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Video Granular Synthesis

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Abstract

This paper introduces a technique that enables the creative reshaping of one or more video signals based on granular synthesis techniques, normally applied only to audio signals. We demonstrate that a wide range of novel video processing effects can be generated through conceptualizing a video signal as being composed of a large number of video grains. These grains can be manipulated and maneuvered in a variety of ways, and a new video signal can then be created through the resynthesis of these altered grains; effects include cloning, rotating, and resizing the video grains, as well as repositioning them in space and time. These effects have been used successfully in a series of interactive multimedia performances, leading us to believe that our approach has significant artistic potential.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Computer Graphics]: Methodology and Techniques—Graphics data structures and data types; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Animation.

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1. Introduction to Video Granular Synthesis

This paper extends *granular synthesis* [Roa96, Roa04a], a popular technique used for electroacoustic composition, to the visual domain. Creative possibilities emerge from conceiving of a video signal as being composed of a large number of *video grains* within a cube (or, more accurately, an orthogonal parallelepiped) that bounds the spatial and temporal range of the video data. These grains— analogous to the way in which audio grains are defined in granular synthesis— are small perceptual elements with distinct features that can be programmatically or interactively manipulated. Our method, *video granular synthesis*, provides a conceptual approach to video processing that enables a variety of creative effects. Each of the effects involve a remapping of data, first from dicing the original video signal into a set of windowed video grains within the new geometrized space, where space and time are conflated, and then back onto a series of image planes, presented as a new video signal.

The main effects are based on three types of operations: *creating* the grains; *manipulating* those grains; and *repositioning* the grains. We define each grain as a cube of a small number of pixels and then apply an envelope so that each grain can seamlessly overlap with the others; we then can manipulate various individual grain characteristics. For instance, we can clone some grains, delete others, scale the grains, and use image processing effects to alter their pixel values. We also can reposition the grains in time and space: we can rotate the grains in place; we can shuffle the grains so that particular regions appear in different orders; or we can pin a grain in place so that it appears frozen in time.

Additional effects are made possible through reinterpreting a video as a cube of grains. The perspective of the camera can be resituated so that the viewer traverses the video geometry in an unexpected temporal trajectory, for example, by swapping the time-axis with one of the spatial axes. Another effect involves mixing together video grains from multiple signals, blending them together, or choosing one video's grain over the other's based on particular parameters of the grains. Multiple video granular synthesis effects can be applied simultaneously. The techniques can, for the most part, be applied in real-time, although some, for obvious reasons, have a greater range if the video signal is already captured (as future grains cannot be repositioned if they have not been captured yet). This conceptualization of the video signal as a cube full of grains, coupled with our methods for manipulating them, provides us with a palette of creative

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Figure 1: *Four frames from a video portraiture project. The video portrait captures the subject as she is singing, and the audio features (pitch and amplitude) change aspects of the temporal shuffling of the grain, including the grain size and the grain delay.*

possibilities. In addition to enabling novel explorations of time and space, our system makes it easy to define and manipulate grains in real-time, to synchronize audio signals to features of video grains, and to mix multiple video signals together. We have designed software that makes it easy to use video granular synthesis to manipulate videos, and we have linked some operations to controllers so that these effects can be explored interactively.

Granular synthesis techniques are commonly used by composers to create new sonic textures. For instance, granular synthesis can be used to manipulate the duration of existing sounds without changing their pitch, or changing the pitch without affecting their length. The fundamental elements of a granular synthesizer are small acoustic objects, called *grains*, that are of such short duration that they are nearly imperceptible as individual sonic events. A composer can manipulate the grains in order to create particular atmospheres, including: the temporal location of the grain, the overlapping factor of adjacent grains, and individual characteristics (such as amplitude or frequency) of each of the grains. Interesting transformations can also be obtained with granular techniques if the sound grains are captured from real-world signals, rather than computationally generated. Grains extracted from the source signal can be rearranged, eliminated, repeated, or otherwise manipulated in order to create compelling effects. This approach is known as micromontage or *granulation* [Roa96, Zö02]. Granular synthesis, based on granulation, and applied to real-world signals, is an extremely successful technique; many of the most popular audio manipulation software suites now include tools for granular synthesis techniques [Opi13].

