Realistic Autonomous Fish for Virtual Reality

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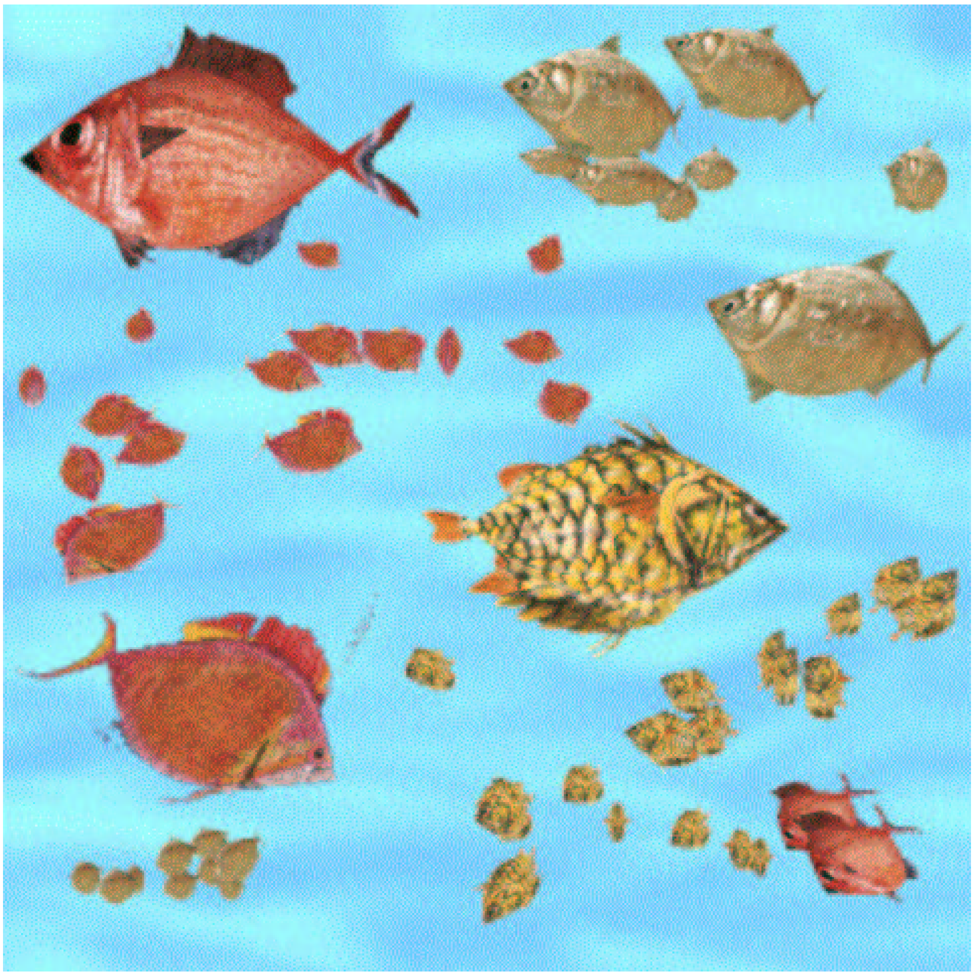

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Abstract

We create a library object, called *VRFish*, which is self contained and can be used with ease by virtual reality programmers to create diverse and interesting underwater environments.

⇒ *VRFish* is a fish library object which is non CPU intensive.

⇒ *VRFish* creates the 3D fish form procedurally. It uses a mathematical function to determine the body profile. The basic fin shape allows for a wide range of structures, and placements of fins. A number of different techniques have been implemented to obtain more realistic and interesting fins. These include semi-translucent fins of the original shape, and two different methods for masking the fin shape. The fish's form sufficiently approximates the true form of the fish to be realistic in appearance.

⇒ *VRFish* produces body animation by rotating the caudal, pelvic and pectoral fins back and forth.

⇒ *VRFish* implements a schooling algorithm to produce fish with realistic, non scripted swimming patterns. When fish of the same species are within the environment, they will swim together, acting as a cohesive whole, closely resembling a school of fish.

Keywords: Modeling, Rendering, Animating, Fish, Procedural Modeling.

Contents

Chapter 1

Introduction

Virtual Reality is a technique for creating a computer generated environment, intended to immerse the user in another world. The aim is to achieve another dimension which is indistinguishable from reality. Unfortunately we are far away from achieving this. Most of the virtual environments are simplistic and sparsely populated mainly due to the time required to create the inhabitants and background objects. There are very few libraries available to enable virtual environment programmers to produce interesting and diverse creatures within their new world without having to create and program the creatures and objects themselves.

The aim of this project is to provide a component for easily populating an interesting and diverse world. One of the virtual reality environments created in RHoVeR, the virtual reality system designed by the members of Rhodes Virtual Reality Special Interest Group, is Atlantis, where one can go swimming with the dolphins. It has water, dolphins and some seaweed, but what it really requires is other fish, a variety of fish which could be added and left to swim as they pleased. This is the inspiration for this project.

We want a fish library object which could be used to create a number of diverse fish. There is a need to create different fish species. But as it is meant to be a "plug and play" library object one should not expect the user to create the 3D fish form before using the object. The fish needs to be autonomous. We do not want the behaviour of the fish to be scripted as this will require programmer intervention whenever it is added to a new system or virtual environment.

The requirements of this project can therefore be summarized as follows:

- ⇒ A fish library object needs to be non CPU intensive in design, as it needs to be incorporated into a real-time virtual environment.
- ⇒ The objects must allow the creation of different types of fish (different in shape, size and colour), without the user needing to create, or obtain 3D fish models.

⇒ The fish’s form needs to be realistic in appearance.

⇒ The fish needs to have some body animation.

⇒ The fish needs realistic, non scripted swimming patterns.

We have called our fish library object *VRFish* and in the following chapters we will discuss related works which influenced this project, explain the design of the *VRFish* which enables us to fulfill these requirements, the methods we used in our implementation and finally we will present the results showing the success of the project.

Chapter 2

Related Work

As the project had two main areas of interest, we looked at the related works in these two areas. Firstly the modeling of the actual fish and any animation of the fish form, and then the group behaviour of the fish.

2.1 Modeling and animation of 3D models

There have been a number of different techniques proposed for modeling 3D forms. Some methods seem easy to implement, while others have a great deal of complexity and mathematics behind them which implies that they will be more CPU intensive.

One can use off the shelf 3D modeling packages such as NewTek's Lightwave 3D to create a model. There are many tutorials to be found on the WWW for creating and animating 3D forms using these well known packages [28]. One can also use data from models constructed by someone else. Proudfoot *et al.* [12] used data of a fish form, created by Terzopolous [23], quite successfully, and added bump-mapping to the body and transparent bump-mapping to the fins to produce a static scene of a fish. Fröhlich [6] used Softimage and Alias/Wavefront to create a textured polygonal geometry structure, which they animated by using the software tools and then storing a number of keyframes to be used by their system later on. The smooth animation of the individual fish is created using linear interpolation between corresponding vertices of each keyframe. They produced very realistic fish in their Virtual Oceanarium.

Creating 3D models using modeling packages is time consuming. Obtaining data for the fish model from someone else's research limits the choice of what is available. Therefore we do not feel that this is the best option.

Ebert [5] presents an alternative in procedural modeling. He defines procedural modeling as "code segments or algorithms used to abstract and encode the details of the model instead of explicitly storing vast numbers of low-level primitives". He goes on to state that the algorithm provides flexibility and removes the burden of low-level control from the modeler/animator and that using parametric control can provide a large amount of geometric detail. Procedural modeling therefore presents an attractive option for this project.

There are also many methods of constructing models with the ability to be deformed for animation. A physically based method is proposed by Miller [7] to create legless creatures such as snakes and worms. The creatures are modeled using a mass-spring system. To simulate the contraction of the muscles, Miller animates the spring tensions. Sederberg [16] uses free-form deformation based on Bernstein polynomials, which can be applied to any surface primitives. Terzopoulos *et. al.* [21] proposes an elastically deformable model. By solving the differential equations that underly the model they create realistic animations. In Turner and Gobbetti's paper [24] they state that physics-based deformations derived from elastic and viscous properties of continuous media can produce realistic looking simulations but can be difficult to control. Platt and Barr [13] proposed methods using mathematical constraints based on physics and optimization theory to create and control physically based flexible models. Chadwick *et. al.* [3] propose a layered construction approach to create deformable animated creatures, where the creatures are built in layers with the relationship between the layers being specified by parametric constraints. Terzopoulos[20] uses an image-based modeling techniques to convert photographs of real fish into 3D B-splines, which he then textures. To achieve the texturing he uses a snake-grid tool to obtain the nonuniform coordinate system for mapping the texture onto the spline surface. He then creates the muscles for the locomotion using 23 nodal point masses and 91 springs. Twelve of the springs running the length of the body also serve as simple muscles. The spring-mass model use Lagrange Equations to control the movement [23].

Although using physically based models produces realistic creatures, the models are by nature complex to implement and normally are computationally intensive.

2.2 Schooling behaviour

The flocking algorithm for bird objects first created by Craig W Reynolds [15] is the obvious one to base fish schooling behaviour on. Reynold creates an approach which uses simulation as an alternative to scripting the path of the birds individually. Scripting a path for each bird within a flock using traditional computer animation techniques is tedious and makes the animation rather static. Reynolds states that the behaviour of a flock is simply the result of the interaction between the behaviours of the individuals.

Reynolds bases his method on Reeves' particle systems [14]. Particle systems are collections of large numbers of individual particles, where each particle has its own behaviour and properties.

Particle systems are used to represent dynamic "fuzzy objects" which have an irregular and complex shape. Particle systems are used to model fire, smoke, and clouds. Reynolds replaced the simple dot-like particle of Reeves particle system with an entire complex geometrical object consisting of a full local coordinate system and a reference to a geometrical shape model. He also adds an orientation attribute to the particles. The particles in the particle system, as presented by Reeves, do not interact with one another. In nature birds do, and hence the objects in Reynolds' flock must interact with each other in order to flock correctly.

Reynolds names his objects boids (short for bird objects). Each boid's behaviour is dependent on an internal state and an external state, the internal state being its own location, direction and velocity, the external state includes the location and state of the other boids as well as any other objects which have to be avoided in the environment.

Reynolds states that natural flocks never seem to get overloaded, or obtain a maximum flock size. This implies that the individual bird does not pay attention to every single bird within its flock. A bird might be aware of three categories: itself, its two or three nearest neighbours, and the rest of the flock [11]. Hence when creating a simulation the boid should only concentrate on its immediate neighbours.

To build a simulated flock, Reynolds starts with a boid model that supports geometric flight. He adds behaviours that correspond to the opposing forces of collision avoidance and the urge to join the flock. Stated briefly as rules, and in order of decreasing precedence, the behaviours that lead to simulated flocking are:

- ⇒ Collision Avoidance: avoid collisions with nearby flock-mates. This is based on the relative position of the surrounding boids
- ⇒ Velocity Matching: attempt to match velocity with nearby flock-mates. Velocity is a vector quantity and refers to the combination of direction and speed.
- ⇒ Flock Centering: attempt to stay close to nearby flock-mates. Each boid tries to get near the center of the flock. Because each boid should have a localized perception of the world "center of the flock" actually means the center of the nearby flock-mates.

In nature flocks sometimes divide to go around obstacles. As long as the individual boid stays close to its close neighbours, it does not care if the rest of the flock splits off. More simplistic models proposed for flock organization, such as central force model or a follow the designated leader model, do not allow splits.

Each of the rules produce a suggested direction in which to steer the boid. Each rule has an associated fractional "strength". The boid has to collect the different suggested directions, combine, prioritize and arbitrate between potentially conflicting urges. One could use some artificial intelligence algorithm to do this, but an easier way is simply to average them.

Reynold's Boid software was written in Symbolic Common Lisp. With a flock of 80 boids, on a single Lisp Machine without any special hardware accelerators, the simulation runs for about 95 seconds per frame.

Conrad Parker [10] has suggested a simplified version of Reynolds boid algorithm. His algorithm involves simple vector operations on the positions of the boid. Each of the boid rules work independently and produce a vector. The first rule: staying a safe distance from its neighbours, looks at all the boids in the environment. If the boid is within a specified small distance then the current boid needs to move an equal distance, but in the opposite direction. The second rule: Match velocity, calculate the perceived velocity and add a small proportion of it to the boid's current velocity. Perceived velocity can be defined as the velocity of all the boids, excluding the velocity of the current boid. The third rule: Fly towards the center, find the perceived average position of all the boids and return a fraction of it. Parker suggests that it might be a good idea to use non-constant multipliers for each of the rules, allowing the influence to be varied over the course of the simulation.

Terzopoulos *et. al.* [22] use a much more complex behaviour algorithm for their artificial marine life. They use computer vision algorithms to enable their creatures to "see", and learning algorithms to allow them to gain complex motor skills similar to trained marine mammals.

Their behaviour model is controlled by an intention generator. The intention generator obtains information about the fish's habits, mental state and incoming sensory information and then issues an intention. Its will then choose and execute a behaviour routine. The purpose of the behaviour routine is to bring the fish one step closer to fulfilling the intention during the current time step.

The innate character of the fish is specified by a set of mental variables, with the value range [0;1]. The closer to one the value is, the higher the urge of that particular mental state.

Terzopoulos *et. al.*'s behaviour routines include *avoiding-static-obstacles, avoiding-fish, eating-food, mating*, *wandering*, *leaving*, *escaping* and *schooling.*

2.3 Summary

For this project we want a fish which would not be CPU intensive but would be believable. The overall concept for this project is to create a library object which can be added to a virtual reality environment with minimal programmer time and effort. This means that expecting the programmer to create or find a new fish form for each different species of fish he /she wishes to add to the environment is not an option. We feel that the procedural modeling presents the best option for creating the 3D fish model. It offers a simple model, which will not be computationally intensive during run-time, but will allow a great level of flexibility for the model shape.

For the behaviour we have taken ideas from both Reynolds flocking algorithm and Terzopoulos's behaviour model. We implement a minimalistic flocking algorithm, and a wandering procedure. We believe this to be sufficient for this project, although we realize that the behaviour model could be improved upon by including more behaviour routines.

Chapter 3

Background Material

In this chapter we give a brief overview of the system in which our fish object has been implemented, followed by the background material required for those readers who are not familiar with OpenGL.

3.1 RhoVeR, version GreatDane

Our fish object, which we will refer to as *VRFish*, is implemented in RhoVeR, the virtual reality system designed by the Rhodes Virtual Reality Special Interest Group. RhoVeR was developed to serve as a platform for developing virtual environments and testing critical aspects of Virtual Reality.

The current version of RhoVeR, called GreatDane is a Java implementation under Linux. It has a Java module called GL which uses native C calls to incorporate OpenGL for rendering.

GreatDane maintains a database of all objects in the current environment. This database has a list of properties for each objects, such as a string identifier to specify the type of object, the velocity, location and orientation of the object.

3.2 OpenGL

This section can be skipped over by OpenGL experts.

3.2.1 Primitives

When using OpenGL a 3D model has to be constructed out of a small set of geometric primitives — points, lines and polygons. These primitives are specified by their vertices. The polygons must be simple (i.e. they cannot intersect), and they must be convex (i.e. given two points in the interior of the polygon, the line segment joining them must also be in the interior.) The triangle is by definition simple and planar and is therefore used within this project.

3.2.2 Lighting

OpenGL approximates light and lighting as if light can be broken into red, green, and blue components. Therefore, the colour of light sources is characterized by the amount of red, green, and blue light they emit, and the material of surfaces is characterized by the percentage of the incoming red, green, and blue components that are reflected in various directions.

The colours across the face of a smooth-shaded polygon are determined by the colours calculated for the vertices. The normal vectors at the vertex determine the orientation of the object relative to the light source and therefore control the intensity of the highlight at the particular vertex. Therefore any surface should be created out of a number of smaller polygons rather than larger ones.

