*Disclaimer: Sorry this is so bad and unfinished especially the Bezier explanation part. I was really struggling with my mental health when writing this so it’s mainly just notes I tried merging into one piece of text. Feel free to fail me, I’m more than happy to redo it in the summer if I’m allowed. I just wanted to submit something, anything. …………………………………………………………………………………………………………………………………………………………*

**Feather generator – Background and Planning**

**Introduction**

Feathers can be fascinating for the ornithologists, mathematicians and computer graphics programmers and artists. They look intricate on their own as well as when all combined together. They have many functions in nature. Since 1995 people tried to mathematically describe feathers as replicating this amazing structure could be very useful in fields of computer graphics and material engineering.

The aim of this essay is to explore ways to procedurally generate feathers.

Focusing on structure and generation not shading or simulating.

**Ornithology background biology**

Feathers come in a variety of forms but have the same basic branching structure. The central rachis of a feather so the stiff central shaft branches out into barbs that can then branch into barbules with small hooks which allow the feather to have a nice smooth form. The hollow barbless base of the rachis is called the calamus. Feathers structure can be divided into plumulaceous and pennaceous. Plumulaceous parts characterise with loosely arranged flexible barbs, they look fluffy and often provide the birds with necessary insulation. An example of a plumulaceous structure can be downy feathers. Pennaceous feathers are stiff, mostly flat and smoother looking. This effect is created because of the tightly interlocking barbules. Those structures are popular in wing and tail feathers which often have to be wind- and water- proof to allow the birds to fly and stay dry. A lot of feathers can be a blend of both plumulaceous and pennaceous structures, like for example contour feathers.

We distinguish around 7 main categories of feathers based on their structure and location: wing, down, tail, contour, semiplume, filoplume and bristle. Wing and outer tail feathers can have asymmetric vanes (sides of the feather made of barbs). The feathers have many functions and some things about them remain a mystery and an object of ongoing research. (Thompson 2013)

Judging by all of the biological structure information outlined above the tool I am creating needs to allow for creation of both plumulaceous and pennaceous structures as well as let the artist blend between the two. It also must allow for the asymmetry of vanes, breaks in the structure of barbules to make the feather look more realistic. It should also allow to control lengths of the calamus, rachis and the barbules, amounts of barbules, spacing between them and the general shape of the feather. It also needs to allow for controlling the width of the calamus and rachis.

**Papers methods I’m using and which ones I rejected**

Feathers are still quite a new area with first attempts of describing them mathematically date back to 1995(Dai et al. 1995). Their fascinating structure is very heavy to generate therefore studios tend to develop their own tools and pipelines to create an illusion of feathers without actually generating all of the geometry.

Based on (Zhang and Kanai 2020) and my own discussions with the industry, currently artists tend to

* use polygon meshes to model large feathers and accompany them by fur to express fine details
* model barbs as line segments and rely on shaders to get the details and right look
* generate barb curves from deformed polygon or NURB surfaces
* have studio specific tools that base of Yeti or Houdini hair and fur generation pipelines
* another way to create the illusion of feathers can be using cards and different alpha channel values

Numerous papers mention that it is possible to generate feathers using L-systems or particle systems but in my opinion it would be much more than I need, so I decided to focus more on the Bezier curves based methods.

As one of the Bezier curves centred feather generation papers claims: *“It is desirable to be able  to  create  a  wide  range  of  results without having to model each substructure on every feather”* (Streit and Heidrich 2002) The publication debates that feathers are much more complex than hair due to having coarser components, varieties in colours and patterns that can reveal the approximations in underlying textures. It claims that feathers are more akin to plants as both present branching patterns. Yet it argues that a different approach is needed as “*with plants the location and type of the branch varies much more than with feathers a collection of plants is not as specific an arrangement as feathers where a specific look to the feather coat is desired”* (Streit and Heidrich 2002). Therefore L-systems, even though widely used to represent the branching structures of plants would probably be redundant in this case. Moreover, the specific look of feathers suggests that more artistic control is needed than over plant structures, which again argues against the typical plant creation workflows.

They base their model on the smooth aerodynamic nature of the surface of the feather and simplify it enough to not to generate any unnecessary detail but also provide enough parameters to control the generation that it makes the model able to generate a variety of results. “A Bezier Curve of varying degree is used to approximate the curvature of the substructures in the feathers. Interpolation between the parameters and control points of the curve allows for smooth changes in the feather structure, and the tessellation of the Bezier curve allows us to control the level of detail.” (Streit and Heidrich 2002) They also use something like guide hair, commonly used in groom tools but more specific to feathers in this case.

