Modeling and Simulation of Flying Birds

B. Tech Project I

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Outline

Abstract

- In this presentation, I present you the work I have done in the development of physics-based model of a flying bird and its simulation.
- I propose an intuitive user interface tool which can be used to generate a 3d model of bird directly using the 2d sketches of a bird.

Introduction

- People all across the world are using Physics-based simulation to come close to the Real World.
- Where enough research has been done in field of motion of humans and animals, not very much work has been done in aerial motion.
- In this presentation, I discuss my attempt on development of physics-based model of a bird and a tool I developed to model any bird quickly using its 2d sketches.

Outline

Realistic modeling of bird flight animations

- Wu and Popović 2003 described a physics-based method for synthesis of bird flight animations.
- He modeled the bird as an articulated skeleton with elastically deformable feathers.

Realistic modeling of bird flight animations

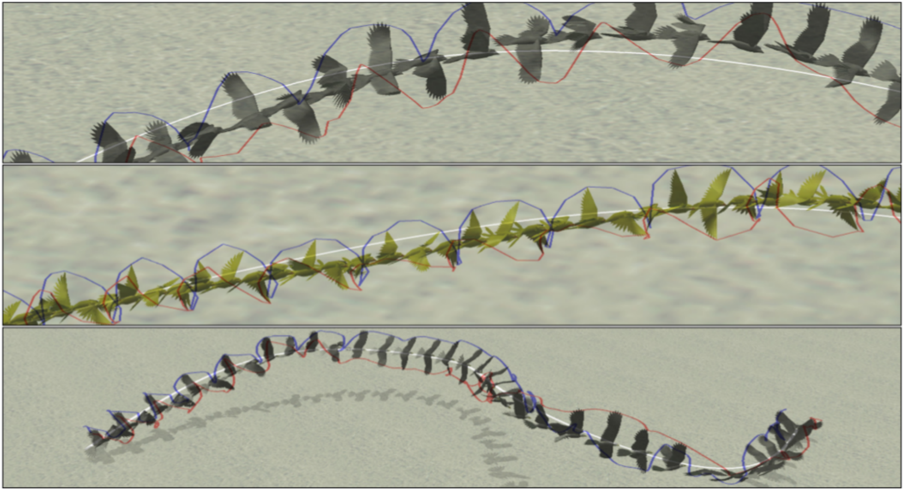


Figure 1: Bird Model by Wu and Popović 2003.

Outline

Modeling and rendering of realistic feathers

- Chen et al. 2002 presented techniques for realistic modeling and rendering of feathers and birds.
- He used L-system to describe the branching structure of feathers of the bird.

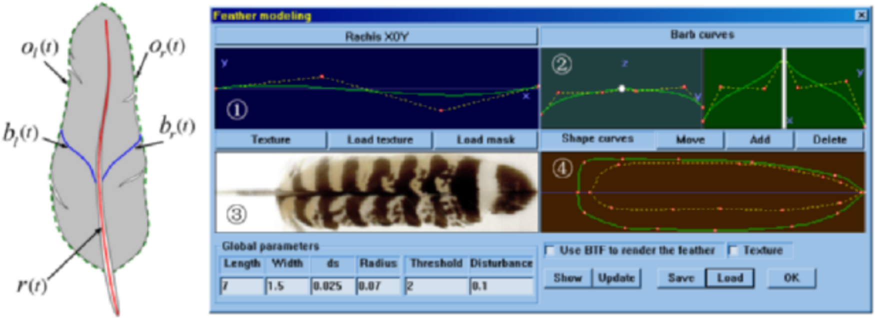


Figure 2: Tool developed by Chen et al. 2002.

Outline

Overview

- Input to system - Bird Specifications. The bird model includes the skeletal structure, mass distribution, and wing feather specification.
- All degrees of freedom can be grouped in a vector $\vec{q}$
- For each Wingbeat, a bird flaps its wing from a neutral position upward, then downward, and then upward to the neutral position again.
- These parameters determine the desired state patterns $\vec{q}(\vec{u}; t)$ for the controllable DOFs during the wingbeat cycle.
- The birds motion is controlled by a proportional-derivative (PD) controller that generates joint torques that bring each of the controllable DOFs $\vec{q}$ towards its desired state $\vec{q}$.

Outline

Bird Dynamics

- The bird is modeled as a hierarchy of articulated links. Each bird has 9 articulated links, 18 joint DOFs(12 local DOF, 6 global DOF to locate position and orientation of bird), and additional DOFs for feathers.
- Ball and socket joints for the wings.
- Articulated Links
  - Torso
  - 2 x Shoulder
  - 2 x Forearm (Divided into two links to model both twist and bend movement)
  - 2 x Wrist

Bird Dynamics

- Joints and Degrees of Freedom.
  - 2 x Shoulder Ball and socket joints. (3 DOF)
  - 2 x Elbow Bend (1 DOF)
  - 2 x Forearm Twist (1 DOF)
  - 2 x Wrist Bend (1 DOF)

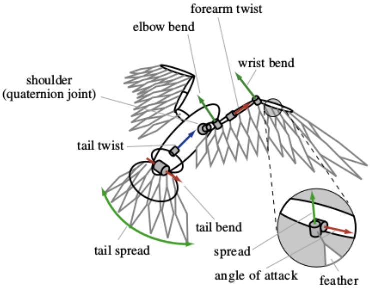


Figure 3: The bird skeleton from Wu and Popović 2003.

Outline

Wingbeat paramaterization

- In order to represent the desired DOF patterns for a wingbeat, set of wingbeat parameters $\vec{u}$ is used.
- The parameters are shown in Table 1.

Parameter	Description
$\vec{u}_1^d$, $\vec{u}_1^u$	arm dihedral angle
$\vec{u}_2^d$, $\vec{u}_2^u$	arm sweep angle
$\vec{u}_3^d$, $\vec{u}_3^u$	arm twist angles
$\vec{u}_4^d$, $\vec{u}_4^u$	forearm twist angles
$\vec{u}_5^d$, $\vec{u}_5^u$	wing spread extents
$\vec{u}_T$	duration of the wingbeat

Table 1: Wingbeat Parameter.

- The superscripts u and d indicate upstroke and downstroke parameters. Most of these parameters are replicated for the left and right wings.

Wingbeat paramaterization

- The dihedral and sweep angles are defined in Figure 4. These parameters are used to determine the composite functions g_k which in turn determine $\vec{q}$:

$$\vec{q}_i(t) = \underline{\vec{q}}_i + (\overline{\vec{q}}_i - \underline{\vec{q}}_i) * g_k(\vec{u}^d_{\mu(i)}(i), \vec{u}^u_{\mu(i)}, \phi(t))$$

where $\overline{\vec{q}}_i$ and $\underline{\vec{q}}_i$ are the maximum and minimum allowed values for DOF i (i.e. the joint limits), and ϕ is the phase of the wingbeat cycle.

Wingbeat parameterization

- Each wingbeat starts with the downstroke, i.e. , $\phi = 0$ is the beginning of the downstroke and $\phi = 2{*}\pi$ is the end of the upstroke.
- The function $\mu(i)$ determines the mapping between DOFs and wingbeat parameters. DOF i is determined by the parameters $\vec{u}^{d}_{\mu(i)}$ and $\vec{u}^{u}_{\mu(i)}$.

Figure 4: Arm dihedral and sweep angle from Wu and Popović 2003.

Wingbeat parameterization

- The composite functions g_k are

$$\mathrm{g}_1\left(\vec{u}_j^d, \vec{u}_j^u, \phi\right) = \left(\vec{u}_j^u - \vec{u}_j^d\right)\frac{1+cos\phi}{2} + \vec{u}_j^d$$

$$\mathrm{g}_2\left(\vec{u}_j^d, \vec{u}_j^u, \phi\right) = \left\{\begin{array}{cc} \mathrm{u}_j^d & 0 \leq \phi < \pi \\ \left(\vec{u}_j^u - \vec{u}_j^d\right)\frac{1-cos(2\phi)}{2} + \vec{u}_j^d & \pi \leq \phi < 2 * \pi \end{array}\right\}$$

- Based on the observations made in the biomechanics literature, the authors of the paper use g_1 for upper arm dihedral and use g_2 for the arm sweep, arm and forearm twists.