3.2.3 Colour

One can specify colour in RGB or RGBA mode. The three component colour, RGB specifies the Red, Green and Blue for the colour. In the four component colour, RGBA there is a fourth value which is called the alpha value. The alpha value does not correspond to a visible colour, but can be thought of as the opacity value.

3.2.4 Buffers

A buffer is the storage of data for each pixel. Within a given buffer each pixel is assigned the same amount of data per pixel. The OpenGL system can manipulate the following buffers: Colour, Depth, Stencil and Accumulation [1] [9].

3.2.5 Rendering an image in OpenGL

To render an image OpenGL performs the major graphics operations in the following order:

1. Construction of the shapes from geometric primitives.
2. Arrangement of these shapes in 3D space, and selection of a vantage point for viewing the scene.
3. Calculation of the colour of all the shapes. The colour might be explicitly assigned, determined from specific lighting conditions or obtained by texturing the surface.
4. Conversion of the geometric primitives making up the shapes and the associated colour information to pixels on the screen.

After the image has gone through these four stages, but before the image is drawn on to the screen, the pixel data can be manipulated [1] [9]. Before the data is finally written it undergoes a series of tests or operations which determine if is to be written. If the fragment is eliminated in an early test, none of the later tests take place on that particular fragment.

The tests are performed in the following sequence [9] :

1. Scissor test
2. Alpha Test
3. Stencil Test
4. Depth Test
5. Blending
6. Dithering

We are only going to discuss two of the tests which are of particular interest to this project, namely the alpha test and the stencil test. More detail about these tests can be found in any OpenGL handbook.

3.2.5.1 Alpha Test

The alpha test compares the incoming fragment's alpha value to a constant. The comparison function used can be set to always accept the fragment, never accept the fragment, or to accept it depending on the value of the fragment's alpha compared to the reference value. [26]. If the fragment passes the test then it will be processed by subsequent fragment tests, otherwise it will be discarded. The alpha test provides a means to reject the fragment as early as possible in order to reduce the memory traffic due to stencil, depth and colour buffer reads and writes [4].

3.2.5.2 Stencil Test

The stencil test compares a reference value with the value stored at a pixel in the stencil buffer. The value in the stencil buffer is modified depending on the result of the test. The comparison function, reference value and new value or mask can be set [9] using:

```
glStencilFunc(func, ref, mask)
```

where *func* sets the comparison function, *ref* is the reference value and *mask* is used in the stencil test.

The stencil value for the target pixel is first masked against the current stencil mask, then compared against the current stencil reference value, using the current stencil comparison function [17].

The function:

```
glStencilOp(fail, zfail, zpass)
```

specifies what happens to the data if the test is passed or failed. *fail* occurs when the fragment fails the stencil test. If it passes the stencil test the depth test is then applied. If the depth test passes then *zpass* is applied, and if the depth test fails then the *zfail* is applied.

If the test fails, then the fragment for the pixel is discarded, and the colour and depth values remain unchanged.

The alpha test and stencil tests are used in the rendering method discussed in **Chapter 5 Section 5.2.2**

Chapter 4

Design and implementation

VRFish has to be "plug and play". We do not want the user to have to create or obtain a 3D model of a fish before using *VRFish*. But we also want to be able to allow for variety. So we create the 3D model procedurally instead of creating it using 3D modeling software or using data from someone else's work. In order to allow for variety, there are many parameters which are specified by the user. These parameters are stored in a ASCII file, which we will refer to as the parameter file. An example of a complete parameter file can be found in Appendix A.

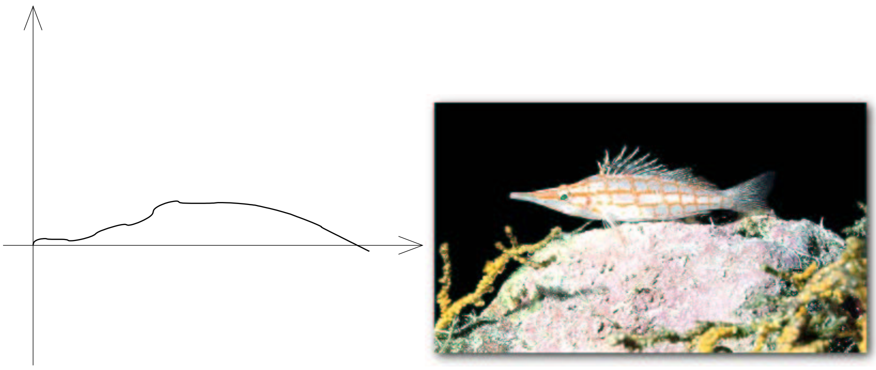
In this chapter we will explain what values are required and why they are required. Most values in the parameter files are expected to be double values. Currently the user is required to set up the values in the parameter file, using a trial-and-error method, in order to create the fish he/she desires. We believe that it would not be difficult to set up a GUI application to aid in this process.

The design, motivations and some relevant implementation details are covered in this chapter for the construction of the fish model.

4.1 Body

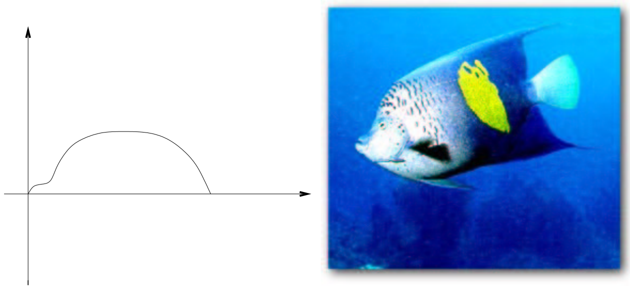
The body is represented by a rigid model, which currently does not allow any deformations. It is constructed by rotating a mathematical function around the x-axis to obtain a closed surface. Any a mathematical function which is closed in the region $0 \leq x \leq 1$ can be used. There is an abstract *FishShapeFunction* class which the classes in *VRFish* use. The name of the actual implementation of this class is specified in the parameter file, to allow for the user to select which mathematical function best describes their choice of body shape.

We have only implemented one child class of *FishShapeFunction* at this stage. *FishShapeSin*



(a) Graph of Body Shape (b) Hawk Fish

Figure 4.1: Body Shape for the Hawk fish



(a) Angel Fish

Figure 4.2: Body Shape for the Angel fish

which implements a sine curve. We elected to use this function as it approximates the body shape of a large number of fish.

There are many different types of fish body shapes and we want to allow the *VRFish* to be easily extended to incorporate more of them. For example one can see the body shape for the Hawk and Angel fish. The graph in **Figure 4.1** could be used in order to get the shape for the Hawk fish, similarly the graph in **Figure 4.2** to achieve the top half of the body for the Angel fish.

One could use a cubic spline interpolation [2] to approximate the curve of the shape of the body and to create additional subclasses of *FishShapeFunction* class. This would allow a wider variety of different body shapes to be created using *VRFish*, within the same environment. We feel that by implementing one, it is sufficient for proof of concept.

The user specifies two values which control the level of detail of the fish. The two values, which we will called BodySections and CircleSections, control how many points are used in the creation of the surface and therefore how closely the end shape approximates the true mathematical surface which has been specified in the *FishShapeFunction's* subclass. **Figure 4.5** shows some different levels of detail. The triangles are drawn on the body to show the level of detail.

Although we have not implemented a change in the level of detail during run-time, it is theoretically possible to recalculate the body points during run-time to allow for fish of a lower level of detail, when the fish is far away from the viewer. This will improve performance when the fish is a large distance from the viewer.

The BodySection specifies the number of sections the function is divided into along the x-axis. Each of these *x*-values are then used to calculate the height of the function at that *x*-value. This height forms the radius of the circle as this point is rotated around the x-axis.

The CircleSections specify how many sections the circle is then divided into. The points on the circumference of the circle at each circle section are then calculated. These points are used to specify the vertices of the triangles which make up the surface of our fish in OpenGL. We will call these points BodyPoints

To calculate the points for the body we use the following algorithm:

```
for (j = 0; j < BodySections; j++) {
     x_j = j / (BodySections-1);
     y_j = sin(x_j);
     for (i = 0; i<CircleSections; i++){
         angle = (i )/(BodySections)
         y_i = sin(angle) * y_j
         z_i = cos(angle) * y_j
         pointsList[j][i] = (x_j, y_i , z_i)
      }//i
}//j
```

Once all the points are calculated they need to be grouped to form triangles which can be used in the rendering process (**Figure 4.3**).

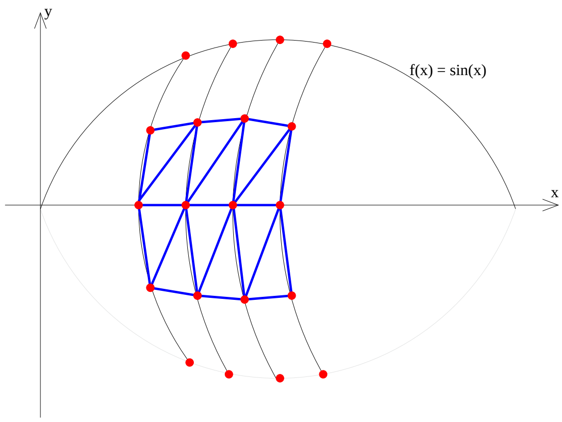


Figure 4.3: Surface of Triangles

To create the triangles the following algorithm is used:

```
p = 0
q = 0
for (j=0;j<(BodySections-1);j++){
     for (i=0;i<CircleSections;i++){
          p=i+1
          if (p >(CircleSections-1)) {
              p=0
          }
         triangle_q(pointsList[j+1][p],pointsList[j+1][i],pointsList[j][i])
         q ++
         triangle_q(pointsList[j][i],pointsList[j][p],pointsList[j+1][p])
     }//i
}//j
```

Once the triangles have been created, a surface normal needs to be calculated for each point to ensure correct lighting in OpenGL. For a particular point all the surrounding triangles need to have their surface normals calculated and then these surface normals are averaged to get the surface normal at that point. To calculate the normal for a triangle, two vectors are found tangent to the surface, the dot product of these two vectors is perpendicular to both, and is therefore perpendicular to the triangle. Two sides of the triangle are tangent to the the surface [9] and are therefore used. It is a good idea to normalize the resulting normal vector. Normalizing a vector produces a vector parallel to the original, but of unit length.

In **Figure 4.4** to calculate the normal at point A, the normal vectors are found for the triangles 1 through to 6, and then averaged.

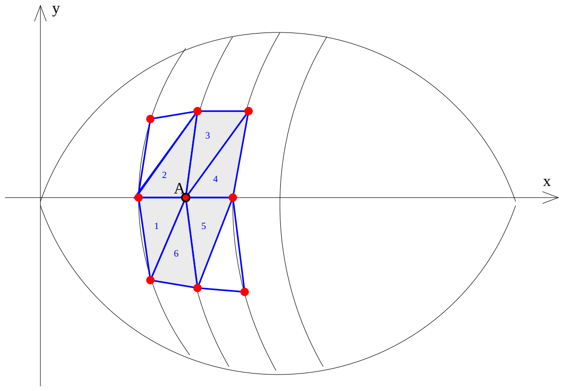
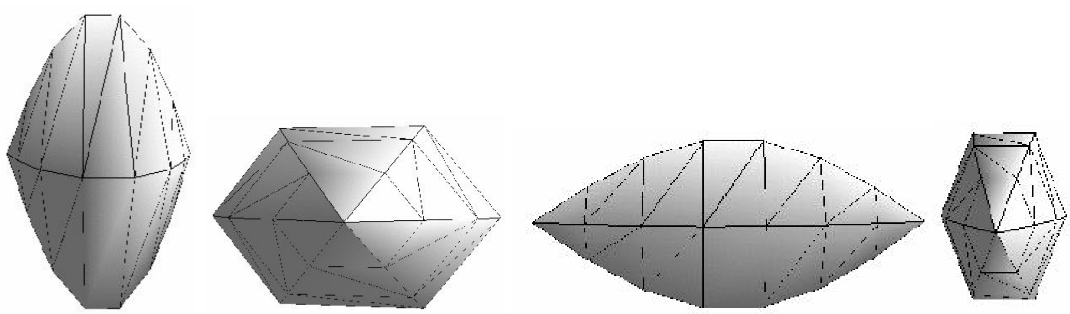


Figure 4.4: Calculation of Normals

We use a *VRTriangle* class which stores the BodyPoints, the corresponding normal vectors and the matching texture points (discussed in **Chapter 5, Section 5.1**) for the triangles.

Each of the BodySections is circular, and the length of the body is between 0 and 1. This can produce a very short, fat body. To adjust the proportions we have included 3 scaling factors, one for the each of the *x, y,* and *z* directions. The user specifies these in the parameter file. (See **Figure 4.6**)

There is also another scaling factor which affects the entire fish size. When registering the *VRFish* with the GreatDane database, one includes an object world scale. We incorporate some randomness at this point, and make this world scale using random numbers. This means that as the fish are created within an environment their sizes will differ slightly.



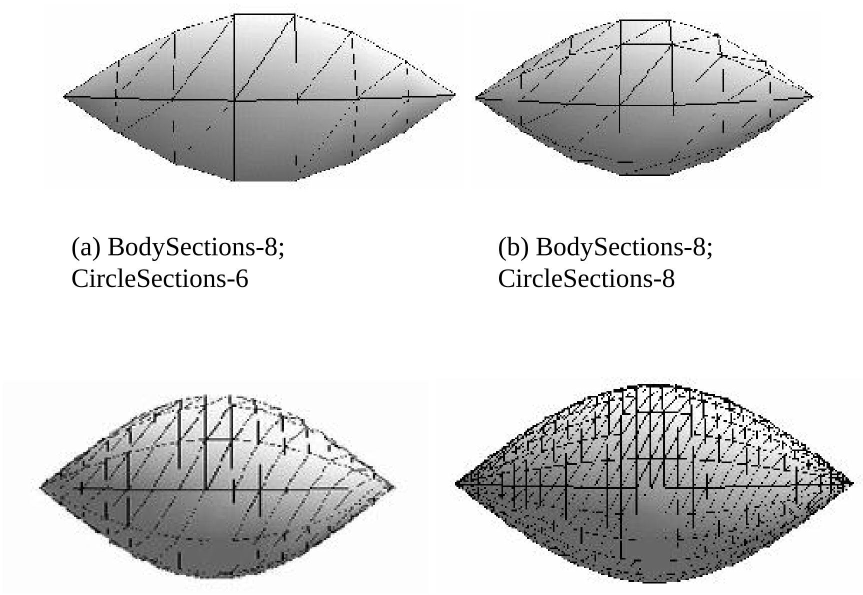
(a) Body Length without scaling

(b) Body Front without scaling

(c) Body Length with scaling

(d) Body Front with scaling

Figure 4.6: Body with and without scaling factors applied



(a) BodySections-8; CircleSections-6

(b) BodySections-8; CircleSections-8

(c) BodySections-16; CircleSections-12

(d) BodySections-32; CircleSections-24

Figure 4.5: Body using different levels of details

4.2 Fins

Figure 4.7 shows the fins of a fish. In nature there is a wide variation in shape and placement of these fins, as can be seen in **Figure 4.8.** The design of the fins allows for this wide diversity.

4.2.1 Caudal Fin

The caudal fin (the tail) is made up of two sets of triangles. The number of triangles, or level of detail is specified by the user. The shape of the caudal fin is controlled by six user specified values. These are: the length of the top, middle and bottom lines, the top angle which is the angle the top makes with the middle line, the bottom angle which which is the angle the bottom makes with the middle line. These can be seen in **Figure 4.9.**

The triangles are formed using linear interpolation to obtain the other two points on the line formed by joining the end points of the top and middle line. (Similarly on the middle and bottom line.)

We believe this allows for a great number of differently shaped caudal fins. (See **Figure 4.10** for some variations).

Figure 4.10 shows some variations in the shape of the caudal fin, depending on the parameters.