Similar to an *audio grain*, we define a *video grain* to be a portion of an input video signal windowed by an envelope so that the video signal is stronger in the center of the grain and attenuated toward the edges of the grains. In audio granular synthesis, different envelopes are used to overlap regions of the input signal, and can be chosen by a composer for particular effects [Roa96]. In adapting granular synthesis to the video domain, we apply a Hann window to create grains with a uniform overlap characteristic [HRS02]. Although our methods for processing video are based on audio granular synthesis techniques, how humans perceive audio signals is quite different from how video signals are perceived. Extending the concept of granulation to video demands a new exploration of the creative possibilities of such techniques.

2. Related Work

While creative approaches using granular synthesis strategies are popular in music composition, they are not as common in the video domain. However, some artworks do use video to accompany compositions created with granular synthesis techniques. For example, Kurt Hentschlaeger and Ulf Langheinrich have presented a series of installations showing videos of expressions and forms cut-up and displayed out of order along with a soundtrack based on granular synthesis [HL96]. Curtis Roads, the primary proponent of granular synthesis, has collaborated with video artists, including Brian O'Reilly, Woon Seung Yeo, and Garry Kling, on a series of compositions collected in his *Point Line Cloud* project [Roa04b]. More recently, the Belgian artist Axel Rijpers has explored similar techniques to create narrative tension [Rij13]. The audiovisual composer John Keston has developed a touchscreen instrument that links short segments of loops of cranes, train engines, and metal cutters with a granulated composition based on the sounds of those machines [Kes13]. By and large, these examples rely on abrupt jump cuts, limiting their expressivity. A recent application of video manipulation, *Eulerian Video Magnification*, enables subtle motions and changes in color to be accentuated [WRS*12]. This technique however operates on single pixels, and while it does provide interesting effects (potentially useful in medical applications), it does not directly enable the manipulation of video signals for creative video compositions.

Other previous work, not based on the generation of video grains, presents spatiotemporal manipulations of video signals which are related to certain effects we introduce here. For instance, the *slit-scan* technique is also based on a conflation of the time and space axes. A manually generated version of slit-scan was first popularized by the special-effects artist Douglas Trumbull [Tru68]. Contemporary photographer Adam Magyar stitches together photos of urban crowds and subway passengers taken with a slit-scan camera into longer video sequences [Mag09]. Golan Levin has collated a repository of computationally-generated artworks based on the slit-scan technique [Lev10]. For example, Camille Utterback's *Liquid Time* allows a user to position his or her body to interactively fragment the temporal aspects of a prerecorded video clip [Utt02]. Our approach can be used to produce visual outputs similar to the ones obtained with slit-scan, but also enables a range of additional effects. Fels et al. [FLM00] also reinterpret the video signal as a space-time cube and present alternative renderings that shuffle these two domains. Our technique differs in that it manipulates a larger perceptual entity, the video grain, rather than individual pixels. Alvaro Cassinelli describes a pixel-based interactive piece that allows spatiotemporal "contortions" using a tangible surface [CI05]. A combination of space-time analysis and non-photorealistic synthesis is presented by Klein et al. [KSFC02], which uses a set of different "rendering solids" to recreate a transformed version of the input. This approach is somewhat similar to the time-varying envelope that we use to create spatiotemporal video grains, but the rendering solids do not extend granulation techniques. Techniques dependent on the conflation of space and time have been developed for a range of visualization techniques [BCD*12, BDA*14] and video analyses, such as comparing motions [SI07], identifying actions [BGS*05], and correcting corrupted frames [WSI07]. The work described in this paper is focused on generating creative outputs, and relates to previous work by the authors on video analysis [FJP14, FV14, VF14a, VEF15] and media arts projects involving video processing [FO12, FHL13, VF14b].