Bird Model

- Following everything mentioned in the previous slides, the final model looks like:

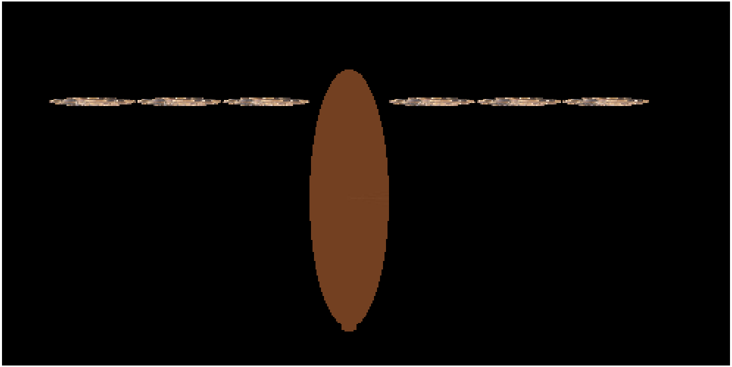


Figure 5: Bird Skeleton

Bird Model

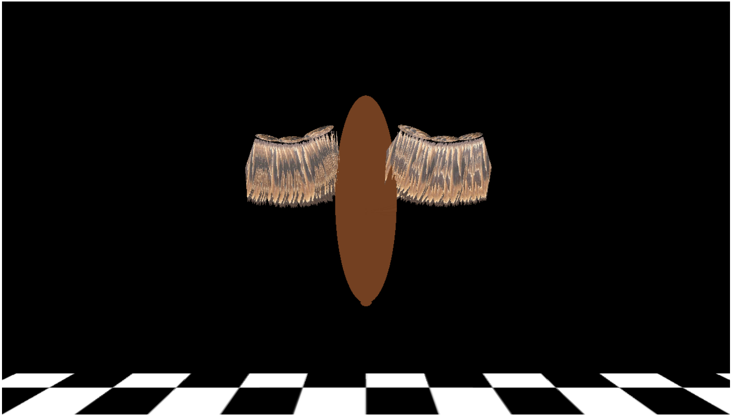


Figure 6: Bird with feathers rolled in

Bird Model

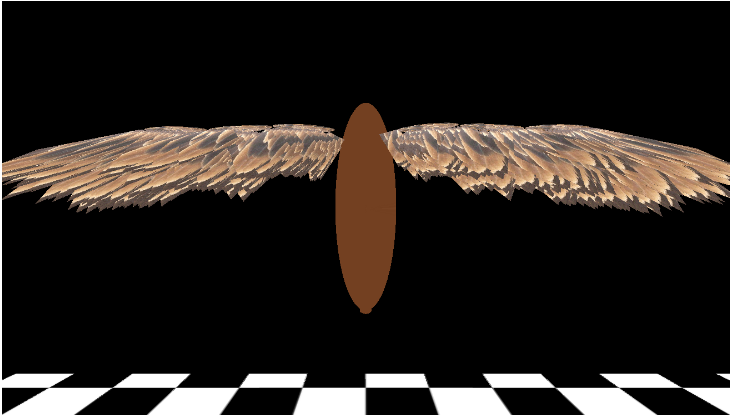


Figure 7: Bird with feathers rolled out

Bird Model

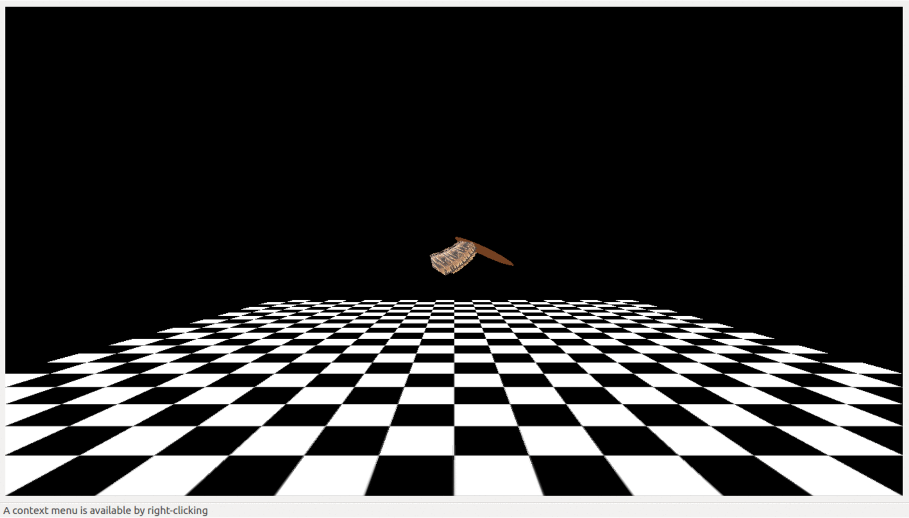


Figure 8: Flying Bird

Bird Model

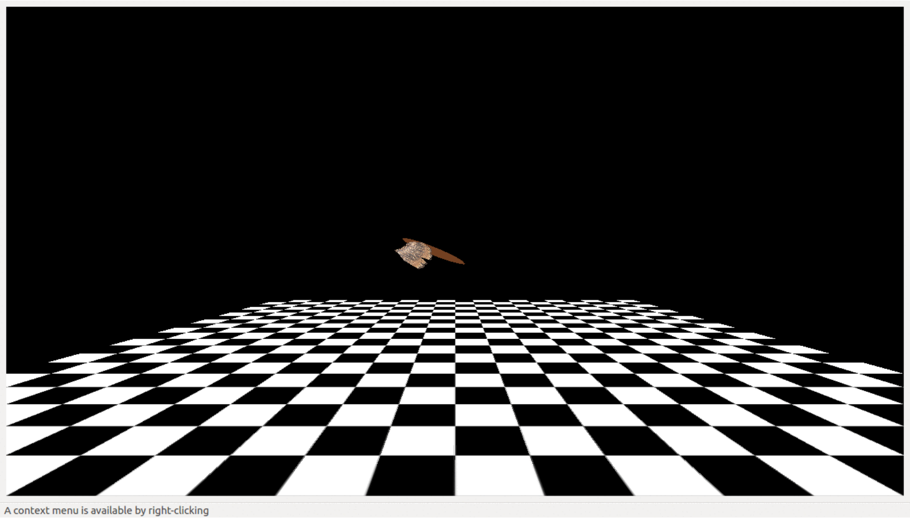
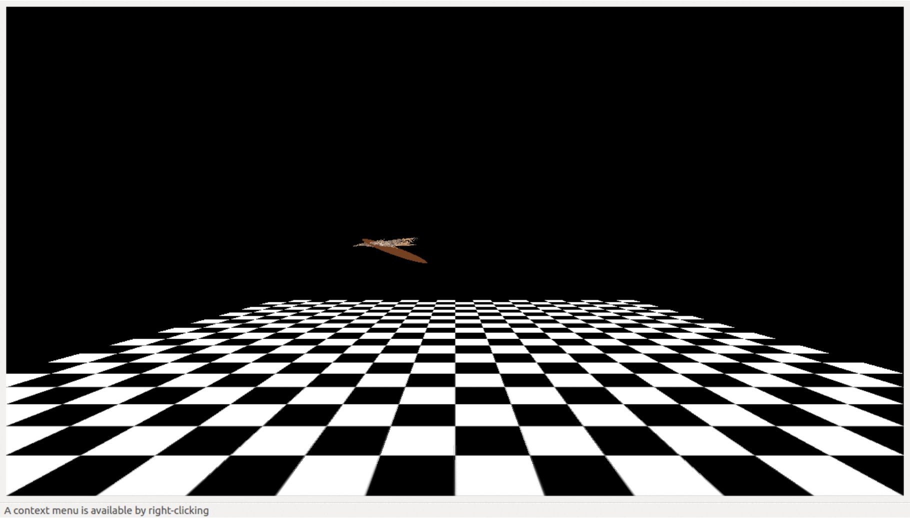


Figure 8: Flying Bird

Bird Model



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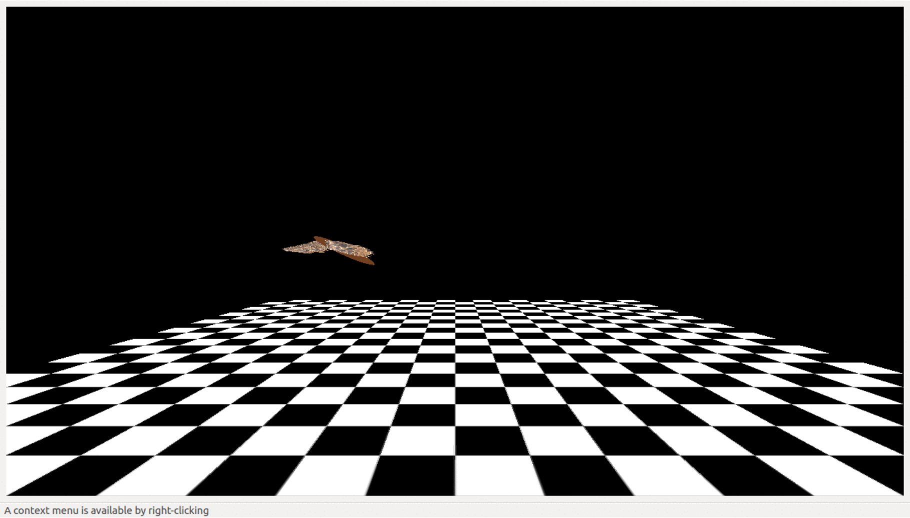

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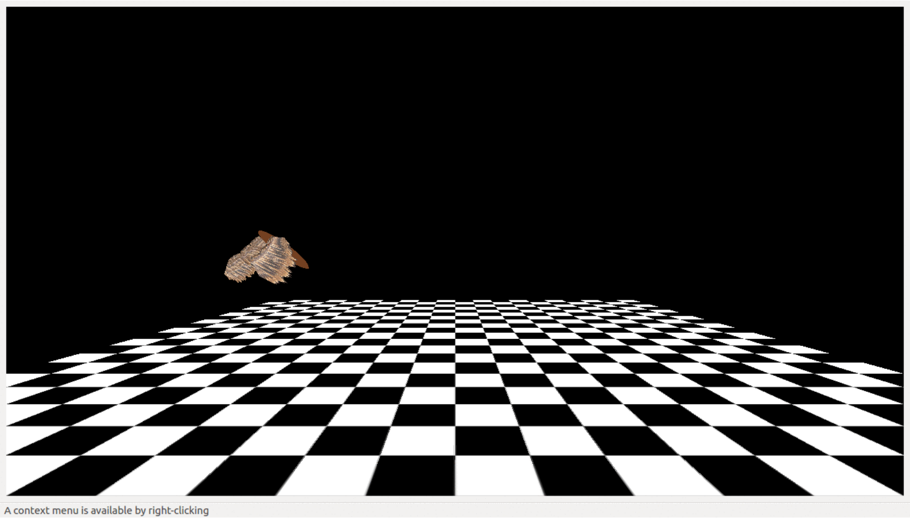
Bird Model