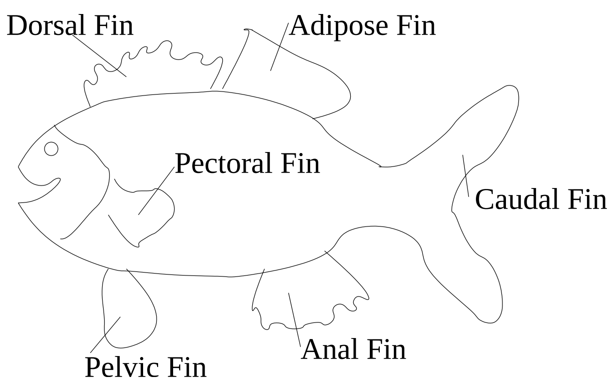
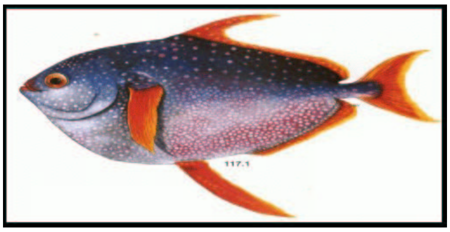
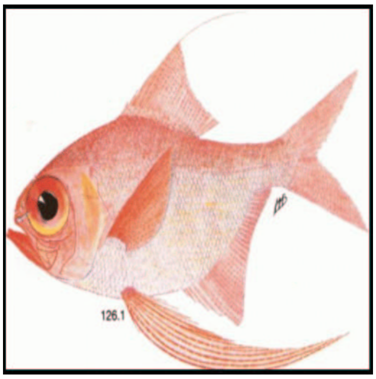


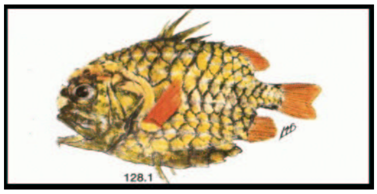
Figure 4.7: Fish Anatomy



(a) Lampris guttatus (Spotted opah)



(b) Beryx decadactylus (Beryx)



(c) Monocentris Japonicus (Pineapple fish)

Figure 4.8: Fin Shapes in Nature [18]

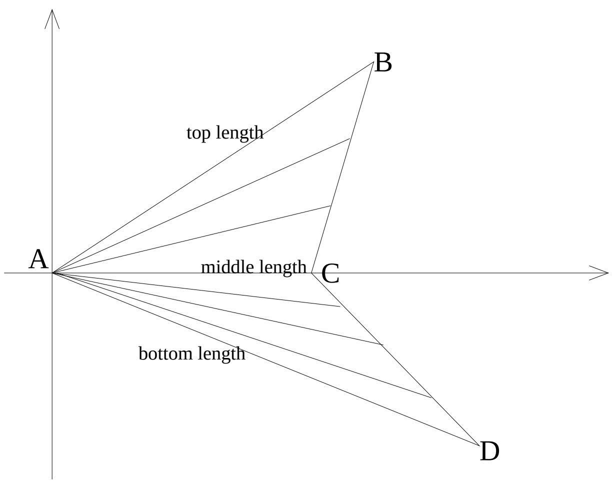
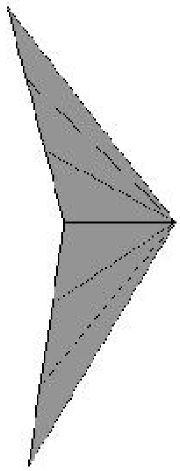
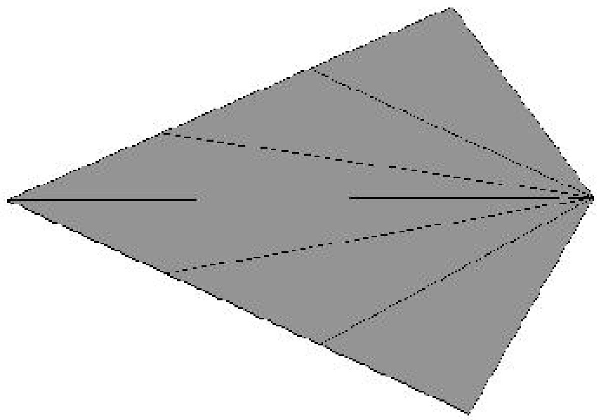


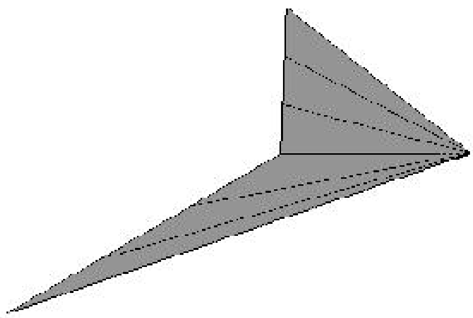
Figure 4.9: Caudal Fin Structure



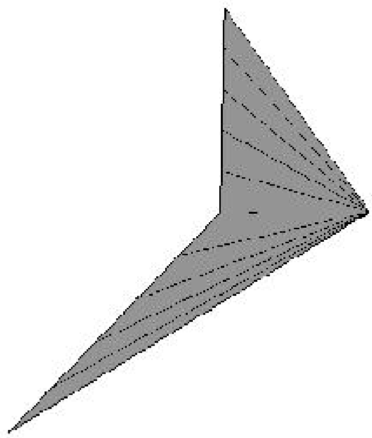
(a) 0.75; 0.13; 75.0; 3.0; 0.83; 78.0; 3.0



(b) 0.75; 0.77; 75.0; 3.0; 0.83; 78.0; 3.0

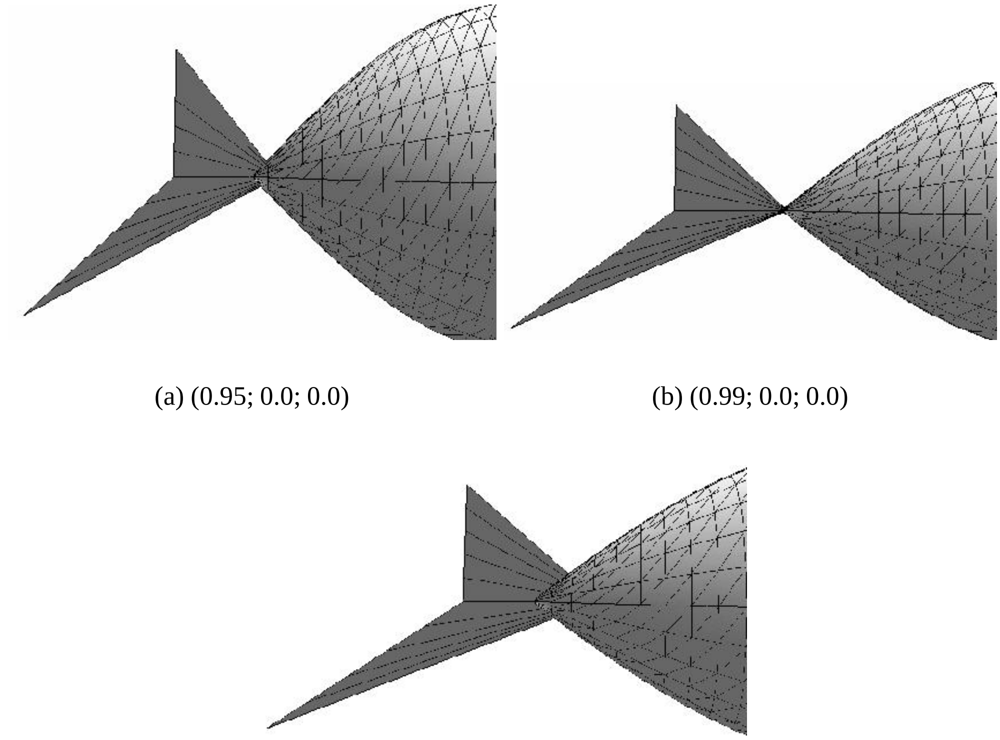


(c) 0.75; 0.2; 75.0; 3.0; 0.9; 58.0; 3.0



(d) 0.75; 0.2; 75.0; 5.0; 0.9; 58.0; 5.0

Figure 4.10: Caudal fin: Parameters in the following order: Bottom line; Middle line; Top angle; Top triangles; Bottom line; Bottom angle; Bottom triangles.



(a) (0.95; 0.0; 0.0)

(b) (0.99; 0.0; 0.0)

(c) (0.90; 0.0; 0.0)

Figure 4.11: Caudal fin in different positions: Position given as (x; y; z)

The caudal fin is formed at the origin and then translated into position. The exact position is specified by the user as a 3D point. This allows the user to vary the thickness of the body-tail section. (**Figure 4.11** shows some different locations for the caudal fin.)

4.2.2 Vertical Fins

The vertical fins, namely the dorsal, adipose and anal fins use the same design structure, but each need their own specified values in the parameter file. When designing these fins we want to allow for diversity, and to have an end shape which appears curved, angular or straight. The fin is created in the position desired. The user chooses where along the body the fin is placed by specifying the start and end BodySections the fin is to span. The level of detail of these fins is therefore limited by the level of detail of the body.

The fin is vertical at the top or bottom of the fish, where $z = 0$. To control the shape the user specifies the length of the start and end lines, and the angle made by the start line with the horizontal line. The curve of the fin is controlled by a value we call the proportion, and is also specified by the user. The proportion specifies how far up along the side of the previous triangle

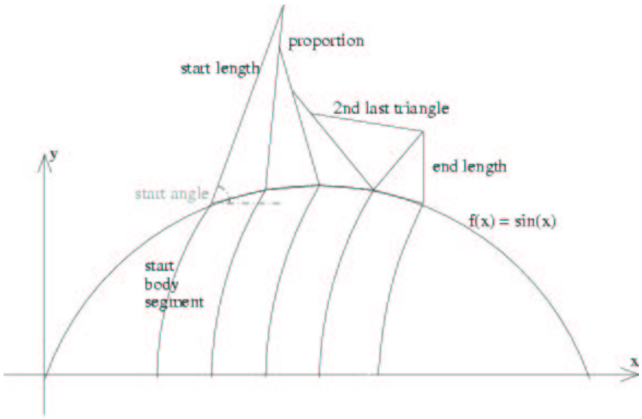


Figure 4.12: Vertical Fin Structure

the top vertex of the current triangle is placed. The end angle is always a ninety degree angle. **Figure 4.12** shows the structure of the vertical fin.

Using this structure the fins shape can be varied a great deal. The dorsal and adipose fins can be placed so that they form one long fin if so desired. **Figure 4.13** shows some variations of the dorsal fin.

4.2.3 Pectoral Fin

The pectoral fin is designed along the same lines as the vertical fin, but is slightly less complex. The level of detail is linked to the CircleSections but is specified as a number of triangles. As each triangle spans a CircleSection the user needs to ensure that the CircleSection from the body and the number of triangles the pectoral fin uses are related. At this stage there is no check — if the user specifies a larger number of triangles then the fin will appear to wrap around the body.

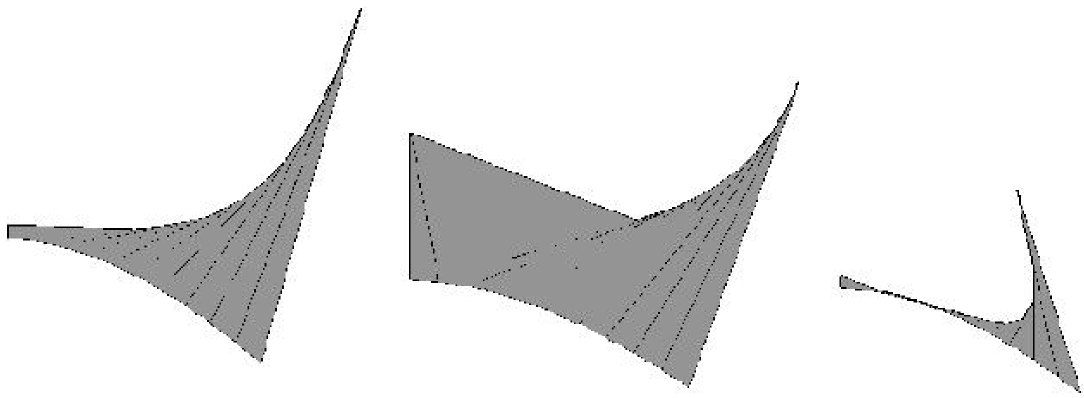
The user controls where along the length of the body the fin is to be placed by specifying the starting BodySection. The start of the fin is specified by the start CircleSection, and the curve of the fin is controlled by the proportion where one triangle joins the next.

The other user dependent values are the length of the first side, and the angle which this line makes with the horizontal.

The user enters only the values for the left fin as the right fin is a mirror image of the left fin.

Figure 4.14 shows the structure of the pectoral fin.

Figure 4.15 shows some variation in shape of the pectoral fin.



(a) 6.0; 16.0; 1.5; 0.05; 95.0; 0.8

(b) 6.0; 16.0; 1.5; 0.7; 95.0; 0.9

(c) 6.0; 16.0; 1.0; 0.05; 85.0; 0.6

Figure 4.13: Vertical Fin: Parameters in the following order: Starting BodySection; End BodySection; Starting line; End Line; Starting angle; Proportion

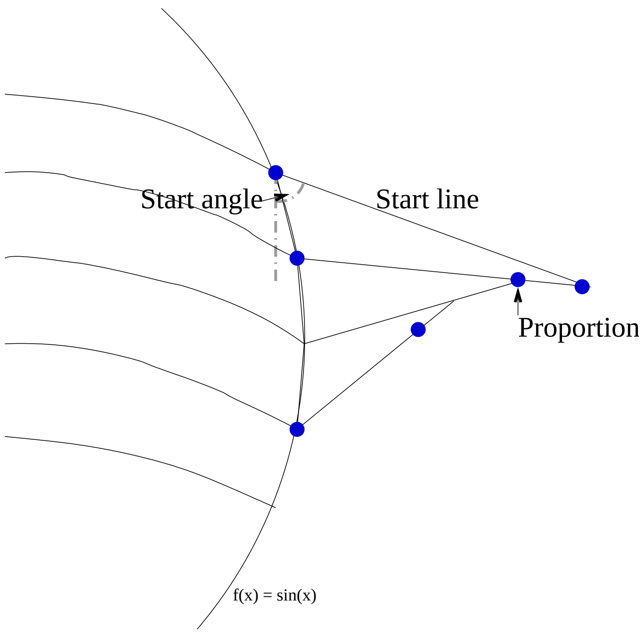
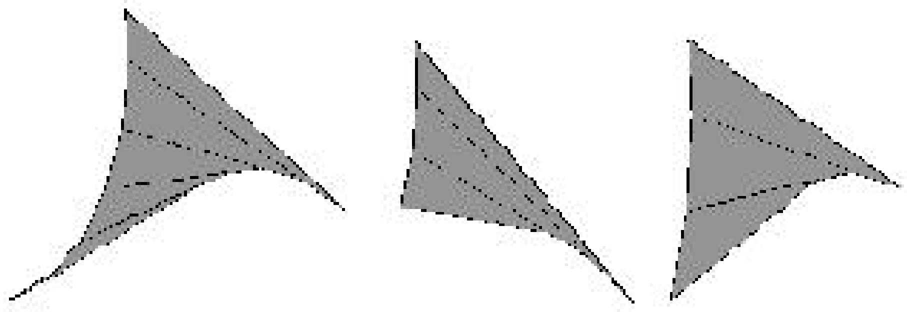


Figure 4.14: Structure of the pectoral fin



(a) 10.0; 2.0; 6.0; 1.1; 30.0; 0.8

(b) 10.0; 2.0; 3.0; 1.5; 30.0; 0.8

(c) 10.0; 2.0; 3.0; 1.0; 15.0; 0.8

Figure 4.15: Pectoral fin: Parameters in the following order: Starting BodySection; Starting CircleSection; No. of triangles; Starting length Starting angle; Proportion

4.2.4 Pelvic Fin

The pelvic fin needs a different structure as it shape seems to differ considerably from the other fins. We want to allow for short fins, or long flowing ones.

