# Simulated World Research Report – Boids (Autonomous Agents)

## Autonomous Agents

“The term ***autonomous agent*** generally refers to an entity that makes its own choices about how to act in its environment without any influence from a leader or global plan” (Shiffman, D. 2012). Autonomous agents are those that, for all intents and purposes, make their own decisions. They do not receive ‘orders’ of any kind and simply follow their own set of rules to define their behaviour. Shiffman goes on to state in his book ‘The Nature of Code’ that autonomous agents have several key components that define their behaviour. They include, but are not limited to, “An autonomous agent has a *limited* ability to perceive environment”, “An autonomous agent processes the information from its environment and calculates an action”, and finally that “An autonomous agent has no leader” (Shiffman, D. 2012). From these three key components, we can begin to understand how exactly these autonomous agents function and operate. They have a limited ability to ‘see’ their environment, evaluate this information and process a response, whether that means going towards something or avoiding for example. Finally, these decisions are made solely by their self and do not communicate with a leader.

“The behaviour of an agent is often determined dynamically based on its current perception of itself and the environment as well as a goal to achieve. This is the main difference between agents and conventional components” (Li, Q. Smith, G. 2016). Autonomous agents can be designed and shaped in many ways allowing for a huge scope of flexibility, from as little as a single behaviour or rule that defines their behaviour to a huge network of behaviours and relationships being the driving force behind them. Li and Smith also go on to state in their journal ‘Refining autonomous agents with declarative beliefs and desires’ that “an autonomous agent is one that is not only directed by its environment, but is also driven by internal motivation to achieve certain goals based on beliefs about the environmental behaviour”. They also go on to talk about how an agent’s beliefs and desires can help refine their actions and behaviours, and that by not only having the more linear ruleset, can lead to much more diversity within their behaviours and increasingly complex networks of agent interactions. “Agents with the same capability may have different goals and be deployed in different environments. Therefore, the design of such agents must not depend on following specific goals or be based on particular assumptions about the environment” (Li, Q. Smith, G. 2016). Such complicated systems are not always useful but it’s interesting to understand that autonomous agents ‘can’ be so much more than just linear rulesets, and to an extent, can almost have their own ‘personality’ within a group.

“In the late 1980’s, computer scientist Craig Reynolds developed algorithmic steering behaviours for animated characters” (Shiffman, D. 2012). These behaviours allowed individual elements of a computer simulation to navigate and interact within their environment in a much more realistic manner than ever before. The simplicity of the rules, and the ability for each character to control themselves allowed for some surprising levels of complex behaviour. With the most famous example being “Reynold’s ‘boids’ model for ‘flocking/swarming’ behaviour” (Shiffman, D. 2012). This example follows the more traditional concept of less is more, with their behaviours being defined by a small ruleset and excludes some more modern approaches involving some of the concepts discussed above. At the time is was perhaps inconceivable to think of adding such complexities due to technological restrains, or simply that the initial concept has evolved over the years with more advanced versions. The fact remains though, that with such a simple set of defined behaviours, a huge diversity of patterns could be constructed by tweaking them.

## Background into Boids

The boids concept was originally developed By Craig Reynolds. The boids system uses an artificial intelligence algorithm designed to replicate the group behaviour of a flock of birds or school of fish for example. In the paper ‘Flocks, Herds, Schools: A Distributed Behavioural Model’ written by Craig Reynolds in 1987, the paper “explores an approach based on simulation as an alternative to scripting the paths of each bird individually”. Reynolds wanted to explore the idea that rather than each boid being scripted and following a given path, that they would have some form of limited AI, allowing for more freedom and a much more natural simulation. The boids system came about due to the realisation that “individual agents are becoming too complex to function as expected to” (Radwan et al. 2012), thus the ‘Multi Agent’ approach was born. This new approach allowed for much more flexibility and improved performance, “Distributing the system over multiple platforms and hardware enhances the robustness and reliability significantly” (Radwan et al. 2012). This was also boosted by the fact that the multi agent approach increased the computational efficiency by sharing the workload.

So, what is an intelligent agent, “An intelligent agent is a sophisticated entity that act autonomously by perceiving information from the environment using sensors, and decide to take action through reasoning process to perform its role and lastly act upon its environment through actuators” (Radwan et al. 2012).