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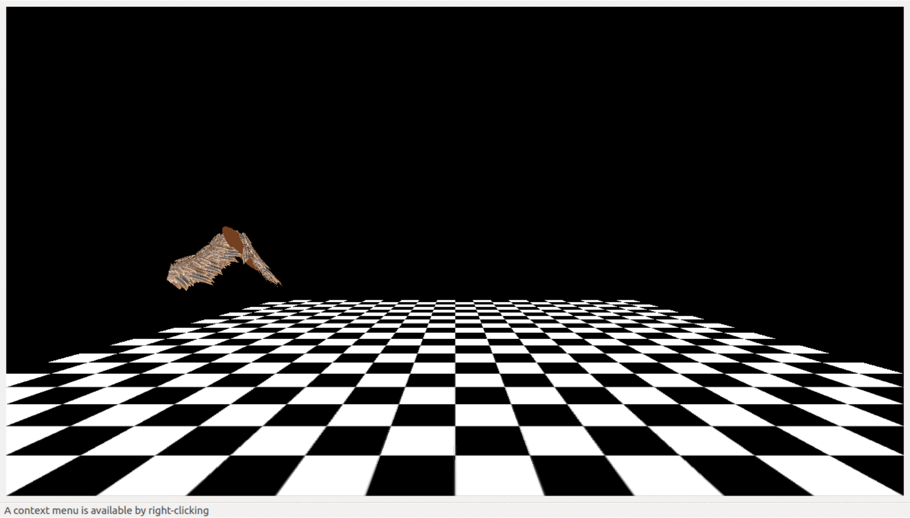
Bird Model



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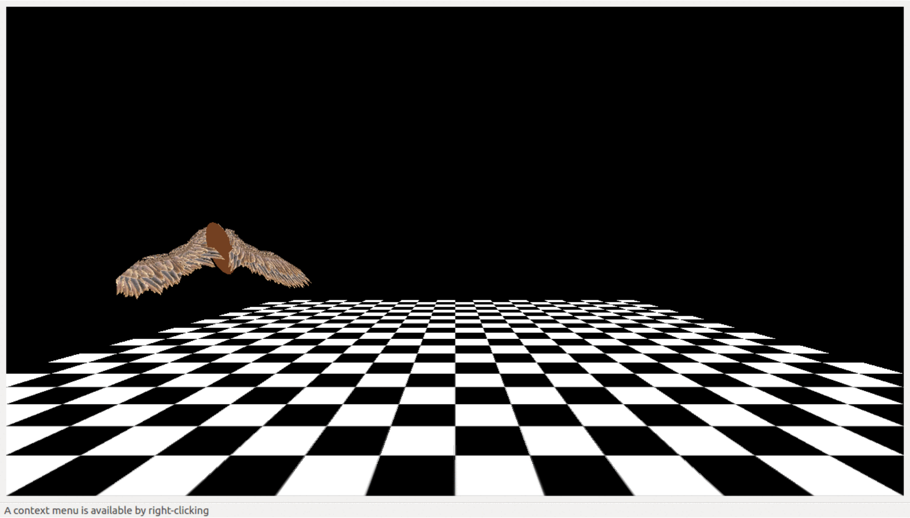

Figure 8: Flying Bird

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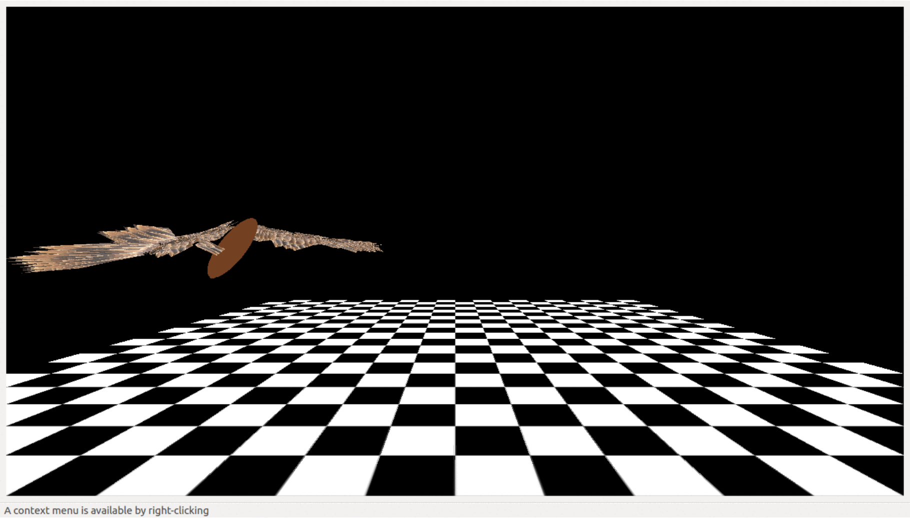

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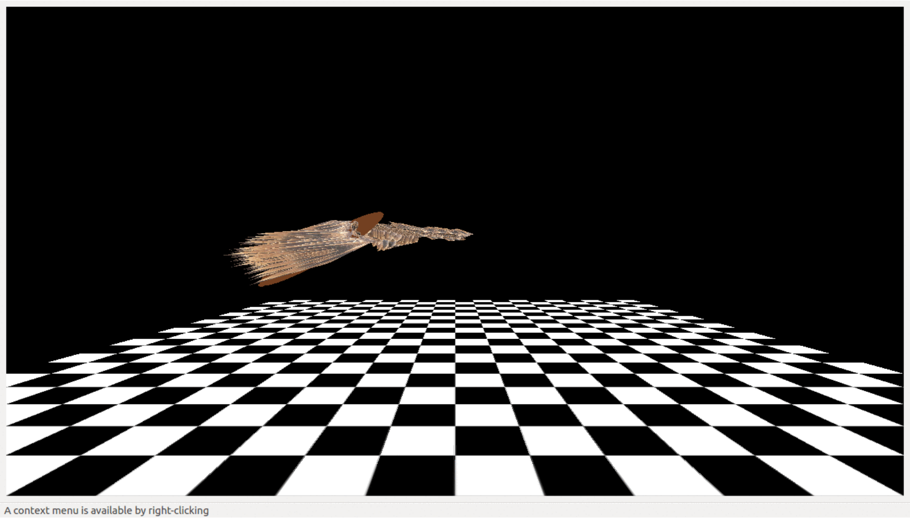

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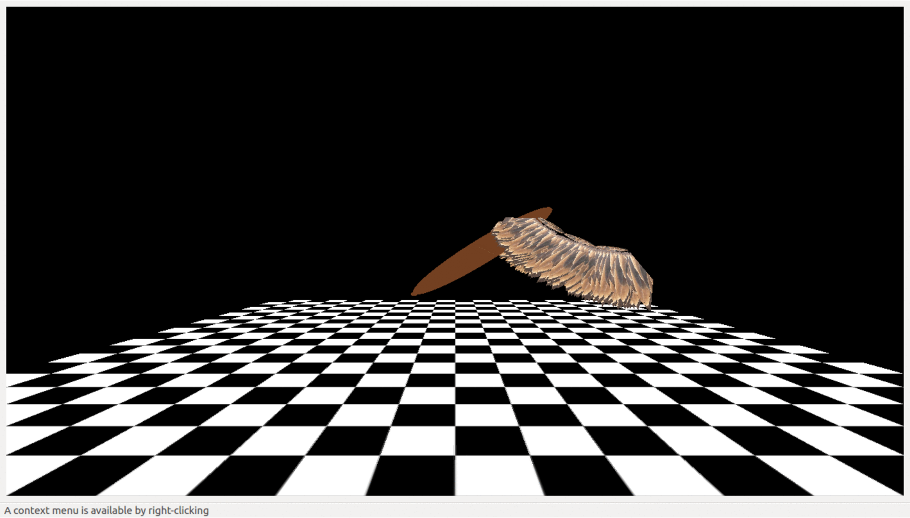

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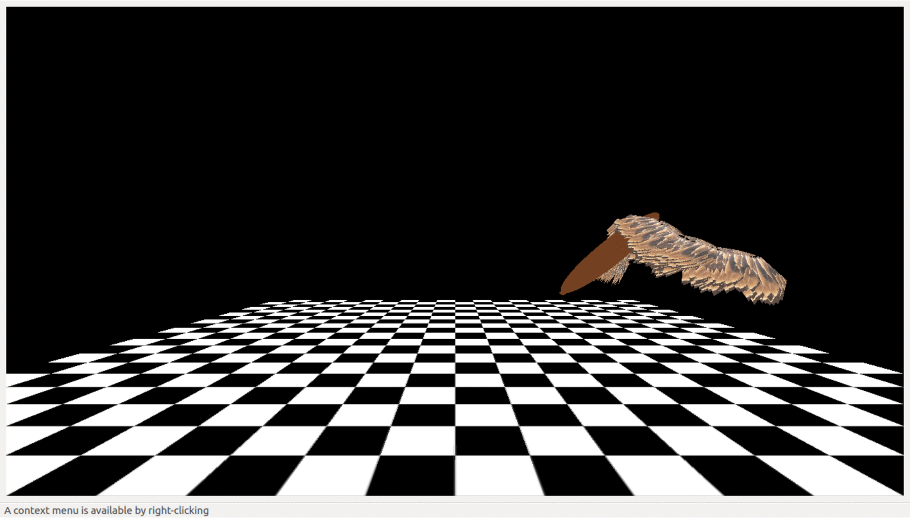