The user specifies where along the body the fin it is placed, by giving the BodySection at which it will start. The vertical placement is specified by which CircleSection it must be placed on, and the level of detail is determined by the BodySection on which the fin terminates.

The shape and size is controlled by specifying the length of the line joining B and C in **Figure 4.16,** the length of the end line (line joining F and H in **Figure 4.16)** and the angle that the end line makes with the horizontal.

If one uses this shape as the final product, the fin shapes which can be represented here are fairly limited. However, when it is used in conjunction with the masking methods (discussed in a later chapter), it provides a great flexibility for long, or unusually shaped pelvic fins.

Once again the user is only required to enter the values for the left fin.

4.2.5 Parameter file

Other parameters pertaining to the fish form which we have not yet mentioned are the starting position of the fish, its default colour and various other parameters used for testing purposes (these have been left in for historical reasons). In the Appendix A the test parameters have the suffix _t behind their description to indicate that they fall into this category. The starting

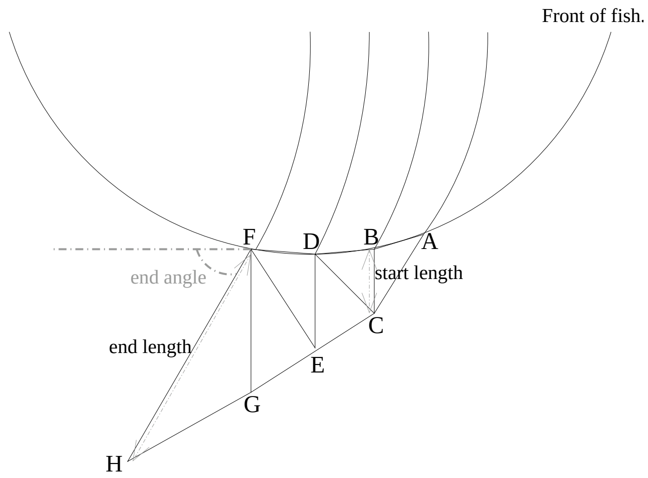
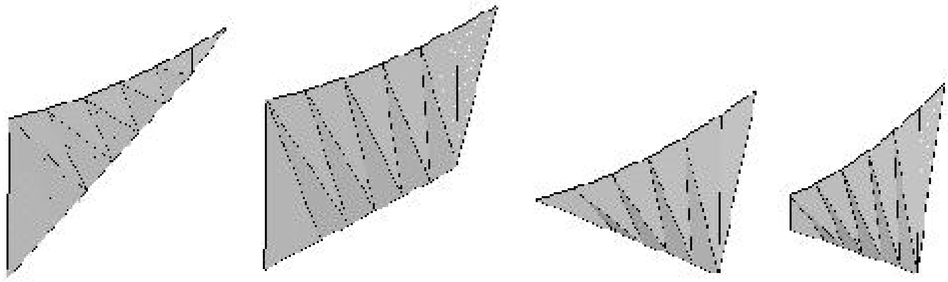


Figure 4.16: Pelvic Fin Structure

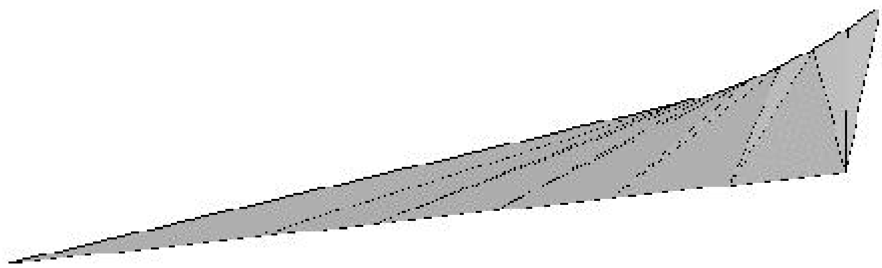


(a) 18.0; 8.0; 14.0; 0.1; 0.6; 90.0

(b) 18.0; 8.0; 14.0; 0.5; 0.6; 90.0;

(c) 18.0; 8.0; 14.0; 0.5; 0.0; 90.0;

(d) 18.0; 8.0; 14.0; 0.5; 0.1; 90.0



(e) 18.0; 8.0; 14.0; 0.1; 0.5; 0.8; 40.0

Figure 4.17: Pelvic fin: Parameters in the following order: Start CircleSection; Start BodySection; End BodySection; Starting length; End length; End angle.

position consists of three numbers for x, y, z. The default colour is stipulated in RGB, so it has 3 numbers, between and including 0 and 1.

There is a lot of information in the parameter file. Not all the different objects within *VRFish* require all the information. *VRFishInfo* reads the parameter file and then creates a number of Information objects. Each object therefore only has information pertaining to one area. For example *VRFishInfo* creates several *VRFinInfo* objects, each *VRFinInfo* contains the parameter values for one fin. This prevents redundancy of information allowing only the required information to be passed to the objects which make up the fish.

4.2.6 Schools

To create a school of fish we have the *VRSchool* class. *VRSchool* uses *VRFishInfo* to read in the parameter file as described above. The file is read in only once. *VRSchool* can then alter the information objects created in *VRFishInfo*, to incorporate some variations for each of the fish within a school. After each set of changes it creates a fish with the altered information object. Although all of the user parameters can be changed we only change to the starting position of the fish at this stage. We spread the fish out along a straight line within the environment.

We use the *VRFishViewer* class to display the fish for testing purposes. When starting *VRFishViewer* the number of fish per school is supplied, together with all parameter file names required. Any number of parameter files can be included at this point, allowing any number of different fish species to be included in the environment. All schools will have the same number of fish within them. Fish only school with their own species.

4.2.7 Summary

The 3D fish model is procedural, with user-specified parameters controlling the shape, size and level of detail of the body shape and fins. The design is such that it allows a great amount of flexibility, without the user having to create the form in another package, or obtain a form from somewhere else. Although the individual components which make up the body cannot be deformed at present, this is not ruled out in theory. The points which make up the surface are accessible and therefore, could be manipulated in some way to create deformations of the structure.

The only animation of the fish form which is currently implement is the movement of the fins. This is discussed in **Chapter 7 Section 7.1**.

Schools of these fish are created in *VRSchool* and viewed through *VRFishViewer*.

A simplified UML type model of *VRFish* can be found in the appendix C.

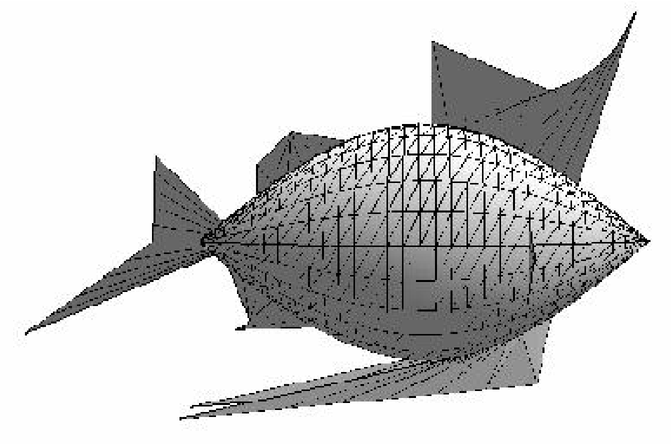


Figure 4.18: Complete Fish Structure

Chapter 5

Rendering

VRFish is created and rendered in a default colour. We add texturing, and different rendering effects to the fins in order to obtain a more interesting and realistic fish. We have implemented four different rendering effects for the fins, but at this stage the fin method to be used has to be decided on at compile time. There are various *VRFin* classes, which can be copied over the *VRFin.java* file and then compiled into *VRFish*. It might be desirable to change this so that the user can specify which which fin method to use at run-time by including a corresponding choice variable in the parameter file.

We first discuss texturing, and then the different fin methods, namely blending, stencil, alpha, and finally, the stencil and alpha method. The last two can grouped together as masking techniques as both produce a "cutout" from the fin structure shape. Performance of these rendering methods are presented in **Chapter 8**)

5.1 Texturing

An important point to remember when texturing is that the height and width of the texture image must be a power of 2 (2, 4, 8, 16, ...).

In order to do texturing every point in the 3D form needs to be mapped to a corresponding 2D point in the texture file. A stand alone application called *Fixel* aids in the calculation of these points for *VRFish*. *Fixel* is discussed in more detail in **Chapter 6**. *Fixel* outputs the texture points to an ASCII file. These points are then copied into the parameter file.

For the body we do not want the default body colour to influence, or to alter the texture colour. The DECAL parameter is therefore used in setting the texture environment variable for OpenGL. Initially we did the same for the fins, but then replaced this with other techniques which are discussed in the section following this one.

The algorithm used is as follows:

```
Load the texture
Enable texturing
Enable (GL_TEXTURE_2D);
Select the texture
       BindTexture (GL_TEXTURE_2D, textureID);
Set the drawing mode so that the textured triangles are drawn
using the colours from the texture map. Use DECAL so that it
overwrites the colour the surface was originally drawn in.
       TexEnvf (GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_DECAL);
Enable Gouraud Shading by setting the ShadeModel to GL_SMOOTH
       ShadeModel(GL_SMOOTH);
Draw the shape setting the texture coordinates, normals and
vertices, in that order
       TexCoord2f(tx,ty);
       Normal3f(nx,ny,nz);
       Vertex3f (x,y,z);
Disable the enabled modes to reset environment.
```

This texturing is adequate for the rendering of the body, but additional techniques are required for the rendering of the fins.

5.2 Fin rendering techniques

To achieve more interesting fins, we implemented and test differented rendering techniques.

5.2.1 Blending

Our first method attempts to obtain semi-translucent fins. To achieve this we use the blending function in OpenGL.

When setting the texture environmental variables in OpenGL we specify the way in which the incoming texture colour must be combined with the colour which is already there.

When using the MODULATE parameter, together with specifying the colours of the texture in RGB mode, we obtain

$$\text{colour}_{final} = \text{colour}_{texture} * \text{colour}_{fragment} \text{ ,}$$

$$\text{alpha}_{final} = \text{alpha}_{texture} * \text{alpha}_{fragment}.$$

Since we are using RGB mode we need to set the alpha value, which we set to 0.5.

If one attempts to use the RGBA mode for specifying the texture colours, it influences the texturing of the body, and produces undesirable effects in the rendering of the body. This is due to the fact that when using RGBA mode for the colour DECAL uses the following formulae

$$\text{colour}_{final} = (1\text{-alpha}_{texture})\text{*Colour}_{fragment} + \text{alpha}_{texture}\text{*colour}_{texture} \; ,$$

$$\text{alpha}_{final} = \text{alpha}_{fragment} \; ,$$

[9].

The algorithm used for blending is:

```
Set the alpha value to 0.5.
Set the texture environment values:
        Tex-
Envf (GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_MODULATE);
Enable Blending and set the blending function to
        BlendFunc(GL_ONE, GL_ONE_MINUS_SRC_ALPHA );
```

The blending produces semi translucent fins. It does not have a performance impact, but the visual effect does depend on how closely the shape structure of the fins can reflect the desired fin shape.

Figure 5.1 shows the blended fins for two fish. in both pictures you can see that the pectoral fins are translucent and the body can be seen through them. The front pelvic fin allows the fin behind it to show through (Hence in **(b)** the pelvic fin looks out of focus.).

5.2.2 Non-triangular fin

Three different methods were attempted to achieve masking to “cutout” the fin shape from the fin structure originally built. These methods have varying degrees of success.

5.2.2.1 Stencil Buffer

This method uses only the stencil buffer. We understood that we could use the stencil buffer to create a stencil shape used to prevent drawing to certain sections of the screen. On attempting to implement this method, we failed to realize that one does not draw directly to the stencil buffer. The values are written to the stencil buffer when drawing a shape to the colour buffer. Although

(a) Bony Bream fish

(b) Pineapple fish

Figure 5.1: Translucent Fins

the value written to the stencil buffer is dependent on the stencil test, it is not dependent on the colour going into the colour buffer. We draw the shape of the fin structure to the colour buffer, and therefore either the entire fin shape is drawn to the stencil, in which case no fin appears, or nothing is drawn into the stencil buffer in which case the entire fin is drawn.

Although this attempt was a failure, much was gained through this exercise. It helped us to obtain a better understanding of the use of the buffers and tests and how to correctly implement them.

5.2.2.2 Alpha Test

This method is a two pass process. It requires two texture files, a black and white one and a coloured one. The black and white version is simply a silhouette of the fish, with the fish in white and the background in black. These need to be identical in all respects except the colour, as the same texture points are used in both files. The black and white texture file is used to create a stencil for masking, while the coloured one is used when applying the texture to the fish model.

In the first pass the black and white texture is used to set the depth and alpha values, using the depth test and the alpha test. In the second pass only the sections with the correct alpha and depth values are drawn to the screen.

The algorithm we use is as follows:

```
First Pass:
     Disable ColorMask
     Set texture environmental variables using
         TexEnvf(GL_TEXTURE_ENV,GL_TEXTURE_ENV_MODE,GL_MODULATE)
     Enable DepthMask and Alpha Testing
     Set the AlphaFunction to LESS, some threshhold level
     Enable 2D texturing, with the black and white picture
     Draw the points. Remember to set the texture coordinates,
     and normals
     Disable 2D texturing
Second Pass
     Enable ColorMask
     Set the AlphaFunction to GREATER the same threshold level.
     Enable 2D texturing, with the texture file this time
     Draw the points. Remember to set the texture coordinates,
     and normals
     Disable texturing, and Alpha Testing
```

This produces shapely fins, but also produces unexpected artifacts.

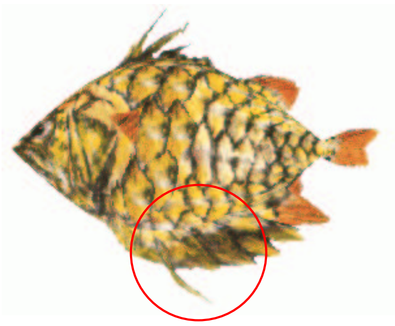
When the fin shape is originally drawn, if it is behind another object, either a fin or another fish then in the first pass the depth value will be set as usual, indicating the fin's position along the z-axis. However during the second pass the fin shape from the black and white texture file is used. The black section of this shape is rejected by the alpha test, causing it to be discarded. This means that no other tests are done on this section. When the fish is translated or rotated the fin might now end up in front of the object it was originally behind, but its depth value will not be re-set and the depth test is never done on this fragment. Therefore nothing gets drawn to this section of the screen, leaving behind a white silhouette of the background section in the fin shape.

This method has a slower performance than the blending method due to the fact that the fish has to be rendered twice.

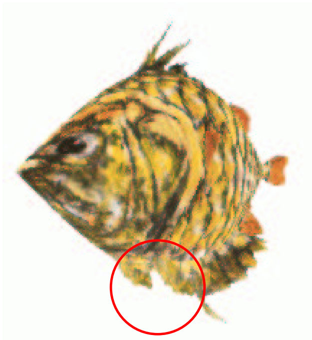
See **Figure 5.2 a, b, c** shows where the one pelvic fin is being obscured by the other fin, thereby making one of the fins disappear at certain angles of view. **Figure 5.2 d, e** shows how the entire fin shape shows up when fish swim in a school.

5.2.3 Stencil test and alpha test

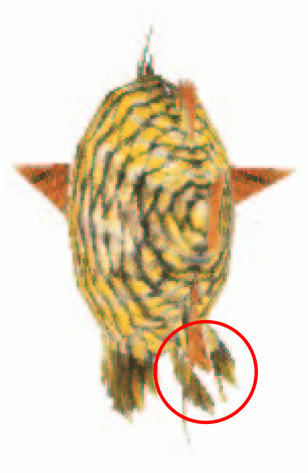
This method uses both the stencil and the alpha test. As in the alpha test method, this is a two pass process and uses both the black and white texture file and the colour texture file.



