Visual Simulation of Melting Ice Considering the Natural Convection

Masaaki Matsumura*
Graduate School of Kyushu University

Reiji Tsuruno†
Kyushu University

1. Introduction

In animation research, simulating the shape of melting ice is difficult because it contains complicated phenomena such as thermal energy transfer and latent heat.

As existing research on melting objects with thermal energy conduction, Jones [Jones 2003] solved the problem of the latent heat by using complex formulas and processing branches, and proposed heat diffusion under a constant thermal field. Carlson et al. [Carlson et al. 2002] simulated melting and flowing process of highly viscous materials such as wax or lava by simulating fluids.

We propose to generate melting ice animations considering the thermal energy transfer with air surrounding ice.

2. Calculation Field Concept

In order to achieve the efficient thermal energy transfer between air and ice, we construct two calculation fields. The calculation field for air (Air Calculation Field; ACF) consists of 3D cells digitized at 1.0[cm] interval, and is used to calculate large-scale convection. The calculation field for ice (Object Calculation Field; OCF) consists of 3D cells digitized at 0.1[cm] interval, and it contains particles of the ice. The OCF is used to calculate the thermal energy given to each particle of the ice from a thermal field of the ACF, and to adjust a thermal field of the ACF.

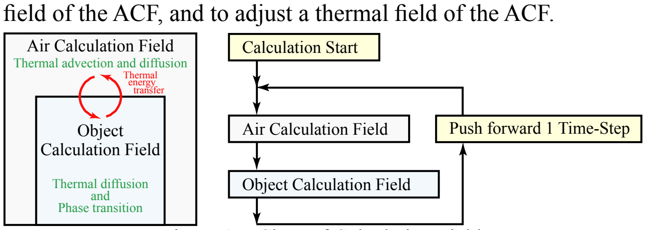

Figure 1: Chart of Calculation Fields

3. Air Calculation Field (ACF)

The air is calculated by a fluid equation using the MAC method: a solver for fluid simulation with free surfaces.

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}\cdot\nabla)\mathbf{v} = -\nabla P + \frac{1}{\mathrm{Re}}\nabla^2\mathbf{v} + \mathbf{F} \tag{1}$$

$$\mathbf{v}\cdot\nabla = 0 \tag{2}$$

$$\frac{\partial T}{\partial t} = \mathrm{k_T}\nabla^2 T - (\mathbf{v}\cdot\nabla)T \tag{3}$$

Equation 1 is Navier-Storks equation, and it constitutes a fluid field. Equation 2 states the incompressible condition; it means that a velocity field has zero divergence everywhere. Equation 3 describes thermal advection and diffusion.

The velocity field is calculated by using Equation 1 and 2, and the thermal field is calculated by using Equation 3 and the velocity field. The buoyancy of each cell is calculated from the difference between the temperature of a cell and the environment temperature that is set at 20[°C] (=293[K]). In Equation 1, an external force **F** is a velocity differentiation value of the buoyancy, it is added only to y-axis (vertical-axis). By constituting the air using the fluid equation, our method simulates natural convection, forced convection, and local forced heating.

4. Object Calculation Field (OCF)

OCF is set inside the ACF. In the OCF, the thermal energy transfer is calculated in three steps.

First, thermal energy Q which each particle of the ice obtains from the thermal field of the ACF is calculated by using Equation 4.

$$Q = \mathrm{h}AT_{\mathrm{Diff}}\Delta t \tag{4}$$

Here h is the thermal conductivity, and A is a surface area of the ice contacting air, T_{Diff} is the difference of temperature between the ice and a temperature of a cell of the ACF, and Δt is Time-Step interval. We define that the temperature of surfaces of ice is 0[°C] (=273[K]).

Next, thermal energy diffuses into ice from its surfaces. Each particle of the ice changes its phase into water when the obtained thermal energy amounts to a quantity required for melt. Equation 5 describes thermal energy diffusion.

$$\frac{\partial E}{\partial t} = \mathrm{k_E}\nabla^2 E \tag{5}$$

Finally, the temperature of each cell of the ACF contacting ice is lowered just by the total thermal energy Q_{Cell} that is absorbed by particles of the ice per cell at the ACF.

$$T_2 = T_1 - Q_{\mathrm{Cell}}\frac{28.2^3(T_1 - 273)}{273\mathrm{R}V} \tag{6}$$

Here T_1 is absolute temperature before energy change, T_2 is absolute temperature after energy change. R is the gas constant (=8.31[J/mol·K]), and V[cm^3] is the volume of the air in a cell that excludes volume of the ice. We do not consider increase or decrease of molecules by temperature changes.

5. Result

We set 20^3 as the grid size of the ACF and 60^3 as the grid size of the OCF, and rendered animations using blobs that are set to the places where particles of the ice exist. Figure 2 shows a free melt without a heat source. Figure 3 shows melting shapes affected by a forced convection. Figure 4 shows melting shapes with the constant 100[°C] (=373[K]) heat that is shown as a red board.

Particles of the ice having wide surface area such as corners of ice melt more rapidly than other areas. As a result, ice loses corners and becomes round. Ice set in the forced convection melts more rapidly than in the case of the free melt because the convection carries away the generated temperature. In the case of the forced heat, ice melts rapidly from the heating side.

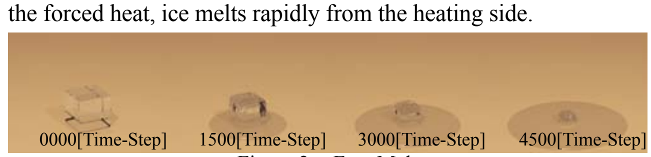

Figure 2: Free Melt

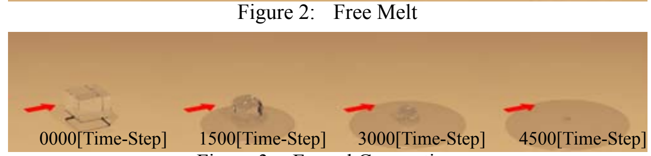

Figure 3: Forced Convection

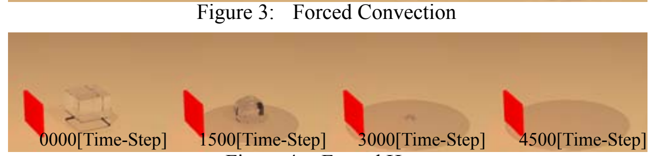

Figure 4: Forced Heat

References

JONES, M. W. 2003. Melting Objects. In *The Journal of WSCG*, 247-254.

CARLSON, M., MUCHA, P. J., VAN HORN, III, R. B., and TURK, G. 2002. Melting and Flowing. In *ACM SIGGRAPH Symposium on Computer Animation*, 167-174.

* e-mail: aki@verygood.aid.design.kyushu-u.ac.jp
† e-mail: tsuruno@design.kyushu-u.ac.jp