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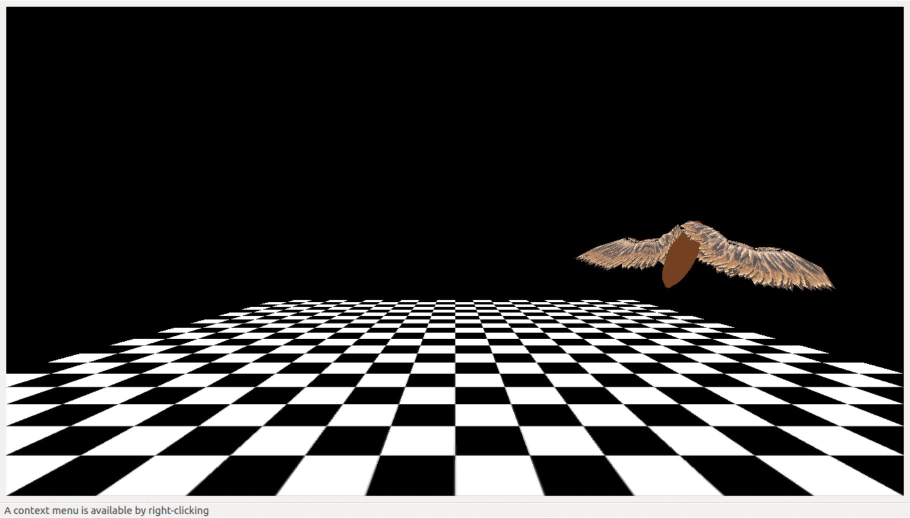

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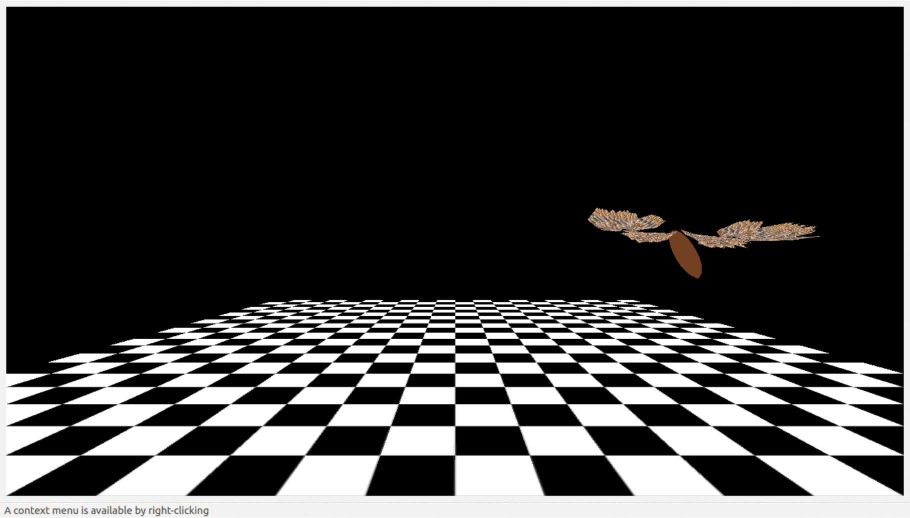

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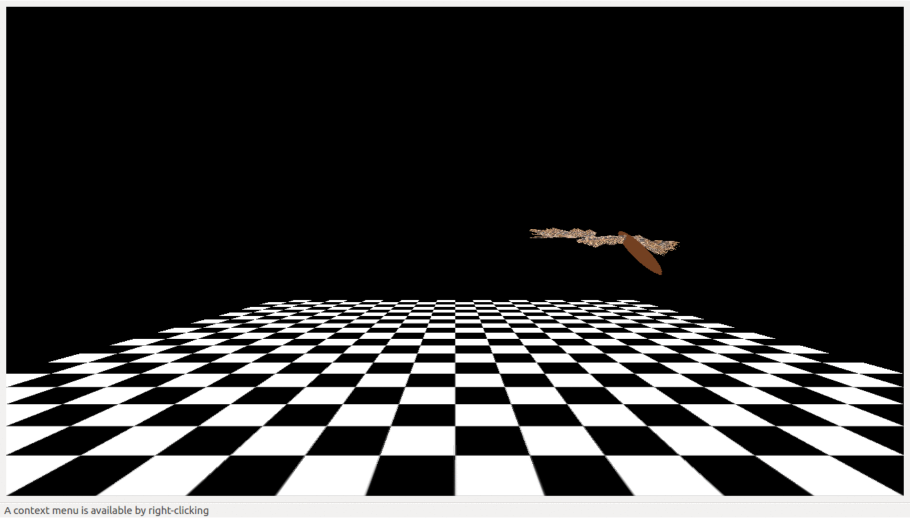
Bird Model



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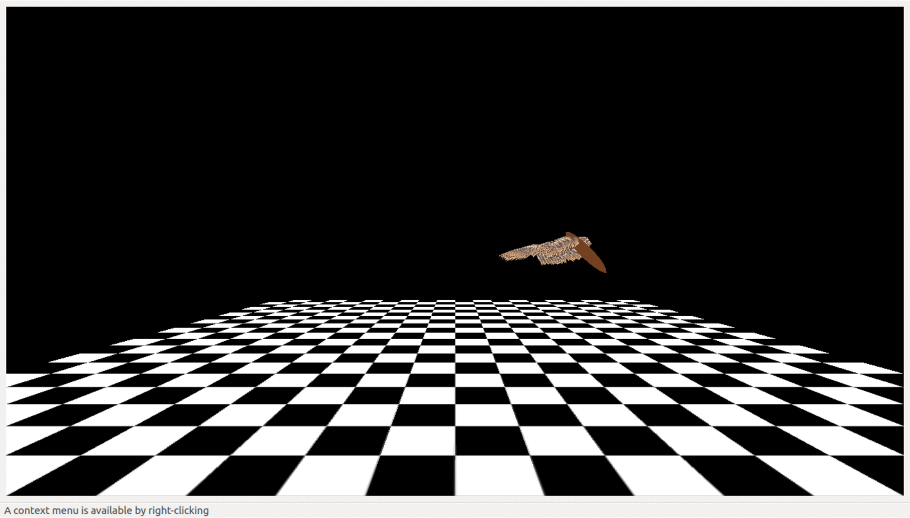

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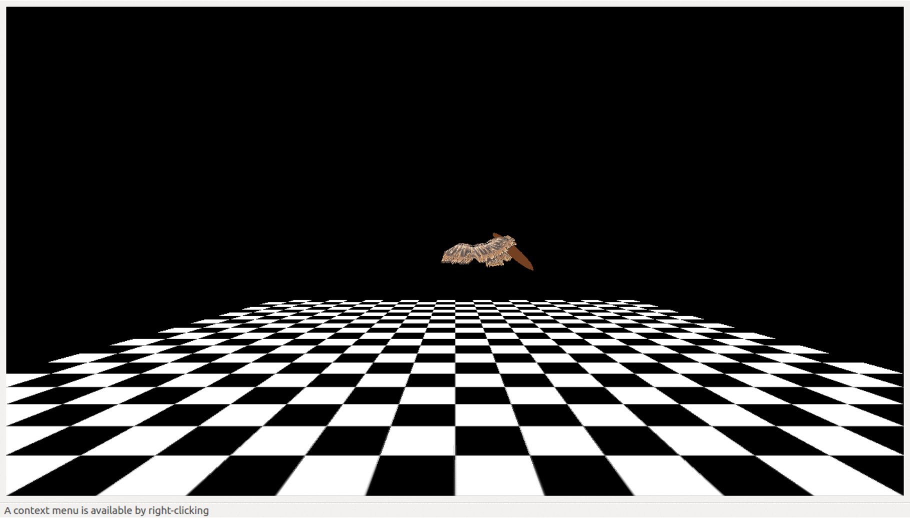

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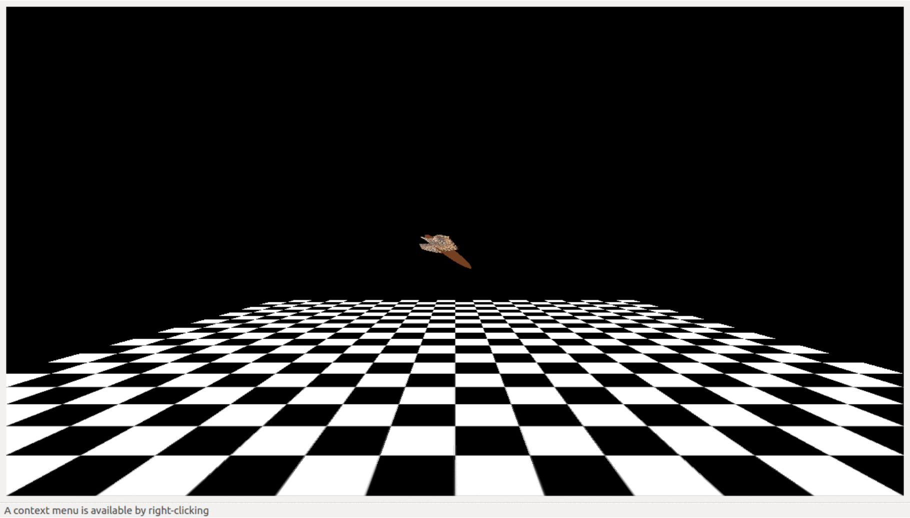