(a) Pelvic fin totally obscured



(b) Pelvic fin partially obscured

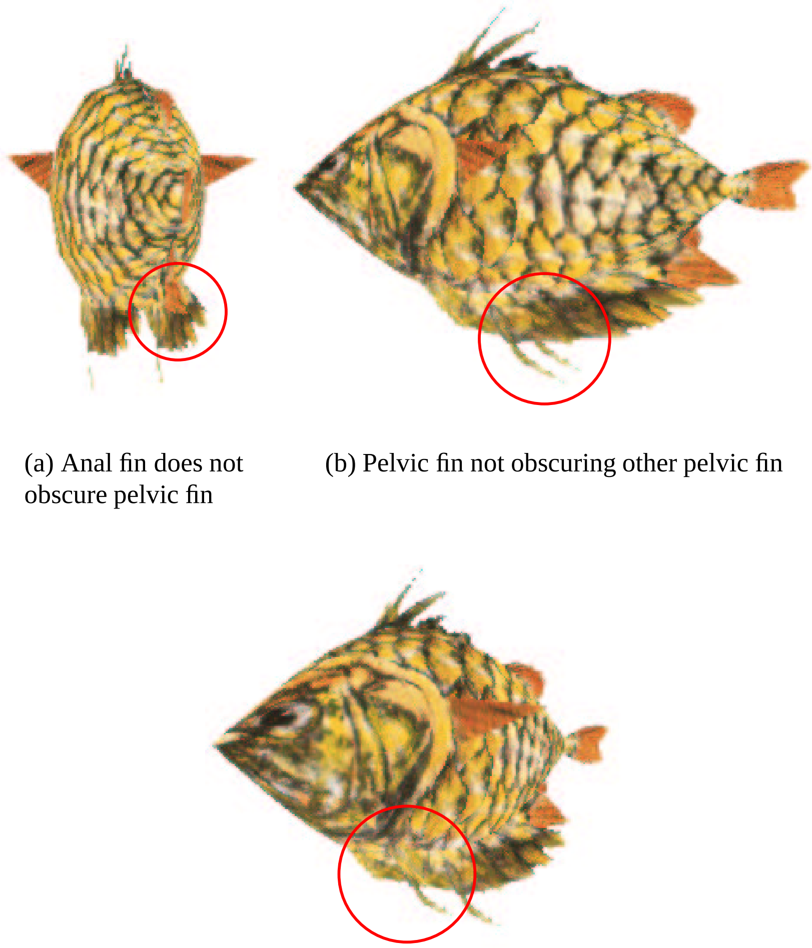


(c) Anal fin obscuring pelvic fin

(d) Pelvic fin obscuring other fish

(e) Pelvic fin obscuring other fish

Figure 5.2: Using the Alpha Test



(a) Anal fin does not obscure pelvic fin

(b) Pelvic fin not obscuring other pelvic fin

(c) Pelvic fin not being obscured

Figure 5.3: Using the Stencil and Alpha Tests

In the first pass the alpha test is used to create a stencil mask in the stencil buffer, using the black and white texture. The fragment's value is discarded if the colour is black, (i.e. the background is discarded). The second pass then uses this stencil from the stencil buffer to determine what is finally drawn to the screen.

This method creates the exact shape fin desired. It has no artifacts, as in the alpha test method. But the disadvantage of this method is that it is lot slower due to the stencil buffer being cleared each and every time the fin is drawn.

Figures 5.3 and 5.4 show the fish using this method.

The algorithm we used is as follows:

```
First pass:
      Enable depth test,
      Set the DepthMask, ColorMask to false.
      Set the colour to white with alpha of one
      Disable lighting
      Enable alpha test
      Set the alpha function to GREATER, with a value of 0.97
             AlphaFunc (GL_GREATER, 0.97f).
      Set the value to clear the stencil buffer to 0, and clear
      the stencil buffer.
             ClearStencil(0);
             Clear(GL_STENCIL_BUFFER_BIT);
      Enable the stencil test
      Set the stencil comparison function to ALWAYS, the
      reference value to one and the mask value to one.
             StencilFunc(GL_ALWAYS,1,1);
      Set the stencil operation to always replace.
             StencilOp(GL_REPLACE,GL_REPLACE,GL_REPLACE);
      Set the Texture environment to GL_MODULATE
             TexEnvf (GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE,
                      GL_MODULATE);
      Enable texturing, using the black and white texture.
      Draw the fin, setting the texture coordinates and
      the normals before defining the actual vertices.
Second pass:
      Enable the DepthTest, set the DepthMask and
      ColorMask to true.
      Disable the alpha test.
      Leave the stencil test enabled, change the stencil
      comparison function to EQUAL and the reference value
      and mask value to one.
              StencilFunc(GL_EQUAL,1,1);
      Change the stencil operation to not change.
              StencilOp(GL_KEEP,GL_KEEP,GL_KEEP);
      Enable lighting
      Enable texturing, using the colour texture.
      Set the texture environment to use DECAL
              TexEnvf (GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE,
                       GL_DECAL);
      Use the smooth shading model
      Draw the fin, setting the texture coordinates and the
      normals before defining the actual vertices.
```

(a) Fins not obscuring other fish

(b) Fish not being obscured by other fins

Figure 5.4: Using Stencil and Alpha Tests

5.3 Summary

The body is textured and three of the four rendering techniques for the fins are successful. The blended fin has the best performance. The alpha and stencil test method has the best visual effect, producing exotic fin shapes, but it has the worst performance. The alpha method is faster than the alpha and stencil method, but has some visual artifacts.

Chapter 6

Fixel

Fixel is a stand-alone program designed and implemented to aid in the calculations of the texture points for *VRFish*. As has already been mentioned, each point which makes up the fish form has to have a corresponding point in the texture file. Texture points are some times referred to as Texels, hence the name for our application - FIsh teXELs.

Fixel is written in Java. It is not incorporated into the GreatDane system. Java has library classes which handle graphics files, hence *Fixel* can use many Graphic file formats, but OpenGL uses the GIF file format and therefore it is recommended that one uses this type of graphics file when using Fixel.

OpenGL uses a different coordinate system for its graphics files to Java. OpenGL uses the bottom left corner as (0,0), the top right corner is (1,1). On the other hand Java uses the top left corner as (0,0) and the bottom right as (x,y) where x is the width of the picture and y is the height. Because of this two texture files are required, one to be used as the texture file in *VRFish*, and one which is used in *Fixel* for determining the texture points. They must be exact mirror images of each other, reflection being in the horizontal axis. The one used for *Fixel*, has the fish the right way up and the one supplied to *VRFish* has the fish upside down. This also means that when *Fixel* calculates the texture points, the Java point is converted into a OpenGL point by dividing the x value of the point by the width, and the y value of the point by the height. (*Fixel* could do the inverting, but this has not been implemented yet.)

The *Fixel* window consists of a menu bar, which contains 3 menus (File, Values and Draw), a graphics area (where the graphics file is displayed) and an instruction bar. The instruction bar has comments, hints or instructions to give the user some indication of what is happening, and what is required at any stage. (See **Figure 6.1** for a screen shot)

At this time *Fixel* is very functional and not exceptionally user friendly.

There are a number of different stages of operation, one per fish body part, namely for the body,

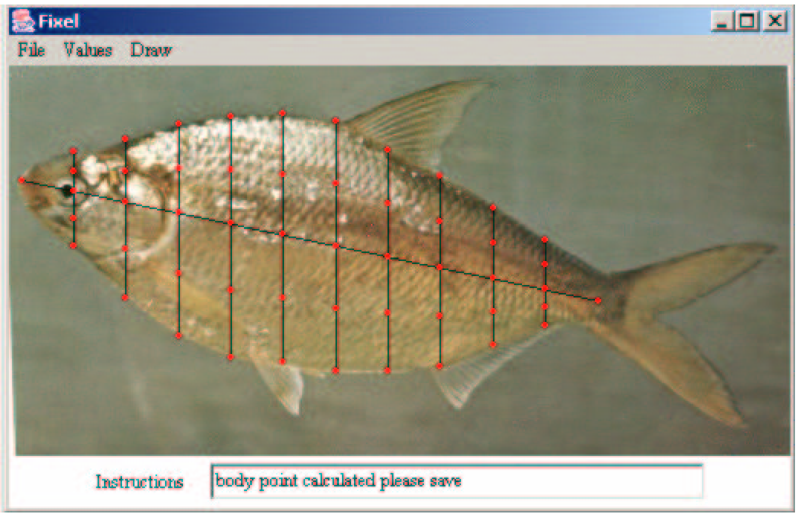


Figure 6.1: Fixel Application Screen shot

and for the dorsal, adipose, caudal, anal, pectoral and pelvic fins. Each stage can be started by selecting it from the Draw menu.

Fixel requires information based on the values in the parameter file for the fish. The values for each body section must be entered through the Values menu, before that specific stage is started.

Once the user has completed the stages of his/her choice the information can be saved. *Fixel* saves the calculated points in a ASCII file with the extension .FXL. Each body part saves its texture points in a list which is preceded by two lines. The first contains a comment starting with //, which specified which body part the texture points are for, and the second the number of actual texture points to follow.

Within each stage there are steps which have to be followed in strict sequential order, in order to obtain the correct points. If a mistake has been made there are no means to correct, add or delete an individual point. The stage must be restarted. Although the steps within each stage are strictly sequential, the stages can be done in any order, or not done at all.

Each stage is a reflection of the algorithm used in *VRFish* to construct that particular body part.

For the body a middle line is drawn across the fish body picture from its nose to the start of its caudal fin. This means that the fish in the picture can have any orientation and placement — it does not have to be perfectly horizontal in this file. The required number of vertical lines are drawn by *Fixel*, evenly distributed across this line. These vertical lines correspond to the BodySections. The user adjusts the length of these lines, so that they just cover the body, starting with the line at the nose and ending with the line at the caudal fin. This is simple way of doing edge detection for the body! Fixel then draws the calculated points on the vertical lines. There is always a point on the intersection of the horizontal line and the vertical line (this is point number 0 in *VRFish*). When the points for the body are saved, each point is saved on a new line in the ASCII file. Preceding the x and y value in the ASCII file is the vertical line number and the point number. The vertical line number corresponds to the BodySection number in *VRFish*, and the point number corresponds to the CircleSection. Fixel determines the points for the back half of the fish body and then saves them in the correct order corresponding to the points created in *VRFish*.

For the fins the user has to click on the picture to set certain points. The points have to correspond to specified points of the fin shape constructed by *VRFish* and these points must be done in a certain order. The required points and their order can be found in the user manual in appendix B. Once the initial points have been set, *Fixel* calculates the remaining points, and draws them in. The user is then required to either click on the point, or to adjust its location by clicking where he/she wants it to be. Again the order of the points is very important.

The texture points for use with the blended fins should have as little background as possible included, preferably none. However, when creating the texture points for the masking methods the background is of little consequence, the points are placed to reflect the constructed fin shape, including the entire fin in the texture file.

We have found that some trial and error is often required in obtaining the texture points for the fins to give the best visual appearance.

Although more work can be done on *Fixel* and its user interface, it is successful in aiding in the calculation of the texture points required for *VRFish*.

Chapter 7

Animation

The animation of the fish is divided into two sections. First there is the animation of the fish form, which at this stage comprises only the movement of the fins. The second section is the behaviour of the fish which determines the way in which the fish moves around the environment. This is achieved by implementing a simple flocking algorithm. Although these two sections are discussed separately they are not mutually exclusive in the rendering process: as fish move around the environment they move their fins, producing a realistic swimming motion.

7.1 Fin Motion

A very simple movement model for the fin motion has been implemented. There is no deformation of the body area at this stage, although this is theoretically possible, nor are the fins deformable. The only movement is due to certain of the fins moving back and forth. The dorsal, adipose and anal fins do not move at all in relation to the body (See Figure 7.1for a summary).

The caudal fin moves back and forth, up to a certain maximum angle, we will call this maximum angle the movement angle of the fin. The movement angle is specified by the user in the

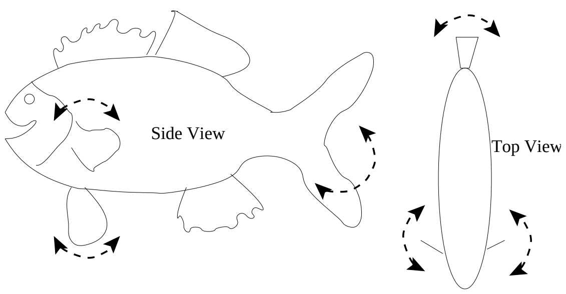


Figure 7.1: Fish structure showing fin movements.

parameter file together with a step value. The step value specifies how many degrees the fin moves at a time.

The caudal fin is created at the origin and therefore can just be rotated around the y-axis.

To rotate the pelvic fin one of the points in the fin is used to determine the point about which it is to be rotated. The point which attaches the fin to the body, and is the the furthest up the y axis is used. The fin is translated so that this point is at the origin, then it is rotated, and then it is translated back into position.

The pectoral fins are handled similarly, with the exception that the point used is the one furthest out along the z-axis.

Although this is a very simple animation model, rotating the fins back and forth produces a fish which appears to be swimming through the water.

7.2 Behaviour

We want to achieve autonomous fish creatures. This means that the swimming behaviour is not scripted. We use a basic flocking algorithm based on Reynolds' flocking algorithm [15] and Conrad Parker's [10] extension to the Reynolds flocking algorithm as discussed in the chapter on related works.

To obtain the swimming behaviour we use the fish's current velocity in conjunction with the three rules specified by Reynolds, namely:

- ⇒ Avoid collisions with nearby neighbours,
- ⇒ Attempt to match velocity with neighbours,
- ⇒ Attempt to stay close to the center of the school,

and a fourth rule which involves the following of a random path, created using a spline. This random path rule allows the single fish in isolation to swim on a random path in the virtual reality environment, but as soon as there are other fish species present, the schooling behaviour manifests. Each rule is weighted differently to create the final direction the fish moves in. These weightings are stored in the parameter text file. Although the weightings reflect the importance of the rule, they are determined using a trial and error method. One of the reasons for this is that the rules do not take into account the fish's size, and therefore if one changes the size of the fish, the weighting values often have to be adjusted slightly to obtain the correct visual effect.

When the *VRSchool* class adjusts the parameters in the information objects it could vary the weightings by a small random amount to create fish which have slightly different behaviour patterns.

To implement the rules, the fish has to obtain information about the state and location of the other fish in the school. As has been already been mentioned, GreatDane contains a database of the objects within the environment. Each object is checked to see if it is the same species of fish as the current fish. If the object is a fish of interest, then the relevant properties of that fish can be used.

Each rule calculates a directional vector which is returned to the “brain”. The brain uses the weightings specified in the parameter text file to obtain a vector for each rule which is a certain proportion of the vector originally calculated for the rule. These are added together to obtain a final directional vector which is used to move the fish.

All the rules use the state of the school, as perceived by the current fish. Therefore the current fish’s state is never included in the results. Any distance between the fish is the distance between their center points, not between the outside of the fish.

The method for the rules in greater detail follows:

- ⇒ To avoid the neighbouring fish, the closest fish is found. If it is within a certain specified distance then the distance vector between the two gets returned. This vector corresponds to movement required to avoid collision between the fish.
- ⇒ To move towards the center, the average position of the school is determined. A vector corresponding to the movement towards the center of the school is calculated by subtracting the average position and the current fish’s position. This vector is returned.
- ⇒ Thirdly the average direction of the school is found. The orientation of each fish is stored as a quaternion. To calculate the directional vector for the orientation the quaternion is multiplied by the original direction of the current fish, and then the average of these directional vectors is found. This average vector is returned, and it corresponds to the movement required of the fish in order for that fish to change its orientation to that of the school.
- ⇒ The velocity of the fish is taken into account and this is also weighted.
- ⇒ The final rule is a random path. A spline is used to create this path. The points for the spline are either set to a point straight ahead or to a random point. The frequency of using a randomly selected point is specified in the parameter text file.

