Animating the Combustion of Deformable Materials

Sameer Moidu James Kuffner Kiran S. Bhat

Carnegie Mellon University

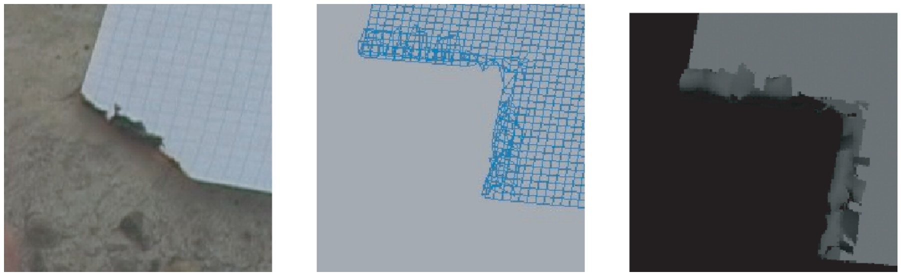

Figure 1: *Left to right*: One frame of real paper deforming under combustion, a wireframe mesh and a rendered result in simulation.

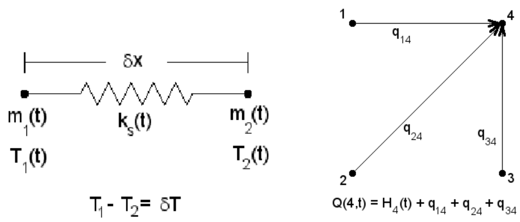

Figure 2: Schematic of the spring mass model and state variables.

Abstract

We present a physically based model for animating the deformation of objects like paper or cloth under combustion. We approximate the temperature changes in the material using a linear conduction model and apply thermal forces on a spring mass system that causes the material to deform as it burns.

1 Introduction

Physically based simulation techniques have been widely used to create realistic animations of smoke and flames [Fedkiw 2003]. Although these techniques model the complex air-fuel boundary during combustion, they do not account for the deformation of the underlying combusting material. This effect is particularly important while animating the combustion of common objects like paper or cloth, which show a dramatic and rapid change in shape during combustion. In this paper, we present an extension to a spring-mass model [Provot 1995] that allows us to capture effects like shrinking, tearing, flaking and curling of material as it burns.

2 Model and Implementation

We use a spring-mass model to simulate the dynamics of the combusting surface (paper or cloth). We assume that the mass of each particle stores the amount of *fuel* at that node. Additionally, we store the temperature of each particle, which changes as the particle combusts. Our current implementation uses a linear conduction term to model the heat transfer between adjacent particles. This model can be easily extended to account for secondary heat interactions like convection.

Figure 2 shows a schematic and various state variables used in the simulation. $m(t)$ represents the mass of a specific particle at time t, and $T(t)$ represents its temperature. The heat transfer between two adjacent particles x_1 and x_2 is proportional to the spatial temperature gradient: $q(x_1, x_2) = k_0 \frac{\delta T}{\delta x}$. As the particle combusts, its mass (fuel) dissipates at a rate given by: $\dot{m}(t) = \{ \begin{array}{cc} k_1, & T > T_0 \\ 0, & \text{otherwise} \end{array}$, where T_0 is the threshold temperature at which the material ignites. Consequently, the heat generated due to combustion, which depends on the fuel dissipation, is given by: $\dot{H}(t) = k_2 \dot{m}(t)$. Now, the total heat of a particle due to combustion and heat transfer is given by: $Q(x,t) = H(t) + \sum_{y \in N(x)} q(x,y)$, where $N(x)$ are the neighboring particles of x. At each step in simulation, we compute the total heat $Q(x,t)$ for every particle x and update its temperature using the gradient: $\dot{T}(t) = k_3 m(t) \dot{Q}(x,t)$.

To model the deformation caused by the temperature changes in the material, we apply a thermal force on the particles. This thermal force accounts for the spatial temperature gradient due to combustion, the internal spring forces of the material and external curling forces normal to the particle. Hence, $F^{tot} = k_4 \frac{\delta T}{\delta x} + K_s \delta x + F^{\text{curl}}(x)$. To account for the change in material properties due to combustion, we vary the spring constant between two particles based on its mass: $K_s(t) = K_0 (\frac{m_1(t) + m_2(t)}{m_1^0 + m_2^0})$. Finally, we simulate the effect of flaking by breaking the springs when the force applied is higher than a user specified threshold.

3 Results and Conclusion

Figure 1 shows a side by side comparison of one frame of the simulation, rendered in Maya, with an image of a real burning paper. We were able to generate fairly realistic simulations of burning and deformation using our simple model. In the future, we would like to add more complex heat transfer models like convection to increase the generality of our model. Additionally, we would also like to explore more automated means of tuning the parameters of our model from real world measurements. Rendering a realistic flame that propagates on the material is another direction of future work.

References

FEDKIW, R. 2003. Simulating natural phenomena for computer graphics. In *Geometric Level Set Methods in Imaging, Vision and Graphics*, 461–479.

PROVOT, X. 1995. Deformation constraints in a mass-spring model to describe rigid cloth behavior. In *Graphics Interface '95*, 147–154.