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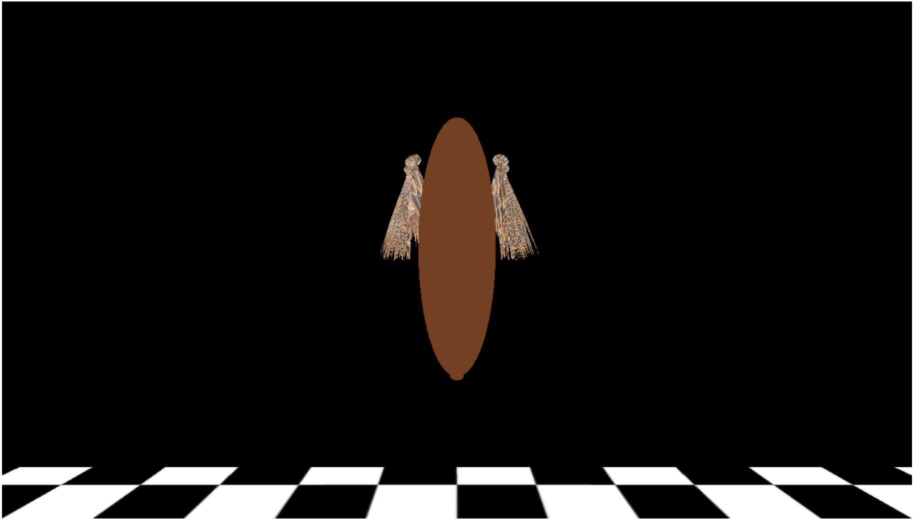
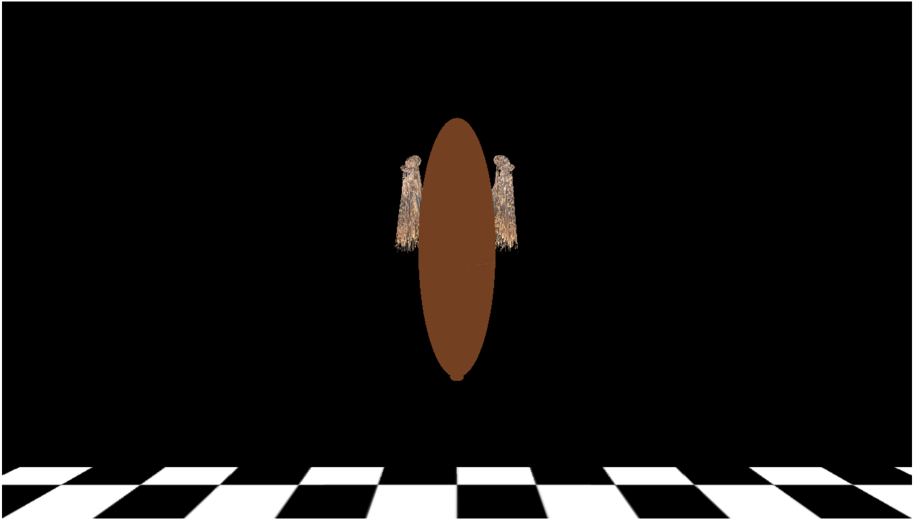


Figure 9: Flapping wings

Bird Model



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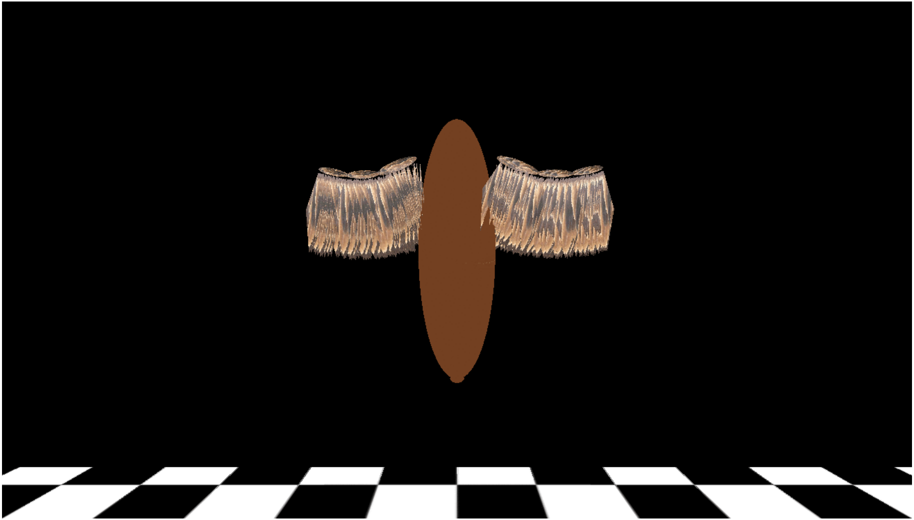

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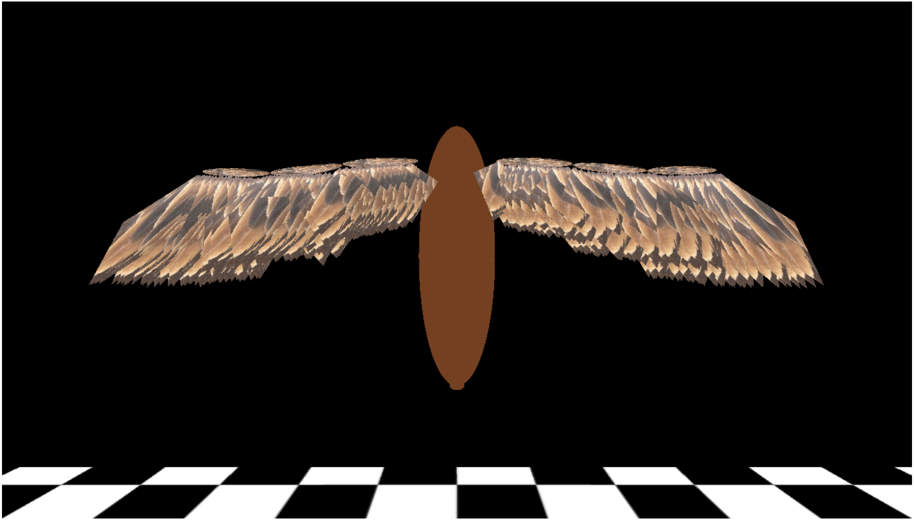

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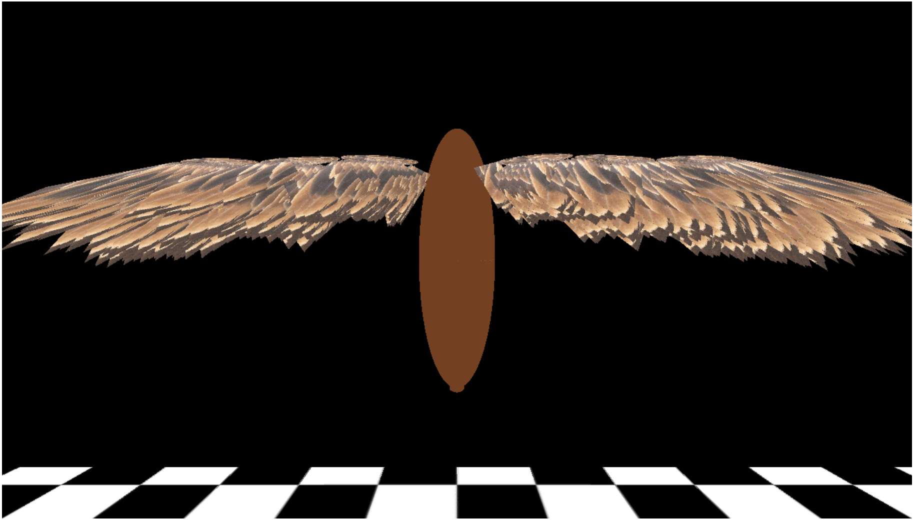

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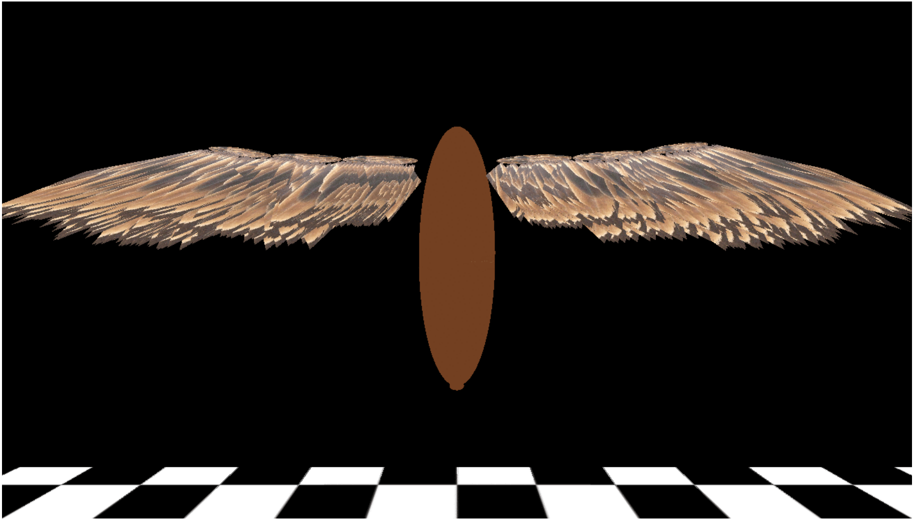

