Other operations smear, scramble, or warp the temporal morphology through convolution, granulation, or modulation.

This chapter examines transformations based on microtemporal representations of sound. It begins by looking at frame-based audio data coding, micromontage, and granulation. After granulating a sound, one can make many transformations on a micro scale, including pitch-shifting, pitch-time changing, filtering, dynamics processing, and reverberation. After a presentation of waveset transformations, we introduce the theory of convolution, and lastly the spatialization of sound particles.

Synthesis and Transformation

Synthesis of sound and transformation of sound have always been closely related. To impose an amplitude envelope on a sine wave—a basic technique in synthesis—is to transform the signal: sharp or smooth attack, single or multiple iterations, steady or tremolo sustain, legato or staccato decay. How then can we distinguish between synthesis techniques and the transformations presented in this chapter and in chapter 6?

In general, synthesis begins with raw material on a micro time scale: a single period of a waveform, an impulse, or a burst of uniformly distributed noise. Transformations, on the contrary, usually begin with a relatively long stream of audio samples (greater than 100 ms) on the sound object time scale. Transformations apply to a vast realm of recorded or sampled sounds, including traditional acoustic instruments, electronic instruments, environmental and industrial noises, the cries of birds and animals, insect noises, and the sounds of human beings. The samples to be transformed can be extracted from a sound file or read directly from a real-time source. Often, we can identify the source of microphone-collected samples, and the goal of the transformation may involve preserving this source identity.

The transformations described in this chapter do not involve a stage of windowed spectrum analysis, which, instead, are surveyed in chapter 6.

Micromontage

Certain transformations clearly articulate the granular texture of sound. Micromontage extracts particles from sound files and rearranges them. The term

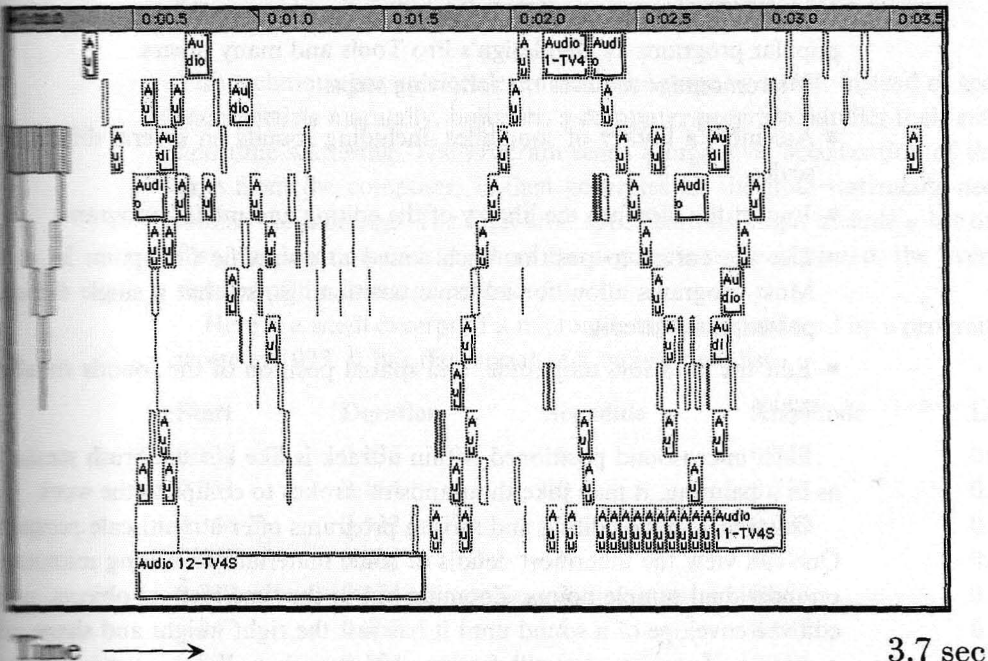

Figure 5.1 Micromontage shown as a display of one hundred and thirty-six sound files organized in a graphical mixing program. The files appear in twelve tracks stacked vertically, while time moves from left to right. Notice that the total duration of this phrase is 3.7 seconds.

"montage" derives from cinema, where it refers to a sequence of rapid images connected through cutting, splicing, dissolving, and other editing operations. With micromontage, a composer can position each particle precisely in time, constructing complex sound patterns by assembling dozens of smaller sounds. Micromontage can be realized by several means: graphical editing, typing a script, or writing a computer program to automate the process.

