

# Deforming Pages of 3D Electronic Books (sketches\_0135)

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## 1 Introduction

By adopting a 3D book metaphor which preserves the look and feel of a physical book in its electronic correspondent, a virtual 3D book can be used as a basic component of e-book systems, information workspaces, and digital libraries. One major challenge in creating 3D books is designing a mechanism for turning the pages. Chu et al. [Chu et al. 2003] reported an ongoing work that simulated page turning using a cloth simulation model. Their implementation took from minutes to hours to calculate a single page turning. Since cloth typically exhibits a stretchy effect, the cloth model may not be ideal to simulate stiff objects like papers. In this paper we present an alternative which produces a realistic page turning effect.

## 2 Page Curling

In our design, page turning consists of two concurrent processes, namely a *rotation process* and a *deformation process* [Hong et al. 2004]. The rotation process gradually rotates a page around the book bindings from one side of the book to the other side of the book. The deformation process, on the other hand, curls the turning page around an imaginary cone of changing sizes to produce various curved shapes at different frames of page turning. This deformation process was inspired by our experiments showing that people turn pages by the corners.

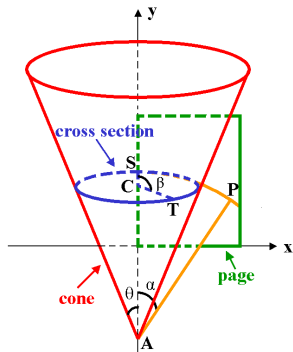


Figure 1: Curling a page around a cone.

Without loss of generality, suppose that a page lies on the  $XY$ -plane, with its bottom page and left page aligning with the  $X$  axis and the  $Y$  axis, respectively (see Figure 1). We lie a solid cone on the  $XY$ -plane. The side (not the axis) of the cone touches the  $XY$ -plane along the  $Y$  axis, holding the left edge of the page still. Curling the side of the cone results in a curved page. By varying the cone angle  $\theta$  and the cone apex  $A(0, A_y, 0)$  over animation time  $t$ , we obtain different curved pages. Specifically, at the beginning of page turning, we start with a cone whose angle  $\theta$  is 90 degrees, making the page wrapping around it virtually flat. Then, we gradually reduce  $\theta$  and move  $A$  down the  $Y$  axis, causing the page to curl up from the  $XY$ -plane, with its lower right corner lifted ahead of the rest of the page. Finally, we translate  $A$  further down the  $Y$  axis to infinity, making the page uncurl into a flat surface at the end of the animation.

As shown in Figure 1, given a point  $P(P_x, P_y, 0)$  on the page, we need to calculate where on the side of the cone it maps to. Let us draw a circle of radius  $R = |AP| = \sqrt{P_x^2 + (P_y - A_y)^2}$  around  $A$  on the  $XY$ -plane, and denote the intersection between the circle and the  $Y$  axis as  $S$ . The cone geometry tells us that, when we wrap the page around the cone, arc  $\widehat{SP}$  will coincide with a circular cross

section that is parallel to the base of the cone and goes through  $S$ . Assuming that  $P$  maps to point  $T$  on the cross section, we have  $|\widehat{ST}| = |\widehat{SP}|$ . Let us denote the center of the cross section as  $C$  and the angle  $\angle SCT$  as  $\beta$ . We have

$$\beta = \frac{|\widehat{ST}|}{r} = \frac{|\widehat{SP}|}{r} = \frac{\alpha R}{R \sin \theta} = \frac{\alpha}{\sin \theta}, \quad (1)$$

where  $r$  is the radius of the cross section and

$$\alpha = \angle SAP = \arcsin\left(\frac{P_x}{R}\right). \quad (2)$$

Now  $T(T_x, T_y, T_z)$  can be computed by first rotating  $S$  around line  $(X = 0, Z = r)$  by  $\beta$  to point  $S'(S'_x, S'_y, S'_z)$ , and then rotating  $S'$  around line  $(Y = S_y, Z = 0)$  by  $\theta$ . In short,  $T$  can be computed as

$$\begin{aligned} T_x &= S'_x = r \cos\left(\beta - \frac{\pi}{2}\right) = r \sin \beta, \\ T_y &= S'_y - S'_z \sin \theta = R + A_y - r(1 - \cos \beta) \sin \theta, \\ T_z &= S'_z \cos \theta = r(1 - \cos \beta) \cos \theta. \end{aligned} \quad (3)$$

To this end, we combine the deformation operation with the rotation operation. This yields the page geometry which is subsequently rendered to produce an animation frame. In our implementation, the functions  $\theta(t)$  and  $A_y(t)$  were empirically constructed to ensure that the animation is smooth.

## 3 Results and Discussion

We have integrated the algorithm described above into a 3D book system that we recently developed. Due to the simplicity of the algorithm, we compute the page geometry *on the fly* at each animation frame. On our laptops or tablet PCs, we are able to turn pages at interactive speeds of 5 to 20 frames/second. Figure 2 shows two frames of a page turning animation. Contrary to the cloth simulation model [Chu et al. 2003], our page curling technique introduces neither stretching nor compressing to the turning pages because of the cone geometry.

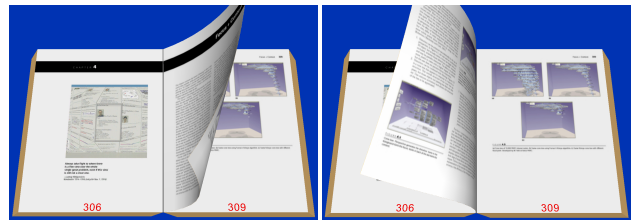


Figure 2: Two frames of a page turning animation.

## References

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