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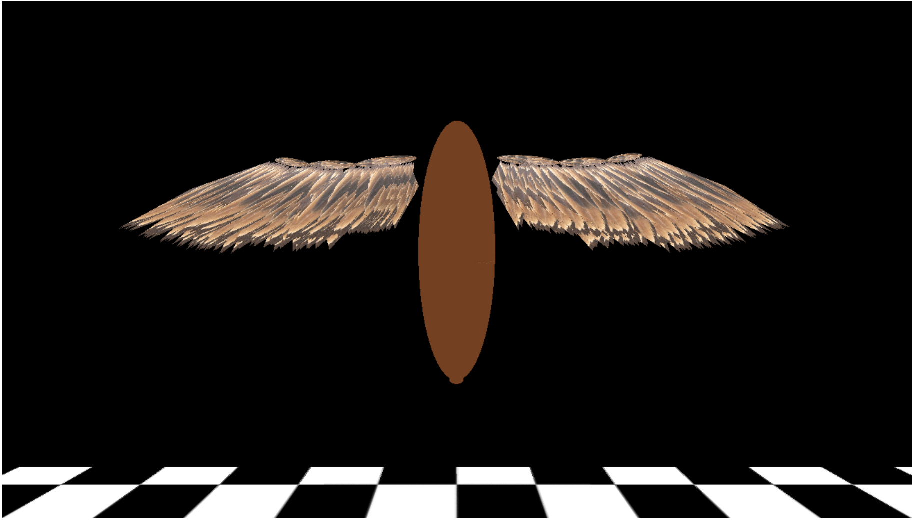

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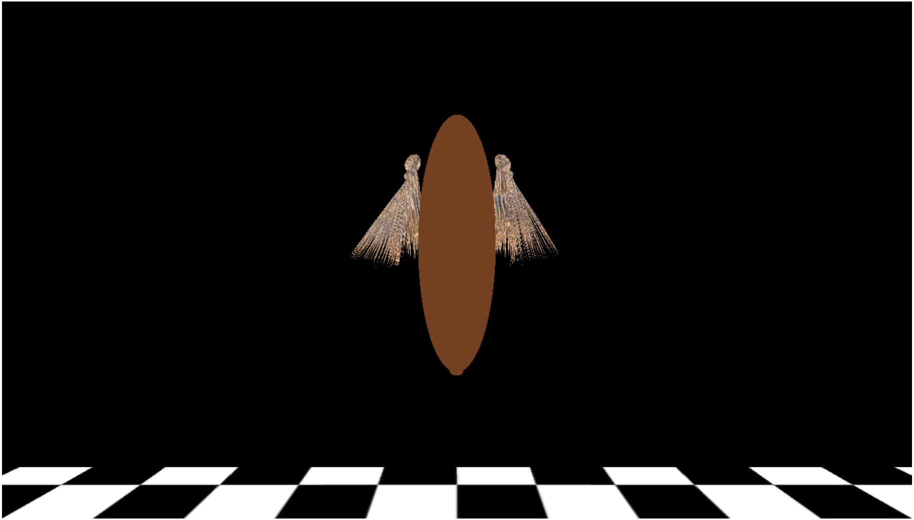

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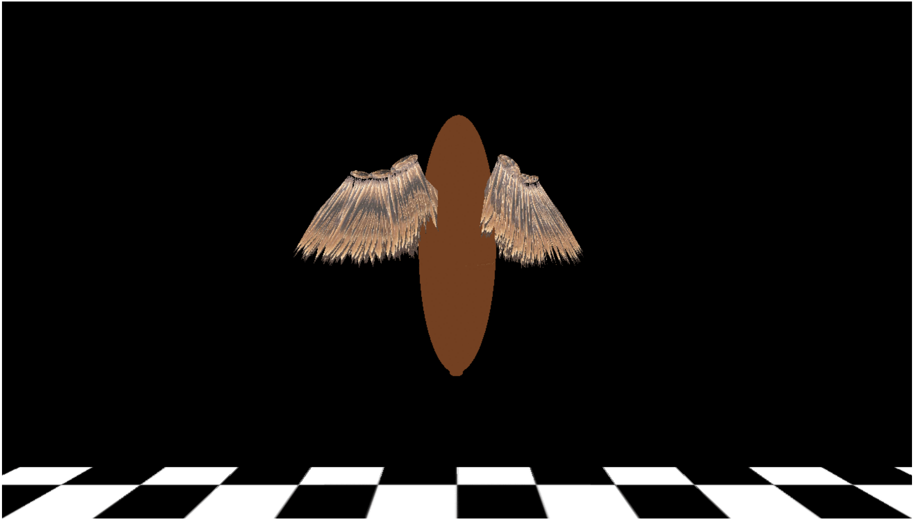

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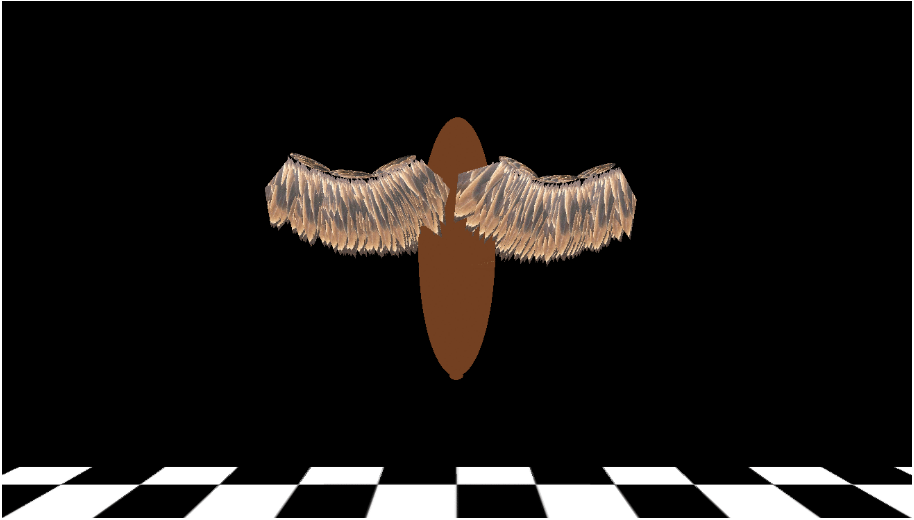

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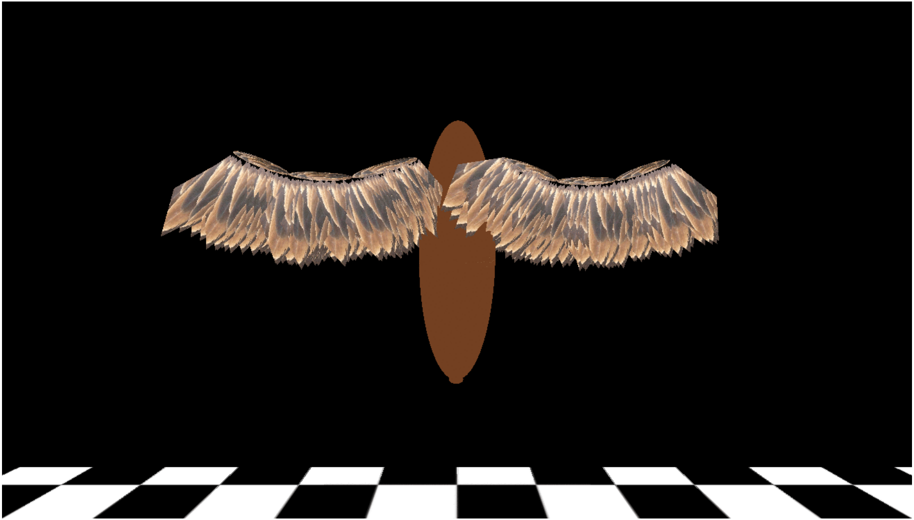