7.3 Summary

The schooling algorithm uses Reynolds' flocking algorithm as a basis, but implements a simplified version of his rules. To this we have added a random path rule. These rules do not take the size of the fish form into account. This means that the fish sometimes swim through each other, most often seen when the fish are changing orientation.

Chapter 8

Results

This chapter presents a number of results. Firstly we discuss the performance results and secondly the appearance. In the first section on performance results we show the different factors which could influence performance, namely level of detail, the different fish species and the rendering method used for the fins. In the second section on appearance we discuss the impact of the level of detail, present the different species of fish we implemented, show the the visual appearance using the different fin rendering methods and then finally we discuss the schooling behaviour.

8.1 Performance

We have created a number of different fish species. (This means that we have a number of different parameter files which the system can read in.)

All tests were done on a Pentium III, 500MHz, 128MB RAM, with a Voodoo 5 graphics card, running Redhat Linux 7.2.

8.1.1 Level of Detail

First we did some experiments to measure the performance of fish with different levels of detail. There is one swimming fish within the environment for these tests.

Figure 8.1 shows the performance of fish with different levels of detail. The results are as expected: the quality of the the 3D fish form certainly improves as the level of detail gets higher, but the performance speed decreases. The lowest level of detail, using BodySections = 8 and CircleSections = 6 has a frame rate of over 85 frames per second. The fish with the highest

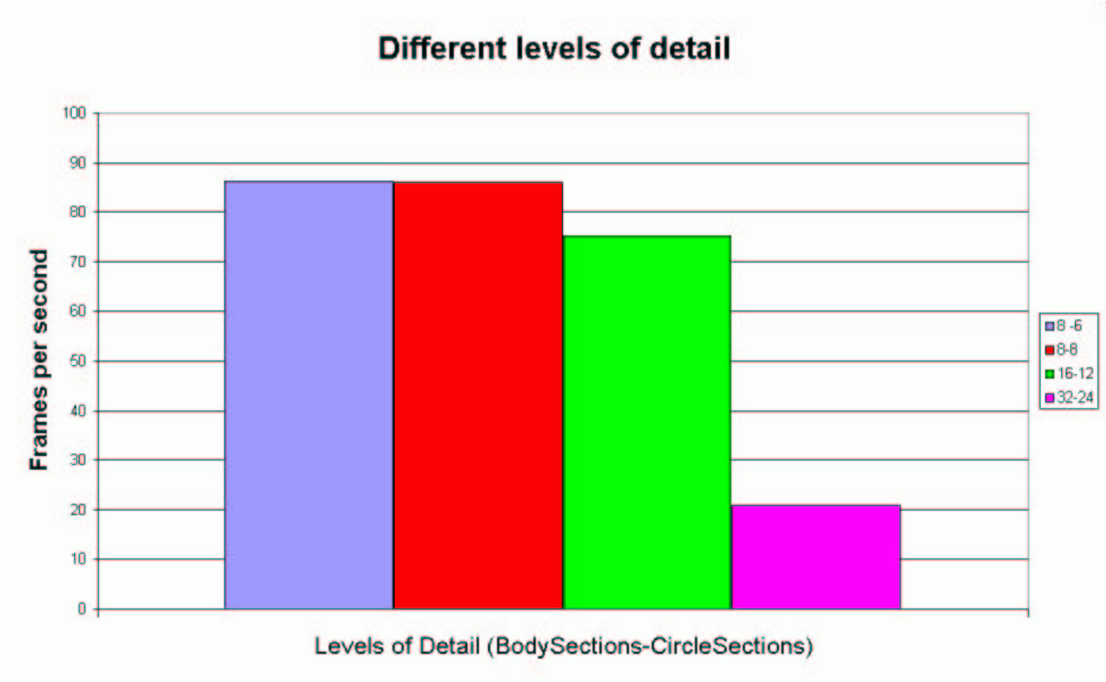


Figure 8.1: Graph of performance for different levels of detail

level of detail, in our experiment, using BodySections = 32 and CircleSections = 24 has a frame rate of 21 frames per second. This is much higher than the minimum frame rates required for a real-time system, (the commonly accepted minimum real-time frame rate is about 10 frames per second).

8.1.2 Different species

For the following experiments all fish are made up of 16 body sections, each of which are divided into 12 points. The size, shape and placement of the fins, urge weightings and initial velocity differ between fish types. In these experiments there are no other virtual objects within the system besides the fish.

Figure 8.2 shows the graph for the results when comparing different fish species which have all been rendered using the Alpha test method.

At the same level of detail, the differences in shape of fins, weightings and initial velocity do not make a significant difference to the performance.

8.1.3 Fin rendering techniques

For the following experiments all fish are made up of 16 body sections, each of which are divided into 12 points. The size, shape and placement of the fins, urge weightings and initial

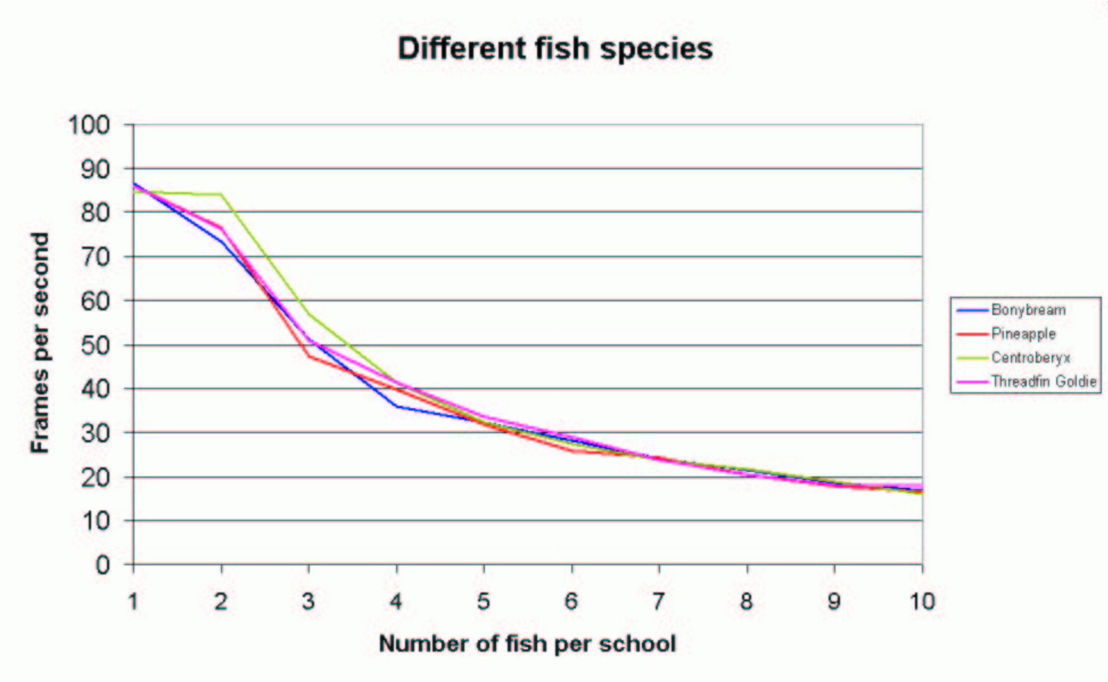


Figure 8.2: Different fish species using the alpha test method

velocity differ between fish types. In these experiments there are no other virtual objects within the system besides the fish.

Figure 8.3 shows the graph which comparing the three different rendering techniques, using only the Bony bream fish.

The different methods of rendering the fins do make a difference to the performance speed. These results are as expected. The blending method is a single pass rendering process ans so is very efficient. The method using only the alpha test uses a two-pass rendering process and therefore is slower than the blending process. The method using the stencil and alpha test is a two-pass rendering process, and the stencil buffer is cleared at each rendering making it slower than the method using only the alpha test.

With ten fish in the environment, using the blending technique we are obtaining a frame rate of just over 20 frames per second, double the requirements for real-time. For the slowest method, using both alpha and stencil test we are obtaining 10 frames per second, still real-time.

8.2 Appearance

Figure 8.4 shows the texture files used. (a) is a scanned photo of a *Monocentris Japonicus* (Pineapple fish) from J.L.B. Smith's Sea Fishes [18], and (b) is a black and white version of the texture file.

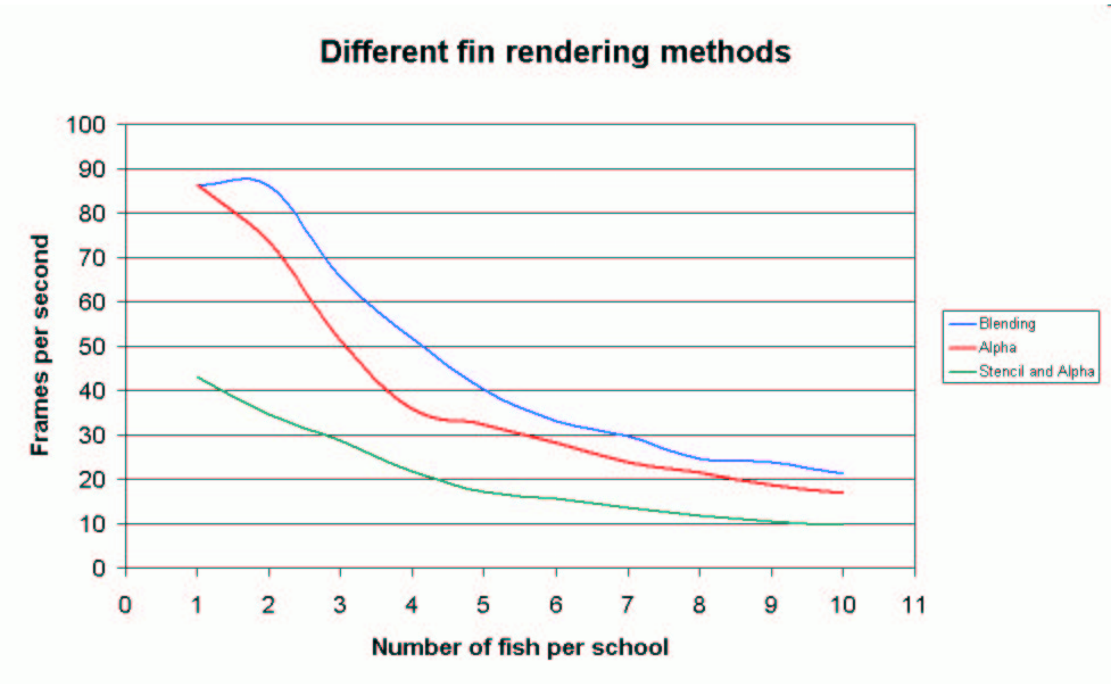
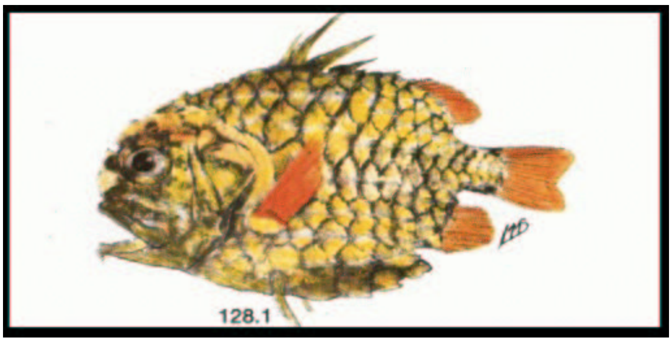


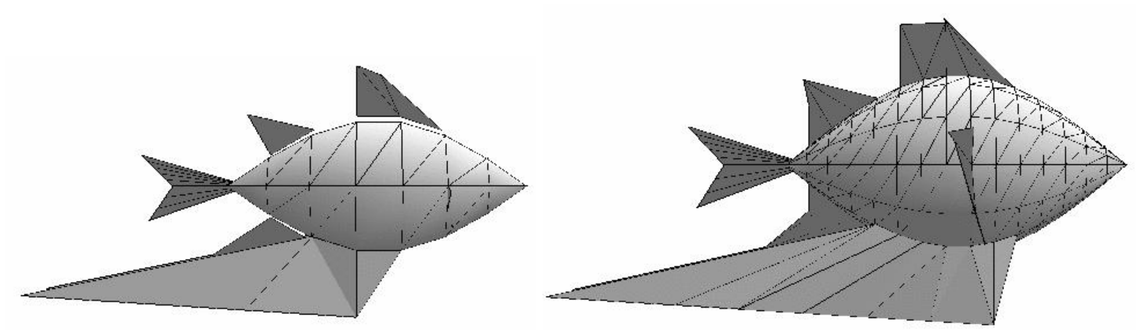
Figure 8.3: The same fish species using the different fin methods



(a) Colour Texture

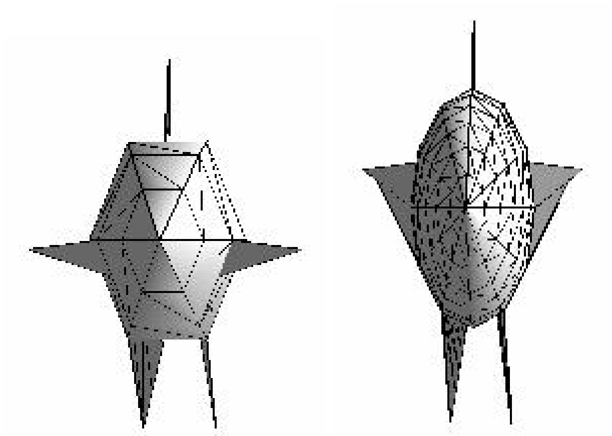
(b) Black and White texture

Figure 8.4: Pineapple texture files



(a) BodySections-8; CircleSections-6

(b) BodySections-16; CircleSections-12



(c) BodySections-8; CircleSections-6

(d) BodySections-16; CircleSections-12

Figure 8.5: Different levels of detail

8.2.1 Level of detail

The appearance is affected by the level of detail. With the simplest level of detail used in the experiments, using BodySections = 8 and CircleSections = 6, we obtain a very triangular fish body, with little flexibility in the shape of the fins. The fins are placed on the true curve and therefore there is a gap between the dorsal fin and the body (see **Figure 8.5 (a)**). But simply doubling these values produces a rounded body, with a great amount of fin shape flexibility and no gap between the dorsal fin and the body.

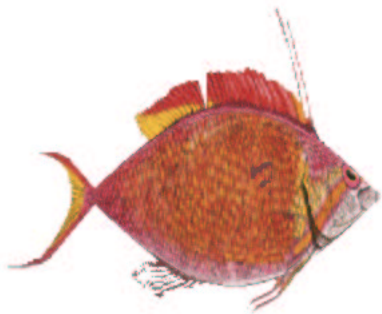
8.2.2 Different Species

Figure 8.6 shows a sample of all four fish species created using the stencil and alpha tests.

(a) Pineapple fish

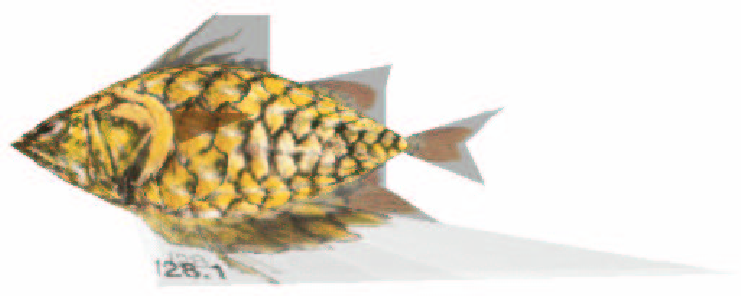
(b) Bonybream fish

(c) Centroberyx fish



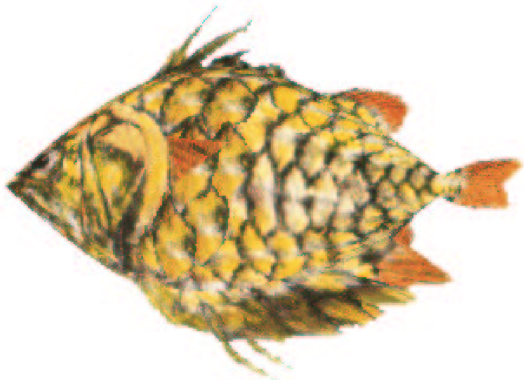
(d) Threadfin Goldie fish

Figure 8.6: Four species using VRFish (created with the stencil and alpha tests).