3. System Overview

Our video granular synthesis software can transmute one or more input video signals into a creatively manipulated output video signal. At Step 1, an input video is interpreted as a *video cube* of three dimensional data, made up of video frames (the x and y coordinates) extended through time (the t coordinate). That is, based on parameters that define the input window size and various factors that define the amount of overlap, the original video sequence is transformed into a set of video grains. At Step 2, the video grains can be manually or programmatically selected (discussed below), and a wide range of grain-manipulation effects can be generated, such as cloning, skipping, shuffling, or repositioning grains. Additionally, the pixel values of the grains can be changed, for example by applying image processing effects on the selected grains. At Step 3, the scale, orientation, and spatiotemporal position of each grain is calculated and stored in a *grain map*. The grain map links the pixel data stored in a grain to its position (x, y, and t) its size (r) and its 3D orientation (θ and ϕ) The grain map can be interactively updated in real-time on a per-frame basis. This grain map also is used to determine how the position of each grain created from the input video cube is mapped to an output signal. At Step 4, a scheduler component interrogates the output of the grain map to determine what portion of each grain will be used to generate the current output frame. Our implementation was created in OpenGL, and uses a GLSL geometry shader to create the actual individual slices of each grain that is currently visible, based on the the current location of the camera and the individual grains, thus speeding up the rendering process by ignoring data not relevant to the current frame. A GLSL fragment shader is responsible for drawing each video grain based on how the current frame intersects it and the current windowing parameters. Fig. 3 provides a general overview illustrating the functionality of the video granular synthesis system and the grain map data structure.

Our system also includes components that make it easier to compose videos and to manipulate video signals interactively. We have developed software that allows a user to maneuver through the cube of video grains and manually select only particular grains. Once these grains are chosen, we can programmatically attach particular effects to them, such as a change in their scale, rotation, or position. Additionally, we have set up keyboard mappings so that effects can be applied to real-time signals, including mixing together video grains from multiple videos. We have also used other types of controllers to select effects and dynamically update parameters. Our system also makes it easy to map audio inputs onto video grains, allowing us to select particular effects based on features of the audio signal, or to change parameters of the currently selected effects. For example, for a particular set of grains we can map the detected pitch of the audio signal to the rotation of those grains. We can also synchronize the mapping of parameters for manipulating the audio signal (using audio granular synthesis) to the video signal (using video granular synthesis).

4. Creative Applications of Video Granular Synthesis

The various techniques described by our video granular synthesis method are currently being incorporated into a series of creative projects. In this section, we briefly describe examples these projects as examples of some of the creative artistic and interactive possibilities that can be generated using video granular synthesis, which include a fixed audio-visual piece, a choreographed multimedia piece with

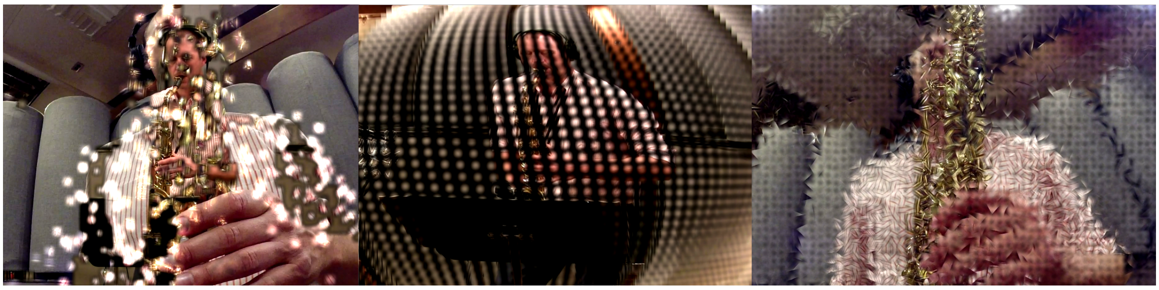

Figure 2: *Three examples of real-time effects created using video granular synthesis, including, from left to right, (a) signal mixing, (b) spatial repositioning of grains, and (c) grain rotation.*

dancers, and an interactive video performance with live video manipulation.