Figure 9: Flapping wings

Bird Model

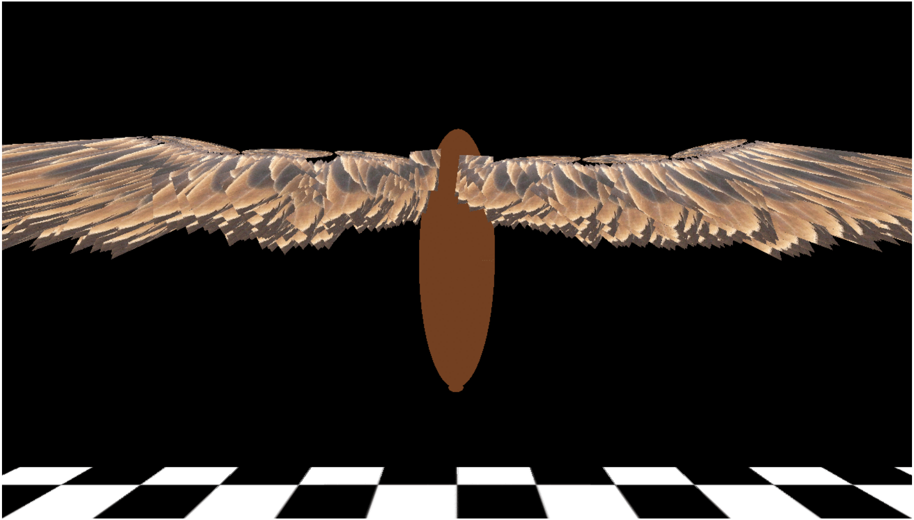

Figure 9: Flapping wings

Bird Model

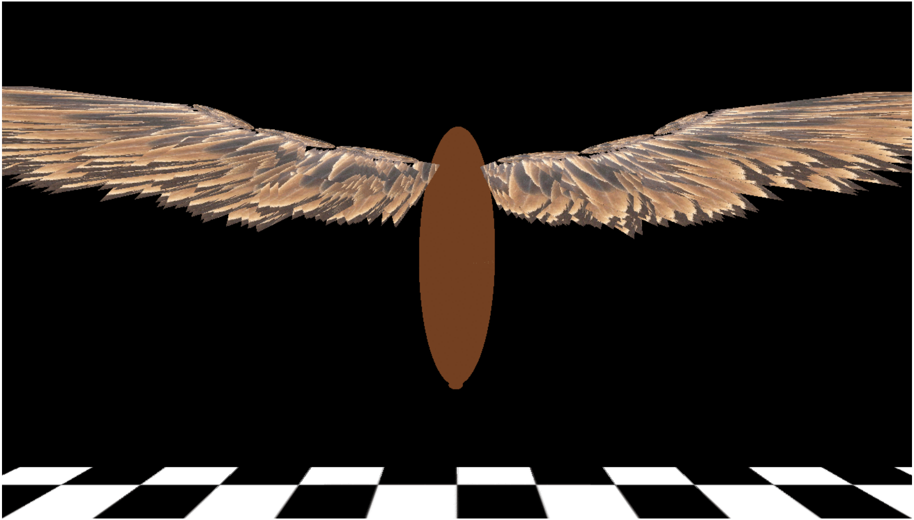

Figure 9: Flapping wings

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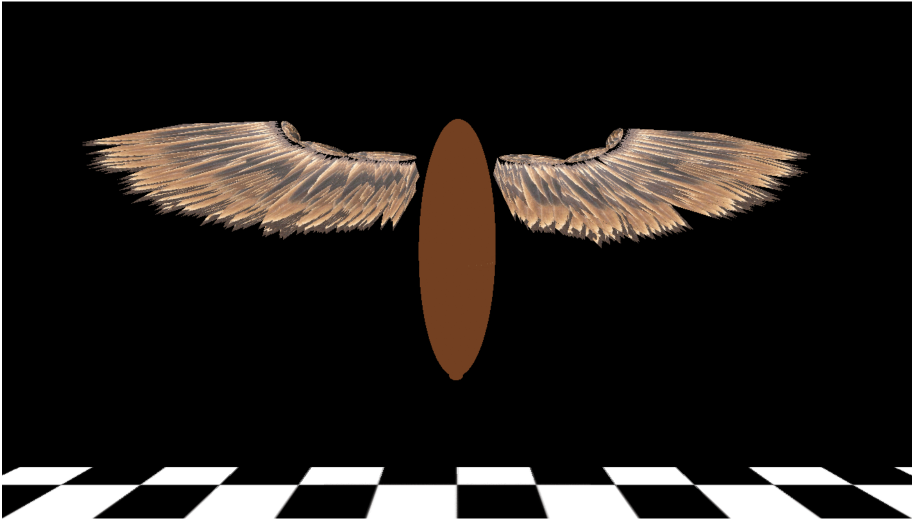
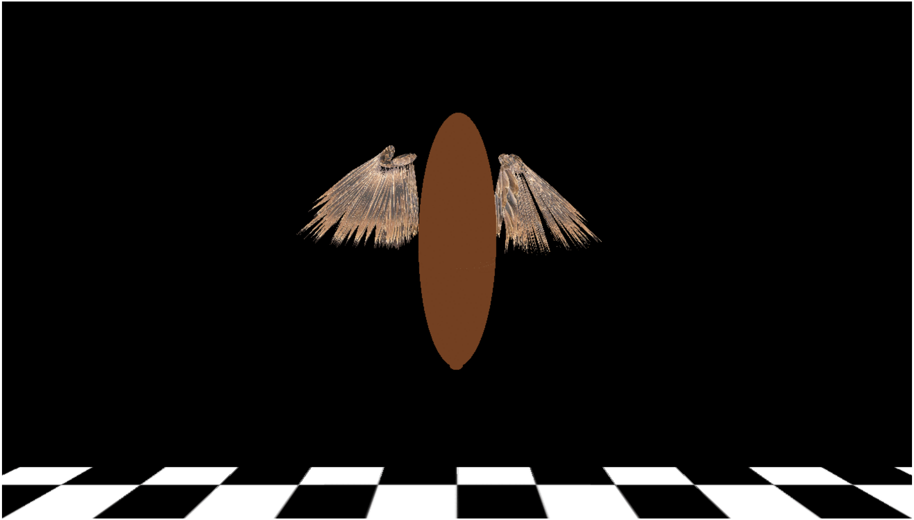


Figure 9: Flapping wings

Bird Model



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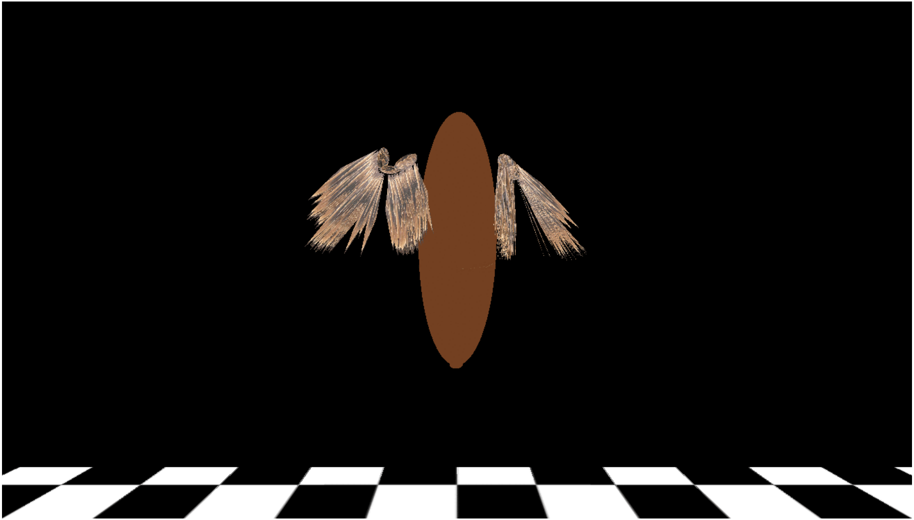

Figure 9: Flapping wings

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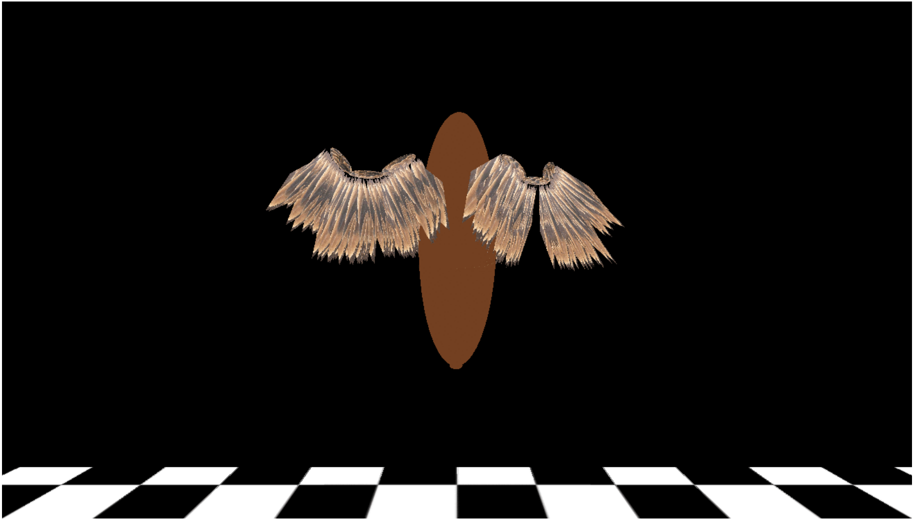


Figure 9: Flapping wings

Bird Model

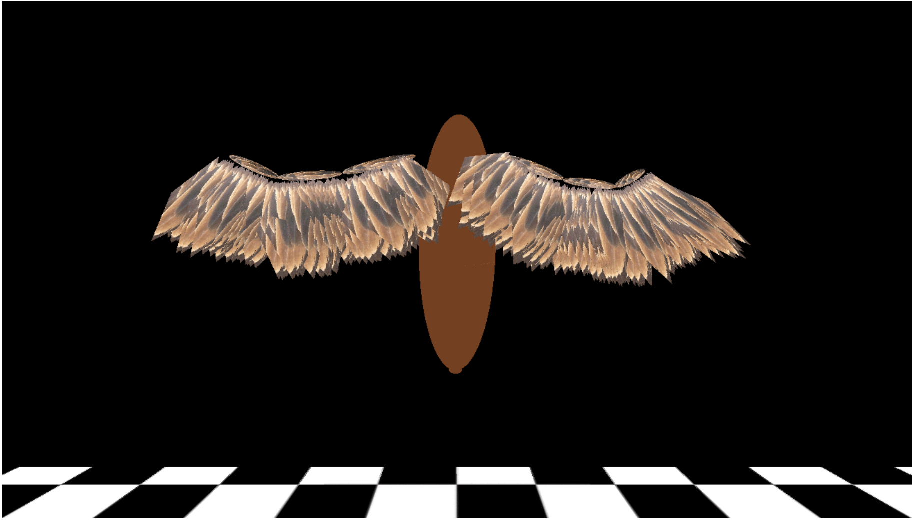
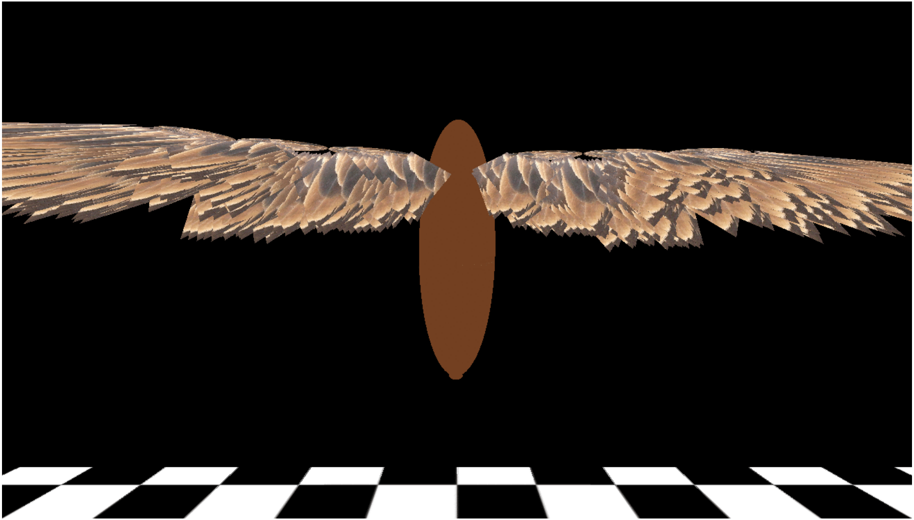