Model presented in *Modeling and rendering of individual feathers* byFranco and Walter seems very similar to Streit and Heidrich. Both papers were published independently around the same time, which is funny as Bezier Curves that are the base of their methods were also independently developed in 1960s by Bezier and de Castelieu. This publication seems to have nicer rendering of images but generally the idea of parametrisation and which parameters to use in order to correctly generate the feather is similar. There are some minor differences in the way the vanes are defined by curves as here there are 2 curves that become the vanes boundaries and specify the general shape of the feather kind of enclosing it inside, unlike previous model which used more curves at the bottom and topof the rachis and interpolated between them to create key barbs and barbs. (Streit and Heidrich 2002) “To model a single feather, the user initially defines a cubic Bézier, which represents the rachis, and two Bézier curves with five control points, that define the boundaries of the overall feather structure (the vanes). From the rachis we generate a variable number of barbs, controlled by the parameters explained below. Each barb is itself a Bézier segment with 4 control points.” (Franco and Walter 2002)

The results from the Bezier generated feather models both have limitations, but some of them could be adjusted or improved. Both models seem to have very sharp edges of the feathers and lack the natural fuzziness. It could be changed by different thickness of the curves of the barbs or by using second model method to define some thickness attributes at the edges of the vanes. But all that is further development.

The newer methods of generating feathers seem very different. Zhang and Kanai decided to follow the natural feather growth as closely as possible and use particle systems and velocity fields in order to generate the feather shapes. Their model seems overly complicated for my purposes as I am planning to use my generated feathers further in groom, not so much focus on the growth process of the individual feather. The method seems much more demanding and complicated when it comes to calculations and algorithms but for situations when a very close up 3Dvisualisation of feather growth is needed it would be perfect and definitely better than simple curve generated structures. However this paper presents very insightful summary of the 2 publications mentioned above “An important parameterized approach proposed by Streit et al. [5] elaborately defined geometry properties for rachis and barbs. The rachis was modeled by a cubic Bézier curve, and barbs were generated by interpolating multiple key Bézier curves along the rachis. In the same year, Franco et al. [6] independently presented a similar parameterized approach, but unlike the previous one, two Bézier curves were used as the outline, and the control points of barb Bézier curves were randomly generated.” (Zhang and Kanai 2020) This method would be perfect when a lot of biological accuracy is needed but as I find the artistic control more important as it allows for more varied designs and possibility to be used both for realistic and stylised feathers, I find the two previous models more likely to provide me with what I need. My goal is to give enough artistic control to the user but also keep the model as simple and efficient as possible and Bezier curve based methods seem like a good start for that.

**Bezier curves maths explanation**

Bézier curves are used to model smooth curves that can be scaled indefinitely. (Devroye, 2017) The easiest way to define the Bézier curve is that it is a result of linear interpolations.

Bezier curves can be generated using linear interpolation. They are basically a type of Bernstein polynomials. The parameter t helps interpolate between the points and to draw the curve.

I explained Bezier curves a few years ago in another written piece about them that can be found here: <https://drive.google.com/file/d/1ORXyWCLh-VKiY5wMWoZYlDkiCfaU0y0P/view?usp=sharing>

**Feathers generation algorithms explanation**

My method is pretty much an implementation of the methods by Streit and Heidrich and Franco and Walter.

**Summary/conclusion**

Expansion how to make it intuitive with a nice UI etc.

**References**

Streit, L. and Heidrich, W., 2002. A Biologically-Parameterized Feather Model. *Computer Graphics Forum* [online], 21 (3), 565–573. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/1467-8659.t01-1-00707?saml\_referrer [Accessed 31 Jan 2022].

Franco, C. G. and Walter, M., 2002. Modeling and rendering of individual feathers. *Proceedings. XV Brazilian Symposium on Computer Graphics and Image Processing* [online]. Available from: https://ieeexplore.ieee.org/abstract/document/1167157?casa\_token=H7dgsZohCYgAAAAA:u2vSB6gZ9btROSFvSGp\_RdtFabARI4gh9aC1bOcGWuwwOo5vsBJ\_5vgE7E5EC3axrYY21QtOuw [Accessed 31 Jan 2022].

Thompson, M., 2013. *Everything You Need To Know About Feathers | Bird Academy • The Cornell Lab* [online]. Allaboutbirds.org. Available from: https://academy.allaboutbirds.org/feathers-article/ [Accessed 31 Jan 2022].

Zhang, J. and Kanai, T., 2020. Biological Modeling of Feathers by Morphogenesis Simulation. *2020 International Conference on Cyberworlds (CW)* [online]. Available from: https://ieeexplore.ieee.org/abstract/document/9240548?casa\_token=ub0C-0bBiyYAAAAA:kKzTTX9zJY-HIbcw2K48wF7gcWT\_SoCu1EPdNTBn1RH979qsCfRc7me7-KvKTrd0YIRfV77WsQ [Accessed 31 Jan 2022].

Devroye, L., 2017. *Bezier curve* [online]. Devroye.org. Available from: http://luc.devroye.org/fonts-71090.html [Accessed 31 Jan 2022].

‌

W. Dai, Z. Shih and Z. Chang, "Synthesizing feather textures in galiformes", EUROGRAPHICS'95, pp. 407-420, August 1995 [lack of source, hard to find the original text only indirect fragments from other sources]

Mike 'Pomax' Kamermans, 2020. *A Primer on Bézier Curves* [online]. Github.io. Available from: https://pomax.github.io/bezierinfo/ [Accessed 31 Jan 2022].

<https://www.jasondavies.com/animated-bezier/> nice demo to play with bezier curves

<https://www.desmos.com/calculator/d1ofwre0fr?lang=pl> desmos Bezier demo