Audio-based Video Manipulation For a recent multimedia event, we used multiple cameras to capture the performance of an electroacoustic composition; by applying video granular synthesis techniques to these videos we augmented the live-performance, controlling the video grain parameters via a laptop. The audio signal was used to control how the grains from each signal were mapped to the output image. That is, we interactively chose particular positions in the grain map, and blended the input video signals programmatically, depending on the pitch and amplitude of the audio signal. This output image was projected on a large screen to one side of the performers. One of the effects featured in this performance was *grain cloning*. In our system, specific grains can be cloned, that is, added multiple times to the grain map. In capturing the performance, we created video grains from the input videos using a 50% overlapping factor, effectively changing the size of the image while preserving the spatiotemporal frequencies. That is, granular effects applied to the audio signal can also be simultaneously applied to video signals. Fig. 2 shows other effects that were used, for instance, Fig. 2c shows example of grain rotation applied to a video of the performance.

Video Portraiture Using Video Grains In another (ongoing) project, we used grain cloning as a technique for exploring concepts in video portraiture. Fig. 4 shows a frame from one of these experiments; the image has a curious resemblance to the "op art" artwork created by Julio Le Parc [GP05]. We also explored the use of temporal shuffling to show fluctuations in a video of subjects expressing themselves in different ways, through dance or through singing. For instance, in Fig. 5, we utilized video granular synthesis to overlay the same person from different parts of a video in order to have multiple copies of the person appear simultaneously in the same frame. That is, we sample backwards in time and bring those previous grains to the present. By using different numbers of grain delays, we can control the number of different forms that are presented in the current frame. Fig. 1 shows a video portrait of a female vocalist performing traditional Iranian songs. For this project, we used more fine-grained manipulations of delays and spatial repositioning to create a sequence of subtler expressivity in order to capture the singer's emotions. We also experimented with synchronizing the audio to the video effects by linking the pitch and amplitude of the audio signal to the intensity of the grain manipulation.

Spatiotemporal Reinterpretation By considering the input video as a cubic array of grains, new interpretations of the data can be created simply by relocating the *point of view* of the array. That is, we can imagine the video being played from a different direction. Fig. 5c shows a frame obtained while looking at the video array from one corner (where a space axis and the time axis, the x and z axes, are partially interchanged). Since the grain map can be updated in real-time, more complex traversals could be created as well, i.e., that do not simply move in a straight line toward the camera. For instance, Fig. 2b shows a new shape forming through shrinking the grains and creating non-uniform spacing between them. Our custom software that can be used to interactively update parameters for navigating the video from alternative vantage points.

Image Dependent Manipulations The position of grains can also be modified by other, non-procedural strategies. For example, higher level information from the video stream can be used to determine the behavior of the grains. In one of our explorations we changed the spatial position of the grains according to the amount of temporal variance detected between image frames. The squared root of the temporal variance for a grain spatially placed at x_0, y_0 is:

$$\bar{\sigma}_G(x_0, y_0) = \frac{1}{G_s^2} \sum_{x=x_0}^{x_0+G_s} \sum_{y=y_0}^{y_0+G_s} \sqrt{\mathrm{VAR}\left[p_{x,y}(t)\right]} \qquad (1)$$

Where G_s is the grain size (assumed to be equal in all dimensions), $p_{x,y}(t)$ is the gray-scaled pixel value at position x_0, y_0 and time frame t, and the variance is calculated over time. Grains that have a variance greater than a predefined threshold move in a random direction by an amount proportional to the square of the averaged temporal variance of the grain. For instance, a hand waving in front of the camera was used to add effects to only those grains that are in the same spatial