(a) Blended fins

(b) Using Alpha test only



(c) Using Stencil and Alpha tests

Figure 8.7: The final product

8.2.3 Fin rendering techniques

Figure 8.7 is the end result for the Pineapple fish created using *VRFish*, showing the 3 different fin methods, with level of detail of BodySections = 16 and CircleSections = 12.

8.2.4 Schooling behaviour

The schooling behaviour which has been implemented is simple, but produces a reasonably cohesive schooling behaviour pattern, with fish fins animating as they move around the environment. The schooling behaviour can be seen on the CD in the video clips directory or on the web page (http://www.cs.ru.ac.za/research/g90f2972).

Chapter 9

Conclusions

In this project we have taken the first step towards establishing a library of objects which could be used by virtual reality programmers, to create a world populated with interesting creatures and objects.

⇒ *VRFish* is a fish library object which is non CPU intensive. On a Pentium III, 500MHz, 128MB RAM, with a Voodoo 5 graphics card, running Redhat Linux 7.2, 10 fish of a single species are rendered in between 9.8 and 21.4 frames per second.

⇒ *VRFish* creates the 3D fish form procedurally. The user/programmer is only required to setup the parameter file before usage. This allows many different species to be created using *VRFish.* We have produced 4 prototypes namely Bony Bream, Pineapple, Centroberyx and Threadfin Goldie. Currently the fish all have the same basic body shape, as only one body shape has been implemented. But it has been shown that *VRFish* can easily be extended to allow for different body shapes. The basic fin shape used allows for a wide range of structures, and placements of fins. A number of different techniques have been implemented to obtain more realistic and interesting fins. These include semi translucent fins of the original shape, and two different methods of creating a fin "cut out" to the desired shape. The one method using only the alpha test, has some artifacts but has a better frame rate than the method using both stencil and alpha tests which does not produce the artifacts.

⇒ The fish's form sufficiently approximates the true form of the fish to be realistic in appearance.

⇒ *VRFish* produces body animation by rotating the caudal, pelvic and pectoral fins back and forth.

⇒ *VRFish* implements a flocking algorithm to produce fish with realistic, non-scripted swimming patterns. When fish of the same species are within the environment, they will swim together, acting as a cohesive whole, closely resembling a school of fish.

We have succeeded in creating a fish model which is self contained and can be used with ease by virtual reality programmers to create diverse and interesting underwater environments.

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Appendix A

Format of parameter file: BonyBream.txt

```
//all comments must start with two for-
ward slashes, and must take up the entire line.
//any description ending with _T was used for testing
//description world_scale urgeFactor start_position_3D_point cube-
size_t
bonybream 25.5 0.009 0.0 4.0 -9.3 10.0
//fish_colours_RGB
1.0 1.0 0.0
//fishshape_subclass BodySections CircleSections tex-
tured masked turn_T catchfish_T
FishShapeSin 16 12 true true false false
//Compression_ratio_of_fish_ body: scaleX scaleY scaleZ
0.26 0.1 0.04
//Caudal Fin
//top_line middle_line top_angel no._of_top_triangles connec-
tion_point_3d_point_x y z rotation_angle bottom_line bot-
tom_angle no._of bottom_triangles movement_angle step_size
0.75 0.13 75.0 3.0 0.95 0.0 0.0 0.0 0.83 78.0 3.0 10.0 1.0
//adiposeFin
//startBodySection endBodySection startLength endLength startan-
gle_in_degrees proportion
13.0 15.0 0.01 0.01 0.0 0.5
//dorsalFin
//startBodySection endBodySection startLength endLength startan-
gle_in_degrees proportion
7.0 10.0 0.6 0.05 70.0 0.98
//pelvicFin
//startCircleSection startBodySection endBodySec-
tion start_length end_length end_angle movement_angle step_size
11.0 4.0 7.0 0.1 0.6 90.0 6.0 1.0
//analfin
```

```
startBodySection endBodySection startLength endLength startan-
gle_in_degrees proportion
12.0 15.0 0.18 0.01 -55.0 0.9
//pectoralfin
//startBodySection startCircleSec-
tion no_of_triangles startLength startAngle proportion version_t
6.0 2.0 3.0 0.95 5.0 0.75 0.0 4.0 1.0
//texture_file_ name black_and_white_version_file_name
./textures/bonybream.gif ./textures/bbshape.gif
//texture point follow.
//number_of_ points_body_points
192
//bodySection_no. circleSection_no body_texture_points_2D
0 0 0.015625 0.3046875
0 1 0.015625 0.3046875
0 2 0.015625 0.3046875
0 3 0.015625 0.3046875
0 4 0.015625 0.3046875
0 5 0.015625 0.3046875
0 6 0.015625 0.3046875
0 7 0.015625 0.3046875
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0 9 0.015625 0.3046875
0 10 0.015625 0.3046875
0 11 0.015625 0.3046875
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1 1 0.064453125 0.296875
1 2 0.064453125 0.26953125
1 3 0.064453125 0.23828125
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1 6 0.064453125 0.32421875
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1 8 0.064453125 0.40234375
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2 2 0.115234375 0.265625
2 3 0.115234375 0.2265625
2 4 0.115234375 0.265625
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2 6 0.115234375 0.34375
2 7 0.115234375 0.40234375
```

```
2 8 0.115234375 0.4609375
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3 0 0.1640625 0.36328125
3 1 0.1640625 0.30859375
3 2 0.1640625 0.25
3 3 0.1640625 0.19140625
3 4 0.1640625 0.25 3
5 0.1640625 0.30859375
3 6 0.1640625 0.36328125
3 7 0.1640625 0.4453125
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3 9 0.1640625 0.6171875
3 10 0.1640625 0.53125
3 11 0.1640625 0.4453125
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4 2 0.21484375 0.234375
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5 5 0.263671875 0.3125
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```

```
6 5 0.314453125 0.32421875
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7 6 0.36328125 0.44140625
7 7 0.36328125 0.55078125
7 8 0.36328125 0.66015625
7 9 0.36328125 0.7734375
7 10 0.36328125 0.66015625
7 11 0.36328125 0.55078125
8 0 0.4140625 0.4609375
8 1 0.4140625 0.359375
8 2 0.4140625 0.25390625
8 3 0.4140625 0.1484375
8 4 0.4140625 0.25390625
8 5 0.4140625 0.359375
8 6 0.4140625 0.4609375
8 7 0.4140625 0.5703125
8 8 0.4140625 0.6796875
8 9 0.4140625 0.7890625
8 10 0.4140625 0.6796875
8 11 0.4140625 0.5703125
9 0 0.462890625 0.48046875
9 1 0.462890625 0.38671875
9 2 0.462890625 0.2890625
9 3 0.462890625 0.19140625
9 4 0.462890625 0.2890625
9 5 0.462890625 0.38671875
9 6 0.462890625 0.48046875
9 7 0.462890625 0.58203125
9 8 0.462890625 0.68359375
9 9 0.462890625 0.78515625
9 10 0.462890625 0.68359375
9 11 0.462890625 0.58203125
10 0 0.513671875 0.5
10 1 0.513671875 0.41796875
```

```
10 2 0.513671875 0.3359375
10 3 0.513671875 0.25390625
10 4 0.513671875 0.3359375
10 5 0.513671875 0.41796875
10 6 0.513671875 0.5
10 7 0.513671875 0.59375
10 8 0.513671875 0.69140625
10 9 0.513671875 0.7890625
10 10 0.513671875 0.69140625
10 11 0.513671875 0.59375
11 0 0.5625 0.51953125
11 1 0.5625 0.44921875
11 2 0.5625 0.37890625
11 3 0.5625 0.30859375
11 4 0.5625 0.37890625
11 5 0.5625 0.44921875
11 6 0.5625 0.51953125
11 7 0.5625 0.59765625
11 8 0.5625 0.6796875
11 9 0.5625 0.76171875
11 10 0.5625 0.6796875
11 11 0.5625 0.59765625
12 0 0.61328125 0.5390625
12 1 0.61328125 0.48046875
12 2 0.61328125 0.421875
12 3 0.61328125 0.359375
12 4 0.61328125 0.421875
12 5 0.61328125 0.48046875
12 6 0.61328125 0.5390625
12 7 0.61328125 0.6015625
12 8 0.61328125 0.6640625
12 9 0.61328125 0.7265625
12 10 0.61328125 0.6640625
12 11 0.61328125 0.6015625
13 0 0.662109375 0.55859375
13 1 0.662109375 0.515625
13 2 0.662109375 0.46875
13 3 0.662109375 0.421875
13 4 0.662109375 0.46875
13 5 0.662109375 0.515625
13 6 0.662109375 0.55859375
13 7 0.662109375 0.59765625
13 8 0.662109375 0.63671875
13 9 0.662109375 0.6796875
13 10 0.662109375 0.63671875
```

```
13 11 0.662109375 0.59765625
14 0 0.712890625 0.578125
14 1 0.712890625 0.546875
14 2 0.712890625 0.515625
14 3 0.712890625 0.48046875
14 4 0.712890625 0.515625
14 5 0.712890625 0.546875
14 6 0.712890625 0.578125
14 7 0.712890625 0.6015625
14 8 0.712890625 0.625
14 9 0.712890625 0.65234375
14 10 0.712890625 0.625
14 11 0.712890625 0.6015625
15 0 0.763671875 0.59765625
15 1 0.763671875 0.59765625
15 2 0.763671875 0.59765625
15 3 0.763671875 0.59765625
15 4 0.763671875 0.59765625
15 5 0.763671875 0.59765625
15 6 0.763671875 0.59765625
15 7 0.763671875 0.59765625
15 8 0.763671875 0.59765625
15 9 0.763671875 0.59765625
15 10 0.763671875 0.59765625
15 11 0.763671875 0.59765625
//number_of_texture_points_for_caudal_fin
9
//texture_points_2D
0.708984375 0.57421875
0.99609375 0.4375
0.966796875 0.5234375
0.91015625 0.59765625
0.85546875 0.65234375
0.966796875 0.96484375
0.94140625 0.85546875
0.90625 0.74609375
0.85546875 0.65234375
//transparency_t
1.0
//no_of_dorsal_texture_points
8
//texture_points_2D
0.646484375 0.015625
0.404296875 0.1328125
0.552734375 0.29296875
```

```
0.57421875 0.23828125
0.455078125 0.1796875
0.501953125 0.2421875
0.64453125 0.015625
0.638671875 0.01953125
//no_of_adipose_texture_points
6
//texture_points_2D
0.619140625 0.046875
0.43359375 0.14453125
0.5390625 0.25390625
0.556640625 0.21875
0.48828125 0.203125
0.494140625 0.1953125
//no_of_anal_texture_points
8
//texture_points_2d
0.576171875 0.875
0.54296875 0.78515625
0.708984375 0.6640625
0.705078125 0.66796875
0.59765625 0.7421875
0.654296875 0.69921875
0.578125 0.85546875
0.5859375 0.84375
//no_of_pectoral_texture_points
7
//texture_points_2D
0.619140625 0.046875
0.431640625 0.14453125
0.546875 0.26171875
0.46875 0.18359375
0.509765625 0.2265625
0.61328125 0.0546875
0.607421875 0.0625
//no_of_pelvic_texture_points
8
//texture_points_2D
0.43359375 0.15234375
0.47265625 0.1953125
0.46484375 0.11328125
0.51171875 0.234375
0.548828125 0.26953125
0.521484375 0.07421875
0.583984375 0.046875
```

