y_Pos are the temporary coordinates of the Velociraptor on the circle as shown in the Figure 6. The FinalAngle δ is calculated in radians using

$$\text{FinalAngle} = \delta = \left(\frac{\pi}{2} - \alpha + \theta\right) \cdot \frac{\pi}{180}$$

Where $\frac{\pi}{180}$ is used to convert an angle from degrees to radians.

The Velociraptor travels a part of the DistPerTimeStep on the circle thereby having turned in the required direction, and then the rest of the distance along a line that is tangent to the circle. The new position of the Velociraptor or the Thescelosaurus is calculated using formula (1). Distance between two points $A = (x_1, y_1)$ and $B = (x_2, y_2)$ is given by:

$$D(A, B) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (1)$$

Where A is the initial position and B is the final position.

From these calculations, the program finds the new x and y positions for the Velociraptor and the Thescelosaurus

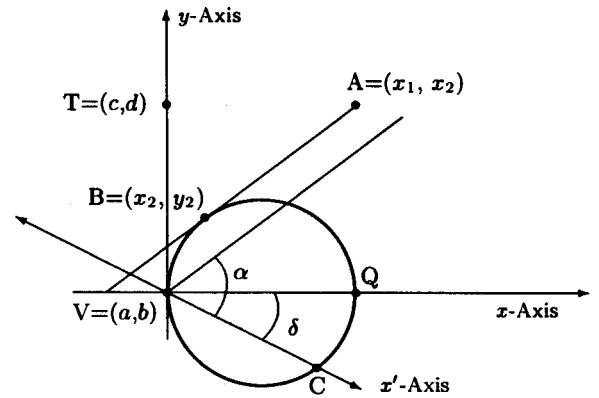


FIGURE 6. Trace of Predator/Prey Interaction

MEMORY TABLE OF THE VELOCIRAPTOR

The concept of Reinforcement Learning (RL) is now introduced as an intelligence for the Velociraptor. A memory table is designed using the Reinforcement Learning as the backbone. What has to be noted is that the memory table is actually a mathematical simulation of the brain of the Velociraptor. The decisions made by the predator are recorded in the memory table and the information stored in the memory table also teaches the Velociraptor how to attack its prey. In other words the memory table is a representation of what is going on in the predator's brain. This table is designed to keep track of all the places visited by the Velociraptor and the reward it gets for each and every move. This ensures (through a series of trial and error) that the Velociraptor eventually closes in on the prey. The memory table is a two-dimensional array. The array has 50 slots running horizontally denoting the separations between the agents in meters and there are 180 slots that run vertically denoting the angle generated. The memory table MT and its properties are illustrated in Figure 7 and Figure 8.

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AMRITA DAS is a sophomore majoring in Computer Science and minoring in Mathematics. The topic of this research project was originally suggested by the 1997 Mathematical Competition for Modeling (MCM), and was extended by Shamim Ara Mollah into a class project for M447, *Mathematical Modeling*. In 1998, Amrita obtained a summer research grant from the IUSB SMART committee to pursue this project. She presented her research at the Indiana University Undergraduate Research Conference in November 1998. She plans to continue her research and convert the current program into a user-interactive interface.