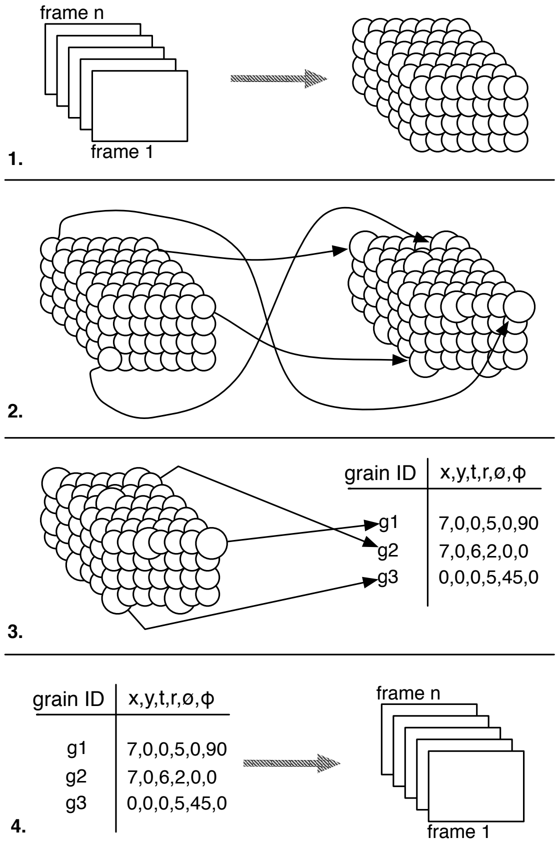

Figure 3: *A system overview of our Video Granular Synthesis software. At Step 1, a sequence of video frames is turned into a set of grains using a particular windowing filter and radius. At Step 2, a user can programmatically or manually select grains and alter them by changing their spatiotemporal position, their size, or their orientation, or by modifying the pixels within the grains. At Step 3, the grains are stored in a "grain map," an internal data structure that keeps track of the parameters and content of the grains. At Step 4, the current image frame uses the grain map to determine which portion of the currently active grains (i.e., based on their position, size, and orientation) will be remapped onto the display.*

position as the detected motion of the waving. Dynamically updating grain characteristics via high-level features introduces many possibilities for interactive systems. A range of analysis techniques could be used to drive this interactivity, such as optical flow [HS81]. Other detected image characteristics that can be used to modify grain behaviors include luminance, chrominance, frequency, spatial position, and face recognition, among others. This approach could be an exciting way to compose or interact with audio-visual pieces via dance or other gesture based performance.

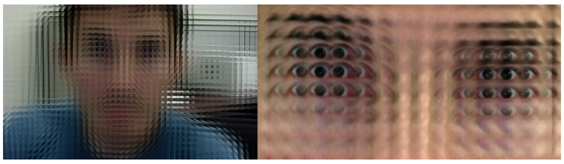

Figure 4: *This image shows a frame (left) and a detail from that frame (right) where the video grains are cloned using a Hann window with a 50% overlap factor. The overlapping factor and windowing functions can be updated in real-time.*

Figure 5: *The left and center frames show the temporal shuffling of video grains. The left frame uses two different settings for the grain delay, enabling portions of two figures (the same person at different times) to be shown simultaneously; the center frame uses three grain delays. The right frame shows an effect similar to those produced using slit-scan cameras, where the video clip is being traversed at a 45° angle around the y-axis. Other paths through the video space could also be defined.*

5. Discussion and Future Work

We have worked with different artists to produce interactive multimedia projects that make use of the techniques described in this paper. For example, a performance with accompanying video, titled *v→t→d*, has been well-received at a number of venues, including the University of Arizona's Confluencenter for Creative Inquiry and at the 2014 International Computer Music Conference in Athens, Greece, with over 5,000 attendees. For this project, live sound inputs affected the position and size of the grains, captured from a live video feed with a 30-second buffer. Additionally, a performer used our software to change rotation and cloning parameters it in response to the varying intensity of the musical performance. A second camera was affixed to the bell of a saxophone, and the laptop performer also was able to blend in grains from both signals simultaneously [JTVF14].

Another multimedia performance that used video granular synthesis was performed as part of an experimental arts festival at *Exploded View Microcinema* in Tucson, Arizona in 2014. For this piece, titled *Coming or Going*, video grains generated from a computationally-generated animation and a sequence of video footage were blended together by manipulating the grain map. The size and movement of the grains were choreographed to follow a percussion track. For this presentation there was no live interaction, but the artists are planning to create a new version where the volume and pitch of the percussion instruments create a dynamic visual accompaniment without the need for prior choreography.