Figure 9: Flapping wings

Bird Model



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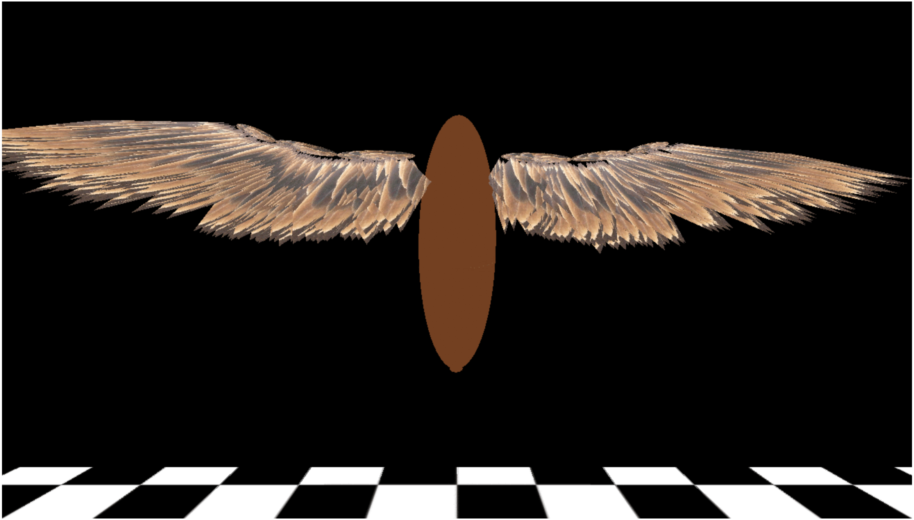

Figure 9: Flapping wings

Modeling Tool

- It is often cumbersome to generate a model of any object from scratch. To ease this process, I have developed a tool to generate a 3d graphical model of bird using the 2d sketches of the bird.
- The model I have used for the bird is very generic right now. The bird has a torso and wings. Using the tool and a top of view of a bird, user can locate the major points on the image.
- I have used Bezier curves for making the sketch, hence by adjusting the control points, the user can fit the final curve on the image. The tool is assuming that the bird is symmetric which makes generatin of model even easier. Figure 10 - 13 shows the tool in action.

Modeling Tool

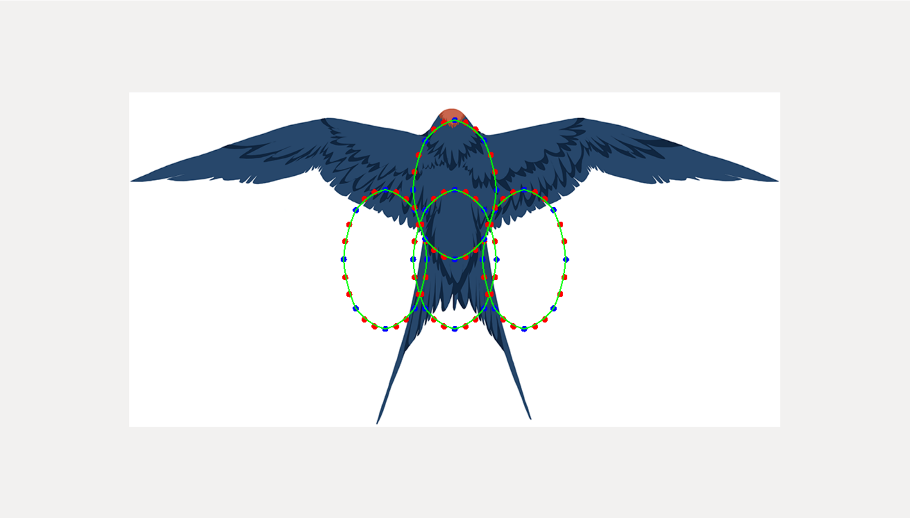

Figure 10: Loading of Image

Modeling Tool

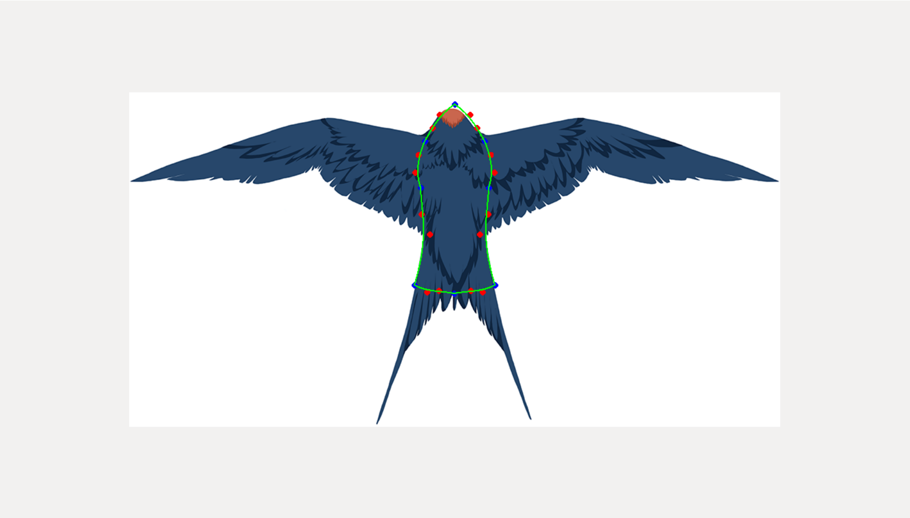

Figure 11: Sketching of Torso

Modeling Tool

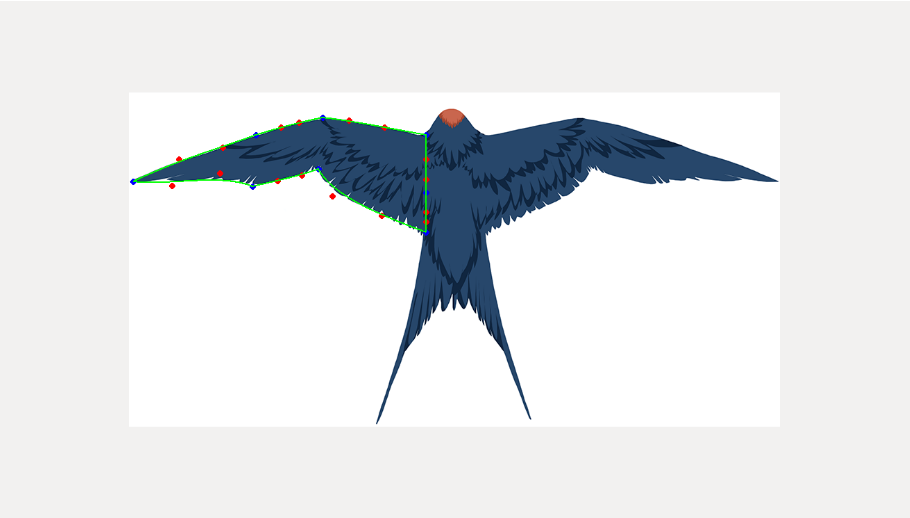

Figure 12: Sketching of Wing

Modeling Tool

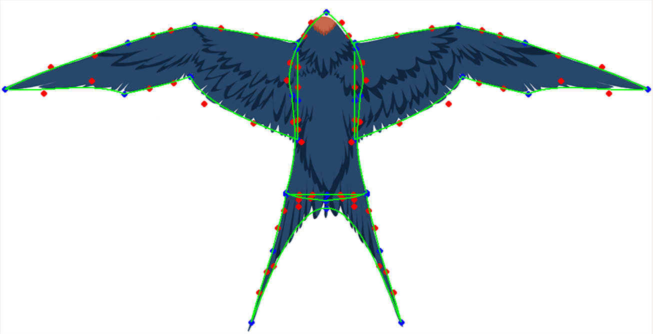

Figure 13: Final Sketch

Future Work

- My next step is to simulate the bird in an actual environment. Right now, I have implemented only the flapping of wings. There exist no external forces on the bird now, the model uses only the internal forces. The external forces will bring quite big challenges to the simulation.
- One of the biggest challenges in physics-based systems is the stability. The model often becomes unstable because of even slightest change in the parameters.
- One major challenge will also be to prevent the toppling of the bird about its center of mass. This will require an enormous amount of calibration and computation of forces at each feather/point. This will also require a good study of aerodynamic forces.
- I will also try to improve the modeling tool. The tool currently takes only the top view of the bird and generate the 3d model using some heuristics. I wish to incorporate all 3 views (top view, side view and front view) to generate better bird models.

References I

Yanyun Chen et al. "Modeling and rendering of realistic feathers". In: *ACM Transactions on Graphics (TOG)*. Vol. 21. 3. ACM. 2002, pp. 630–636.

Jia-chi Wu and Zoran Popović. "Realistic modeling of bird flight animations". In: *ACM Transactions on Graphics (TOG)* 22.3 (2003), pp. 888–895.