Reynolds clearly had a fascination with birds, “The motion of a flock of birds is one of nature’s delights” (Reynolds C.W. 1987), and their almost synchronised group behaviour. These behaviours can also be seen in similar animal groupings, that Reynolds also states, including schools of fish and herds of land roaming animals. One of the most interesting components of a flock of birds is their “Strong impression of intentional, centralised control” (Reynolds C.W. 1987). Reynolds goes on to talk about the fact that a flock appears to have this form of centralized control but that the evidence shows that a flock’s motion is possibly the mere aggregated results of the actions of each individual bird with the flock. It was this conclusion and thought process that brought the concept of boids to life.

## What does it mean to be a Boid?

Following on from Reynolds theory it’s clear to see that he suggests that a flock’s motion is the culmination of each individual bird’s actions. So, to begin this concept Reynolds wanted to replicate the behaviour of each bird individually, instead of having a central control component. “For a bird to participate in a flock, it must have behaviours that allow it to coordinate with those of its flock mates” (Reynolds C.W. 1987). Reynolds decided upon three very simple behaviours, behaviours that most living creatures have to some extent. These behaviours are drawn upon by their needs, firstly their need to avoid a mid-air collision. Secondly their need to survive, to stick together is to survive. Birds are often not at the top of the food chain and as such having strength in numbers, is a key driving force behind their need to fly together as a single cohesive unit. Finally having so many eyes in the sky allows for a much larger search pattern with regards to searching out sources of food and spotting predators. With a couple of other advantages with regards to social interaction and mating also coming into to effect.

## How do they Work?

Now with a grounding into what they are, we can look at how. “In his 1999 paper ‘Steering Behaviours for Autonomous Characters,” Reynolds uses the word ‘Vehicle’ to describe his autonomous agents”. (Shiffman, D. 2012). Shiffman suggests that Reynolds took his inspiration from an Italian neuroscientist and cyberneticist ‘Valentino Braitenberg’. “in 1986, Valentino Braitenberg described a series of hypothetical vehicles with simple internal structures in his book ‘*Vehicles: Experiments in Synthetic Psychology’*. Braitenberg argues that his extraordinarily simple mechanical vehicles manifest behaviours such as fear, aggression, love, foresight and optimism. With Reynolds taking inspiration from Braitenberg” (Shiffman, D. 2012).

“Reynolds describes the motion of *idealized* vehicles (idealized because we are not concerned with the actual engineering of such vehicles, but simply assume that they exist and will respond to our rules) as a series of three layers - Action Selection, Steering and Locomotion” (Shiffman, D. 2012).

The first layer Reynolds discusses is ‘Action Selection’ and refers to that vehicles goal or goals. The Vehicle is also free to select an action or combination of actions to achieve these goals. The vehicle is able to perceive its local environment and decide upon an action based upon its desire.

Shiffman uses the example of a person who can see a zombie approaching them, the person does not wish to get eaten and as such steers away from the zombie and moves away. “Reynolds paper describes many goals and associated actions such as: seek a target, avoid an obstacle and follow a path” (Shiffman, D. 2012). This represent ‘Action Selection’ and involves strategy, goals and planning to achieve the desired outcome.

Now that the vehicle has a goal, or set of, its free to select an action, or combination of, based on the goal. This is the second layer and involves the vehicle calculating its next move, this involves using Reynolds steering force formula ‘***steering force = desired velocity – current velocity****’*. Whereby the vehicle calculates it steering force based on its desired velocity, a combination of its actions, and then subtracting that from its current velocity creating a steering force that equates to the combination of the action(s) it chose to take earlier.

The third and final step refers to Locomotion, the animation or articulation of the vehicle in question. “Locomotion is the bottom of the three-level behavioural hierarchy described above. The locomotion layer represents a character’s *embodiment*. It converts control signals from the *steering* layer into motion of the characters ‘body’” (Reynolds, C.W. 1999). This final layer doesn’t alter behaviour in any way, but rather involves the animation of the vehicle or character and how they respond based on the actions from the previous two layers.

## The Golden Rules of Boids (Flocking)

## Separation

“Separation: steer to avoid crowding local flockmates” (Reynolds, C.W. 2001). Separation refers to a boids will to avoid the space occupied by other local boids. “steering behaviour gives a character the ability to maintain a certain separation distance from other nearby” (Reynolds, C.W. 1999). This is useful to avoid overcrowding and can be increased or decreased based on a specified distance.

To calculate this behaviour, a ‘neighbourhood’ check is made, with a certain distance used to represent the boids ‘sight’ to calculate which boids are deemed neighbours. These neighbours are then checked against to see just how close they are. If any are too close, less that the ‘min neighbour distance’, “a repulsive force is computed by subtracting the positions of our character and the nearby character, normalising, and then applying a weight” (Reynolds, C.W. 1999).