The projects described above present initial forays into using granular synthesis techniques applied to video. We believe that this method will enable new artistic possibilities based on introducing "pieces of time" into a video sequence. Much of the previous work involving temporal manipulations of video has an abrupt, disjointed sensibility. Our current explorations successfully investigate the technical feasibility of mixing grains of time and space in a more subtle manner, but a more coherent artistic focus could generate even more compelling aesthetic results.

A principal artistic effect that uses video granular synthesis involves thinking of a single frame as being composed of multiple moments simultaneously. Using our method, artists are able to frame particular regions of the image as being windows into other times (or only previous times if the video signal is a live recording). In addition to experimenting with how different conflations of time could introduce novel narrative effects, artists could also manipulate the spatial placement of where these times occur for additional narrative impact. An additional artistic effect that we investigate utilizes our method in order to think of a video as if it were a block of information. Current explorations that involve traversing a video from unusual vantage points produce somewhat "glitchy" looking videos (as in Fig. 5). We believe that a more nuanced use of this technique could provide interesting perspectives that could augment more traditional spatial representations.

We also are continuing to explore the idea of mixing signals, that is, of interweaving multiple videos at multiple points in time. While further research needs to be done to determine how multiple viewpoints could be most effectively integrated into a single video sequence, this technique seems rich with possibility. For example, the artistry of many films involves providing insight into how different people see the same situation, providing empathy with a range of characters. Video granular synthesis, which enables a superimposition of scenes, could promote new explorations of perspective in narrative videos.

Our work shows that creative manipulations using a granular approach are also possible with video signals; our artistic explorations lead us to believe that this approach to processing video signals has significant narrative potential. Different video atmospheres can be created by introducing these effects and applying them to spatial or temporal dimensions. By conflating these dimensions, diverse interpretations of the same block of visual information can be generated via unorthodox trajectories through the video data, revealing interesting relationships between the perception of time and space. In sum, our video granular synthesis method presents the following contributions:

- It provides a way to transform a video stream into a set of video grains, each of which has a range of attributes that can be modified either individually or collectively;
- It makes it possible to conflate the spatial and temporal elements of a video;
- It makes it easy to mix together multiple video signals in novel ways;
- It enables novel video processing techniques that can be used to manipulate video streams in real-time;
- It encourages the mapping of these video processing techniques to audio signals or to a performer's live control.

Thus far, our creative explorations have focused on applications of video granular synthesis to relatively simple video compositions. Many possibilities exist for exploring effective ways to use the techniques we introduced in this paper to augment more complex compositions. We are especially intrigued by the idea of mixing multiple viewpoints to create novel approaches to augment storytelling. Future work will focus on a more sophisticated integration of video granular synthesis techniques and narrative elements.

We also believe that there is a natural synergy between granular synthesis in the audio and video domains. Although there are strong differences between audio and video representations and in the way in which human perception works in the two domains, some of the strategies can be extended in a very straightforward way. This is the case when we clone or skip grains. In the audio domain, this strategy is commonly used to modify the length of an audio signal without changing its pitch [Roa96]. But this trade off is not as meaningful when processing visual information. While, for instance, relatively small changes on the reproduction rate of a voice signal can immediately sound artificial, we are used to seeing faces at different scales. However, although this pitch-preserving time-modification is not as important in images (an exception might involve periodic textures), even a straightforward application incorporating cloning and/or skipping grains produces visually appealing results.

Another interesting area for future exploration is the interaction *between* both streams. Some of the effects introduced in this paper, including cloning and randomization, can be straightforwardly applied to audio and video signals. Highly coupled audio-visual pieces can be generated if both streams undergo similar operations simultaneously. Moreover, an audio granular synthesizer can be used to generate the soundtrack of a granular video, and audio events can be triggered by the video grains. Characteristics such as the density or frequency content of the audio grains can be mapped to other features in the video grains. Finally, spatialized sound and 3D audio compositions that place audio grains at different positions within a virtual space could be complemented by video grains moving with similar dynamics throughout an immersive environment.

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