```
0.62109375 0.046875
//movement of fish
//initVelocity_vector
0.000009 0.0000075 0.0000071
//urge_weightings
//random center keepaway repelDistance speed changeRate direction
0.04 0.35 0.01 0.15 0.7 50.0 0.0015
//flee_info
0.04 10.0
```

Appendix B

Fixel user manual

B.1 Introduction

Fixel is a program designed to aid in the obtaining of the texels (texture points) for VRFish. Two copies of the texture are required. The one used in VRFish should be the inverse of the one used in Fixel.(Fixel uses the one with the correct orientation, VRFish uses a GIF which is flipped. See **Chapter 6**.)

The Fixel window contains a menu bar at the top, this contains three menus:

- ⇒ File menu, from which you can save, open and exit the program.
- ⇒ Values menu - all values are set or changed from here.
- ⇒ Draw menu - to start any set of points.

The center will contain the texture file. At the bottom of the window is the Instruction Bar. This contains context sensitive instructions to aid you with the next step. These are not step-by-step instructions but hints to help with ease of use. See Figure B.1

The File menu has three options, (**FigureB.2**) Open - to open a picture file (GIF, JPG), Save - to save all points that have been calculated into a text file with the extension .FXL and the Exit option which will close the Fixel application.

The Values Menu (**Figure B.2**) has options to allow the user to enter the relevant parameters that *VRFish* will use when creating this particular fish. (**Figure B.3** shows the value dialog boxes). For example Change Body Values displays a dialog box where the user can input the number of body sections, and the number of divisions at each of these are divided into (circle sections / angular resolution). In order to create the caudal fin, we need to know how many triangles are

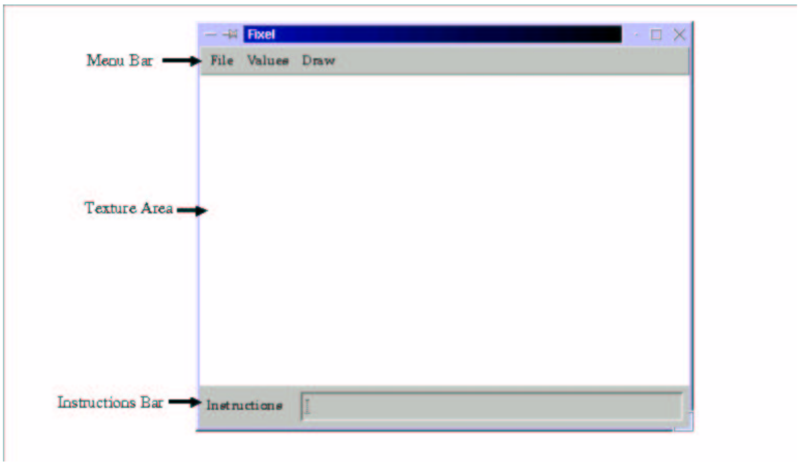


Figure B.1: Fixel application window

in the top half and how many are in the bottom half. Similarly, in order to create the dorsal fin we need to know the number of body sections the fin spans, and the proportion parameter.

The Draw Menu (**Figure B.2**) has options to start the process of each set of texture point calculation. Each of these options sets the state of Fixel appropriately.

B.2 Open a texture file.

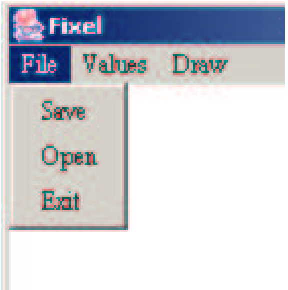
The texture file used by VRFish has to be a GIF file. But the file for Fixel can be any picture format. (GIF, jpg etc). Click on the File Menu. Select Open.

B.3 Body

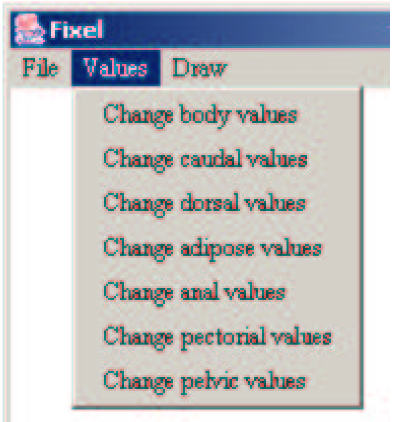
To do the Fixel (Fish Texel) points for the body follow these steps:

1. Set up the values for the body by clicking the Values menu, select "Change body values". The first requirement is the number of divisions the body will be divided into. The 2nd requirement is the number of points each section will be divided into when it is rotated to obtain the body. Click in the Body Sections box , delete the current value, and enter the new value. Click in the Circle sections box (or press tab). Delete the current value and enter the new value. Once these are correct click the OK button.

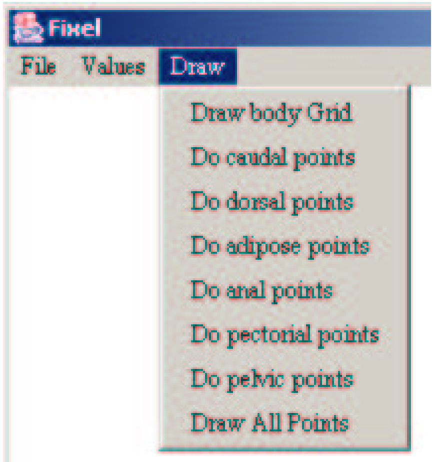
2. Start setting the body points by clicking on the Draw menu. Select "Draw body grid"



(a) File Menu

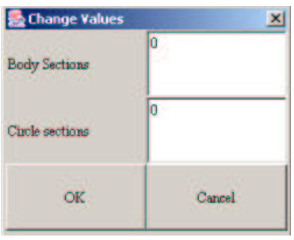


(b) Values Menu

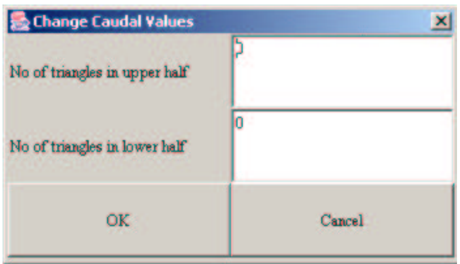


(c) Draw Menu

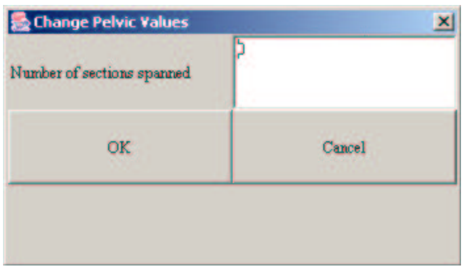
Figure B.2: Fixel Menus



(a) Body Values



(b) Caudal Values



(c) Pelvic Values

Figure B.3: Fixel: Value Dialog Boxes

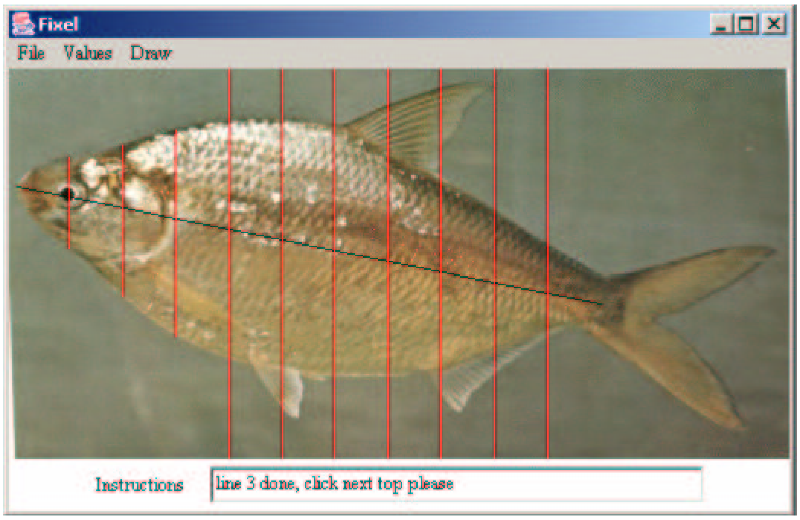


Figure B.4: Vertical lines on the body

3. Draw the middle line. From the "nose" to the tail point of the body. This should be in down the center of the fish. The vertical lines dividing the fish are then drawn.

4. Resize each line, starting at the "nose" end of the fish. First click the top, then the bottom of each line. See Figure B.4. Once all the lines are resized, the points are calculated and drawn. See Figure B.5.

B.4 Caudal fin

1. Set the Caudal values: (Values, Set Caudal Values: See Body for method)
   Requirement: The number of triangles in the top half, and the bottom half of the tail

2. Start setting the points (Draw, Do Caudal Points).

3. Click on points 0,1,2,3. (These are always in these positions, and must be done in the correct order). The rest of the points will be drawn, as a guide line of where the points should be. See Figure B.6.

4. Click to confirm, or to adjust the point starting with point 4 and work up to point 1. (in **Figure B.7**, it would be points 4, and 5 in that order.) Then start at the point closest to point 3 and move up to point 2. (in **Figure B.7** it would be points 6, 7, and 8, in that order)

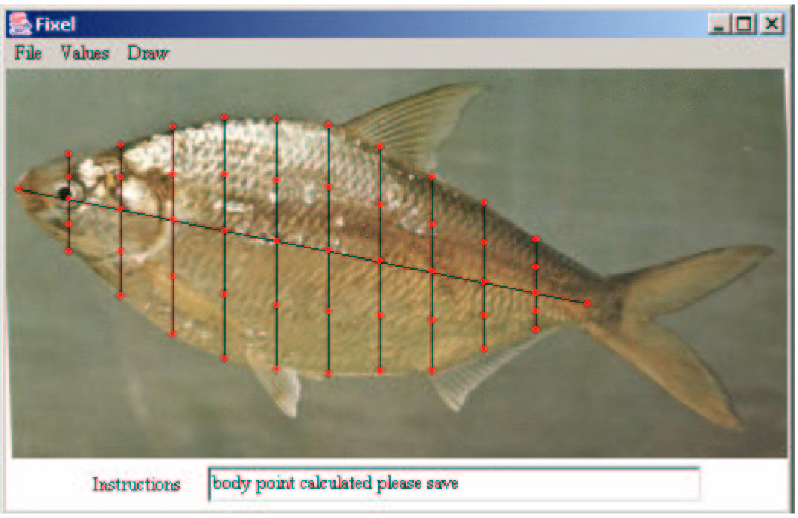
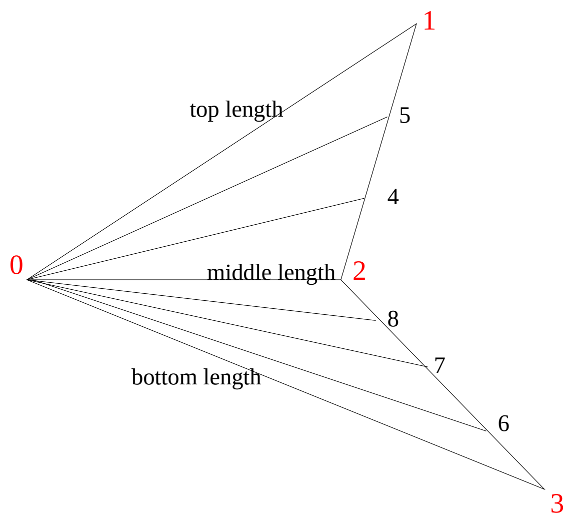
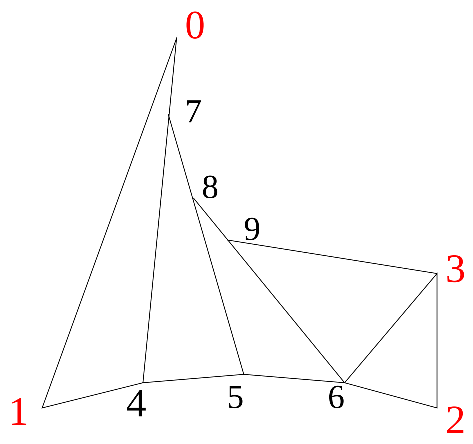


Figure B.5: Body points drawn



(a) Point order

Figure B.6: Caudal Points



(a) Point order

Figure B.7: Dorsal fin points

B.5 Dorsal fin

1. Set Values (Values, Change Dorsal Values)
   The values required: The number of body sections that the dorsal fin will span (in the Figure B.7 span is 4). The proportion the next triangle's third point is placed on the side of the triangle.

2. Start setting the points (Draw, Do Dorsal Points).

3. Click the top point of the dorsal fin first (point 0), then points 1,2, and 3 - in that order. The other points are drawn in, as a guide. See **Figure B.7**.

4. Click each point, to confirm or correct it, in order starting from point 4, moving across to point 2. (In the Figure B.7 it is the points 4,5, and 6). Then click at the point closest to point 0 and move down to point 3. (In Figure B.7 it is points 7,8, and 9).

B.6 Adipose fin

The structure is the same as the Dorsal fin

1. Set the values for the adipose fins. (Values, Change Adipose values: see dorsal fin for method).

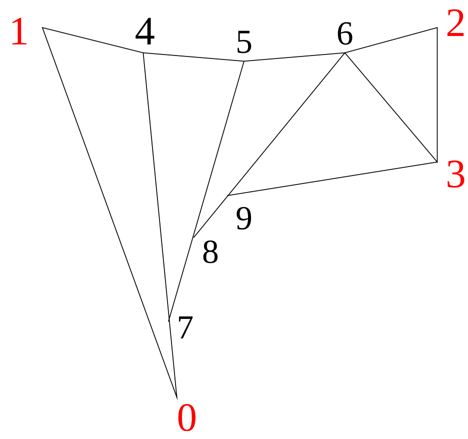


Figure B.8: Anal point order

2. Start setting the points. (Draw, Do Adipose Points)
3. Do the points as for the dorsal fin.

B.7 Anal fin

The structure is the same as the Dorsal fin but it is inverted.

1. Set the values for the anal fins. (Values, Change Anal values)
2. Start setting the points. (Draw, Do Anal Points)
3. Do the points the same way as the dorsal fin. See Figure B.8 for the point order.

B.8 Pectoral fin

Structure is the same as the dorsal fin The dorsal fin can be used as the texture if the pectoral fin cannot be clearly seen

1. Set the values: (Values, Change Pectoral Values).
2. Start setting the points. (Draw, Do Pectoral Points)
3. Do the points the same way as the dorsal fin

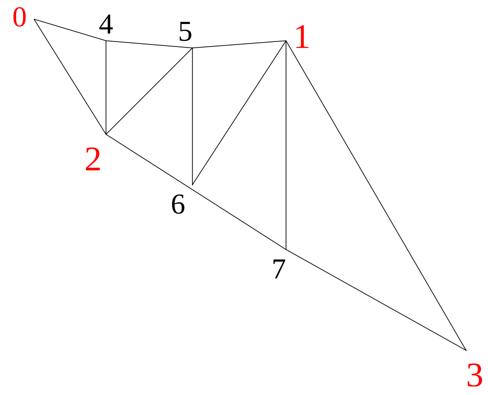


Figure B.9: Pelvic fin points

B.9 Pelvic fin

1. Do Pelvic values (Values, Change Pelvic Values).The number of sections the pelvic fin will span. (In the Figure B.9 the span is 3)

2. Start setting the points (Draw, Do Pelvic Points).

3. Click on points 0,1,2, and 3. The rest of the points are drawn as a guide line, click one each point to confirm or to change that point. Start with point 4, the point on the base line next to point 0, and move towards point 1. (In **Figure** B.9 points 4, and 5 - in that order.) Then click the point closest to point 2 working towards point 3. (In the **Figure B.9** points 6, and 7 - in that order.)

B.10 Save file

Once you have set all the texture points you require, you can save these points to a text file with the extension FXL.

Below is a sample of a FXL file showing points for the Dorsal and Anal fins. Each list of points is preceded by a comment to indicate what the points are for, and on the following lines the number of points there are for that specific structure.

```
//dorsal
14
0.228515625 0.00390625
0.13671875 0.31640625
```

```
0.396484375 0.328125
0.439453125 0.1796875
0.181640625 0.29296875
0.22265625 0.2890625
0.263671875 0.29296875
0.3125 0.30078125
0.353515625 0.30859375
0.2265625 0.01953125
0.23046875 0.02734375
0.234375 0.0390625
0.244140625 0.046875
0.25 0.05859375
//anal
8
0.40625 0.875
0.37890625 0.71875
0.5390625 0.65625
0.59765625 0.76171875
0.431640625 0.69921875
0.486328125 0.6796875
0.41015625 0.84765625
0.41796875 0.83203125
```

Appendix C

UML Diagram

An UML type diagram to give an overview of the VRFish.

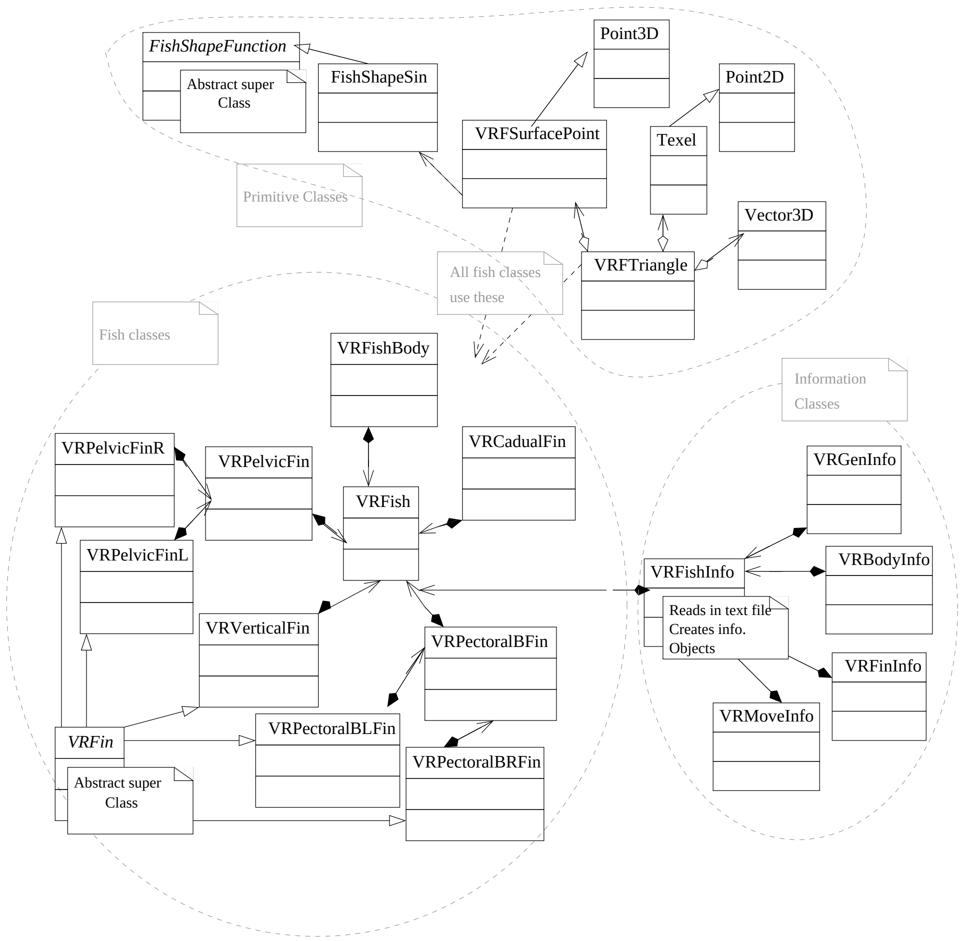


Figure C.1: UML type diagram to show the classes, and their relationships, which make up *VRFish*