Micromontage in a Graphical Sound Editing and Mixing Program

A graphical sound editing and mixing program provides a two-dimensional view of sonic structure (figure 5.1). The vertical axis presents multiple rows of tracks, while the horizontal axis presents a time line. An early sound mixing program with a horizontal time-line graphical interface was MacMix (Freed

1987). This interface is now standard in audio workstations, including such popular programs as Digidesign's Pro Tools and many others.

Micromontage requires the following steps:

- Assemble a library of soundfiles, including sounds on several different time scales
- Import the files into the library of the editing and mixing program
- Use the cursor to position each sound at a specific time-point in a track. Most programs allow for multiple positionings, so that a single file can be pasted in repeatedly
- Edit the duration, amplitude, and spatial position of the sounds on all time scales

Each microsound positioned within a track is like a sonic brush stroke, and as in a painting, it may take thousands of strokes to complete the work.

Graphical sound editing and mixing programs offer a multiscale perspective. One can view the innermost details of sonic material, permitting microsurgery on individual sample points. Zooming out to the time scale of objects, one can edit the envelope of a sound until it has just the right weight and shape within a phrase. Zooming out still further one can shape large sound blocks and rearrange macrostructure. The availability of dozens of tracks lets composers work precisely on the micro time scale. A set of sounds that cannot fit on a single track can overlap on several tracks. Multitrack mixing capability also facilitates the construction of dense and variegated textures.

Micromontage by Script

Micromontage by script emerged in the 1980s, when dialects of the Music N synthesis languages were extended to handle input from sampled sound files. In the Csound language developed at MIT, the soundin and loscil unit generators read from a sampled input file (Boulanger 2000). Such a capability made it possible to create arbitrarily complex montages of sound files according to a precise numerical score or script. In these languages, a note statement creates a sound event. In the case of micromontage, each note statement corresponds to a microevent. Thus one must stipulate hundreds or thousands of microevents to create a composition. This process is laborious, but it offers extraordinary control over the montage.

Micromontage by Algorithmic Process

This technique has similarities to micromontage by script. Instead of specifying each particle manually, however, a computer program handles their extraction and time-scattering. The program reads a high-level specification of the montage from the composer. It then generates all the note statements needed to realize the montage. The high-level specifications might include a list of sound files, the location and length of the segments to be extracted, the overall tendencies of the montage, and so on.

Here is a small excerpt of a micromontage text produced by a program that I wrote in 1993. It has the format of a typical note list.

Start	**Duration**	**Soundfile**	**Amplitude**	**Location**
0.137	0.136	8	0.742	0.985
0.281	0.164	10	0.733	0.899
0.346	0.132	12	0.729	0.721
0.628	0.121	1	0.711	0.178
0.748	0.174	3	0.693	0.555
0.847	0.062	6	0.687	0.159
0.974	0.154	8	0.686	0.031
. . .				

Seven events occur in the interval of one second. Each sound file has a number label—from 1 to 12 in this case—shown in the third column. The location parameter indicates spatial location in the stereo field, with 1 corresponding to left, and 0 corresponding to right. The Granulate program generates the score for the micromontage according to high-level instructions stipulated by the composer. The composer specifies the parameters of a cloud, such as which sound files to granulate, the density of particles, their amplitude, shape, and so on. Each cloud may contain hundreds of particles.

The effect of automated micromontage is much the same as granulation. One difference between them is that micromontage is based on a script—a text—that is read by a Music *N* synthesis program, meaning that the user can edit the script before the montage is rendered into sound.

Composition with Micromontage

Micromontage has been a specialty of the composer Horacio Vaggione for some time, in such works as *Octuor* (1982), *Thema* (1985, Wergo 2026-2), and

Schall (1995, Mnémosyne Musique Média LDC 278-1102). In *Octuor*, the composer began by synthesizing a set of five sound files. He then segmented them into small fragments using the S sound editor, and mixed the fragments into medium-scale and large-scale structures using the MIX program (Moorer 1977b). He further processed these structures and combined them in eight-voice polyphony using an automated mixing program (Vaggione 1984).

Thema explores automated mixing in the Cmusic language (Moore 1990). It features streams of microelements—such as resonant bass saxophone breath-bursts—scattered in both synchronous and asynchronous patterns along the time line.