## Alignment

“Alignment: steer towards the average heading of local flock mates” (Reynolds, C.W. 2001). Alignment refers to the accumulated direction of all neighbouring boids in relation to a given boids current heading, to calculate this value the boid must first identify its neighbours. Again a ‘neighbourhood’ check is made, with a certain distance used to represent the boids ‘sight’ to calculate which boids are again deemed neighbours. These ‘neighbours’ combined velocities are then added together and averaged out by the number of neighbours, thus creating a new average velocity or heading of the group.

“Alignment can be computed by finding all characters in the local neighbourhood, and averaging together the velocity. This average is the ‘Desired Velocity’, and so the steering vector is the difference between the average and our character’s current velocity” (Reynolds, C.W. 1999).

The steering behaviour this rule creates will lead the boid to turning and facing the same direction as its neighbours or ‘flock’, and thus head in the same general direction

## Cohesion

“Cohesion: steer to move towards the average position of local flockmates” (Reynolds, C.W. 2001). Cohesion represent a given boids ‘desire’ to form a group, to cohere and attracts agents pulling them in. Once again to begin a calculation for this behaviour, the ‘neighbourhood’ check needs to take place first, a central position within the given boids neighbours is the identified by adding all the positions together and averaging them out, thus creating our cohesion position. Reynolds relates this behaviour to that of a ‘magnet’ or ‘center of gravity’, pulling in the boid.

## Seek

Following on from cohesion is seek, seek used the position provided by Cohesion to form the attraction and can be calculated like so - ‘***Desired velocity = normalize (boid position – target positon’***. The ‘target’ is provided by cohesion, seek simply uses this information to calculate a given boids ‘desired velocity’ i.e. the position it wants to head towards, or goal.

## Other Behaviours

In Reynolds journal ‘Steering Behaviours for Autonomous Characters’ he discusses several other behaviours. These behaviours can be used to enhance the boids knowledge and ability to perceive its environment, and some of note include:

### Flee

Flee is one such example, “Flee is simply the inverse of ***Seek*** and acts to steer the character so that its velocity is radially aligned away from the target. The ***Desired Velocity*** points in the opposite direction” (Reynolds, C.W. 1999).

As Reynolds states this behaviour is simply an inverse of seek, and instead of acting as a magnet or center of gravity, its acts as a repelling force, like pushing the same poles of a magnet together.

### Pursuit

Pursuit acts in a similar manner to that of seek with one key difference, instead of heading towards a current positon, it moves towards a predicted position based on where it is currently and its velocity. “Pursuit is similar to seek except that the target is another moving character. Effective pursuit requires a prediction of the target’s future position” (Reynolds, C.W. 1999).

### Obstacle Avoidance

This behaviour is all about a given boids ability to, you guessed it, avoid obstacles. This behaviour can be seen as similar to ***Flee*** but with one key difference, flee will cause the boid to turn away regardless of the position of the other party relative to its own position and heading. Obstacle avoidance is slightly more advance in that it only triggers a response from a boid if that party lies directly in its path. Reynolds describes a scenario involving a car driving along a road, parallel to a wall. No response is triggered as the wall is not directly in its path. If the car had a flee behaviour it would pull away from the wall regardless of its position in relation to its forward facing direction.

“There is an important distinction between obstacle avoidance and flee behaviour. Flee will always cause a character to steer away from a given location, whereas obstacle avoidance takes action only when a nearby obstacle lies directly in front of the character” (Reynolds, C.W. 1999).

## Combining Behaviours

By mixing and matching individual behaviours hugely varied and diverse systems can be created and serve as building blocks to create much more specialised patterns and behaviours. For the creation of realistic and believable patterns to emerge, these behaviours need to be finely blended together to create the correct balance and desired outcome. One of the simplest ways to combine behaviours is by weighting. Each behaviour creates some form of value or output, and by multiplying the ‘importance’ of these behaviours together can lead to incredibly diverse patterns and wild changes with even the smallest weight changes.

Reynolds on behaviours - “They are components of a larger structure, like notes of a melody or words of a story” (Reynolds, C.W. 1999).

## Real World Examples

Batman Returns (1992) - Bat Swarms & armies of penguins

The Lion King (1994) - Simba Stampede Scene

The Matrix Revolutions (2003) - Attack on Zion

## Implementation

How I implemented it, talk about code structure ect

## Performance enhancement

Spatial partitioning?

Group Update (Behaviours)! Talk about what ive implemented to help aid performance

## Evaulation

What went well? What not so well? What could be changed improved?

References:

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