Chapter 2
Flow Simulation with Vortex Elements

Mark Stock
Independent artist, scientist, and programmer, USA

ABSTRACT

While fluid flow is a ubiquitous phenomenon on both Earth's surface and elsewhere in the cosmos, its existence, as a mathematical field quantity without discrete form, color, or shape, defies representation in the visual arts. Both physical biology and computational physics are, at their roots, very large systems of interacting agents. The field of computational fluid dynamics deals with solving the essential formulas of fluid dynamics over large numbers of interacting elements. This chapter presents a novel method for creating fluid-like forms and patterns via interacting elements. Realistic fluid-like motions are presented on a computer using a particle representation of the rotating portions of the flow. The straightforward method works in two or three dimensions and is amenable to instruction and easy application to a variety of visual media. Examples from digital flatwork and video art illustrate the method's potential to bring space, shape, and form to an otherwise ephemeral medium. Though the rules are simple, the resulting behavior frequently exhibits emergent properties not anticipated by the original formulae. This makes both fluid simulations and related biological computations deep, interesting, and ready for exploration.

INTRODUCTION

The state of the Earth and all of the life upon and within it are profoundly affected by flow. The convection in the mantle slowly transfers heat and pushes continents around; the currents and gyres in the ocean regulate and affect climate; the rain, ice melt, and surface runoff erode mountains into plains; the wind spreads seeds across vast distances; and tiny vessels inside plants and animals transport life-giving nutrients between organs. Indeed, the shapes of many organisms have evolved to not only accommodate flow, but to thrive in a fluid environment. Birds' wings and fish tails both flap to generate elongated vortex rings to provide thrust, seed pods are dispersed

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widely because they contain elements that make them to fall very slowly, and the varying strengths of trees' branches allow them to survive high winds by bending to reduce drag. If not an essential quality of life itself, flow clearly seems to support the variety and vitality of life on Earth.

In the context of this chapter, *flow* means the ensemble motion of matter in which the individual elements are allowed to move relative to one another. A *fluid* can be a gas such as air, a liquid such as water, or a collection of solid particles such as sand. Seemingly solid materials can behave as fluids if one observes them over a long period of time; examples of this are ice (glaciers) and rock (mantle convection).

How do we quantify a flow? Flowing matter is composed of disconnected, non-uniformly-spaced molecules, each with its own motion. But it is grossly inefficient to describe flows at human scales with such detail. One solution is to assume that the properties of nearby elements vary smoothly. With this *continuum* assumption, the ensemble motion can be written as a mathematical function. Still, most flows retain more complexity than a single function can easily describe. In these cases, the fluid volume is typically *discretized*: broken up into discrete volumes for which the flow properties in each volume are considered uniform. This turns out to be a useful approximation of the real flow, as it makes it amenable to description and prediction on digital computers.

It is difficult to describe flow using the traditional elements of visual art (texture, form, space, line, color, value, shape). Flow doesn't necessarily have a surface to support a texture, nor does it edges necessary for shape. It defies these categories because it fills space, is constantly moving, and even exists where it is not visible. In many situations, line, form, and texture appear in flow due to visible material being carried by the flow. A collection of clouds, for example, defines negative and positive space, while a thin cloud layer provides texture to the background. Further, the shape and position of foreground subjects can imply their presence in a flow field: hair or branches blown by a breeze, or boats being tossed about on the open ocean.

As an alternative to relying on external elements affected by flow, the properties of flow itself may be used as visual elements. In the methods and artwork presented below, certain properties of the flow, such as volumes of quickly-rotating fluid, or numerical elements used to compute the flow, have been instantiated as solid objects, becoming fluid-like lines or forms within the volume. Flow then allows transformation of spatial entities such as points and lines, and in special cases, those entities themselves recursively define the flow. The non-deterministic nature of this feedback makes fluid simulations powerful and often-surprising tools for visual art.

In the following chapter, we will describe how points, lines, and surfaces can be made into elements which describe a flow, and how their positions and properties can evolve under their self-influence. This capability is described with a simple computer algorithm, but allows spontaneous generation of higher-level dynamics not suggested by the simple elemental rules.

PARTICLE SIMULATIONS

Very simple systems of interacting elements can produce non-deterministic, emergent behavior. Conway created a set of rules governing the life cycle of a square pixel in a grid (a *cellular automaton*): it becomes "alive" if exactly three of its 8 neighbors are alive, survives if two or three are alive, and dies otherwise (Gardner, 1970). Despite the simplicity of these rules, this "Game of Life" generates a remarkable diversity of behaviors—such as the Gosper Glider Gun seen in Figure 1 (Britton, 2011)—and is still the subject of active research forty years after its creation. A limitless number of cellular automata are possible, though most research focuses on emergent behavior of simple rule sets (Wolfram, 2002).