Figure 5.2 shows time-domain (a) and frequency-domain (b) views of a 120-ms frame, which partitions into five microsections A-E. Microsection A contains 2.5 cycles of a waveform in a space of 34 ms, corresponding to a low fundamental frequency of 73 Hz. Microsection B begins with an impulse of 90 μsec pulse-width, corresponding to a fundamental of 1.1 kHz, followed by decaying bursts in a pattern: 17 ms, 8 ms, 17 ms, 8 ms. Superimposed on these bursts is a waveform with a period of 589 μsec, corresponding to a fundamental of 1.697 Hz. Microsection C lasts 21 ms divided into 2.5 periods, corresponding to a low-frequency fundamental of 116 Hz. Microsection D contains a single 113 μsec click, corresponding to a frequency of 8.894 kHz. Finally, microsection E lasts 13 ms and contains two periods of the frequency 153.8 Hz (slightly south of D-sharp), upon which are superimposed partials in the 8 kHz region.

The raw material of *Schall* consists of sampled piano sounds, granulated and transformed by convolution, waveshaping, and the phase vocoder. According to the composer:

> *The work plays essentially with tiny textures of feeble intensity, composed of multiple strata, which contrast with some stronger objects of different sizes, in a kind of dialog between the near and the far—as an expression of a concern with a detailed articulation of sound objects at different time scales.* (Vaggione 1995 program notes)

For more about this composition, see chapter 7, which also discusses the work of the Princeton-based composer Paul Lansky, another pioneer of micromontage.

Assessment of Micromontage

Micromontage is an open-ended approach, still with many unexploited aesthetic possibilities. Granulation techniques, presented next, have absorbed

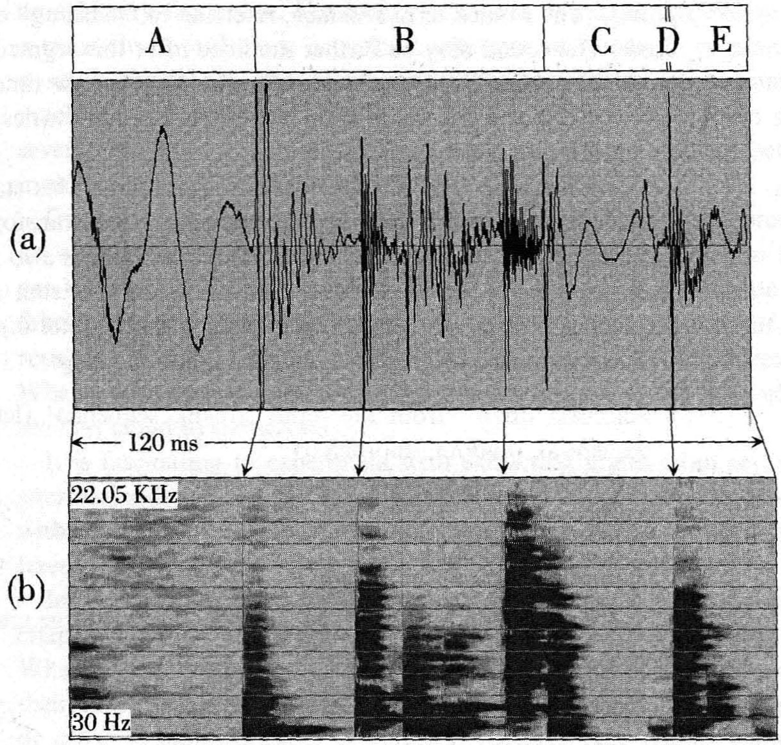

Figure 5.2 120-ms excerpt from H. Vaggione's *Thema* (1985). (a) Time-domain view shows microtemporal variations divided into five sections A-E. See the text for an explanation. The amplitude of the signal has been compressed in order to highlight low-level microvariations. (b) Frequency-domain view plotted on a linear frequency scale.

many of the techniques of micromontage. Perhaps the best way to draw a distinction between granulation and micromontage is to observe that granulation is inevitably an automatic process, whereas a sound-artist can realize micromontage by working directly, point by point. It therefore demands unusual patience.

Granulation

The automatic granulation of sampled sounds is a powerful technique for sound transformation. To *granulate* means to segment a sound signal into tiny