The Metasurface – Applying Natural Neighbour Interpolation to Two-to-Many Mapping

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ABSTRACT

This report describes *The Metasurface* – a mapping interface supporting interactive design of two-to-many mappings through the placement and interpolation of parameter snapshots on a plane. The Metasurface employs natural neighbour interpolation, a local interpolation method based on Voronoi tessellation, to interpolate between parameter snapshots. Compared to global field based methods, natural neighbour interpolation offers increased predictability and the ability to represent multi-scale surfaces. An implementation of the Metasurface in the AudioMulch software environment is presented and key architectural features of AudioMulch which facilitate this implementation are discussed.

Keywords

Interpolation, Mapping, High-level Control, User Interface Design, Design Support, Computational Geometry

1. INTRODUCTION

One of the challenges of controlling musical systems is in designing mappings which afford musically expressive control. Some practitioners consider mapping as a separate activity in the instrument design process. A significant body of research has been directed toward building systematic understanding and exploring techniques for implementing mappings; this paper describes one such technique. However, mathematical descriptions of mapping methods are not enough – just as important is direct support for the activity of mapping specification and design. The process through which a mapping is designed and the interface with which it is expressed can have a significant impact on the musicality of the result.

This report presents the Metasurface – an interface for mapping specification designed with the above considerations in mind. The Metasurface supports exploratory, interactive specification of two-to-many mappings without requiring technical knowledge of the underlying mathematical technique. In fact, the underlying technique, natural neighbour interpolation, was selected specifically to avoid over constraining the mapping design process.

This report begins by surveying predecessors of the Metasurface, following which the Metasurface is presented as implemented in AudioMulch Interactive Music Studio[1] – software developed by the author to support his improvisation practice [2, 3]. After this, the two dimensional natural neighbour interpolation technique is described and some implementation details are discussed. Finally, directions for further investigation are suggested.

2. PREVIOUS AND RELATED WORK

This section reviews related work in the field of interpolated surface based mapping interfaces. Following that the author's overSYTE preset interpolator, the predecessor of the Metasurface, is described.

2.1 Interpolated Surface Mapping Systems

Although the exact mapping strategies have not always been disclosed, computer music systems have used multi-axis controllers such as graphics tablets and X-Y joysticks for some time. In 1976 Wessel describes control of an oscillator bank using a mapping from X and Y to compound spectral and temporal parameters [22]. In 1982 the SYTER system "used a graphic tablet as a general 2D input device." Its INTERPOL window supports continuous interpolation between up to 16 parameters by placing variable-sized circles representing parameter sets in a 2D 'gravitational' field [1, 17]. These two examples serve to illustrate the distinction between systems which implement a hard coded mapping and those providing a scheme for interpolating between *parameter sets* (also referred to as 'presets' or 'models'). It is the latter category which is of most relevance here.

GRM Tools provides one dimensional parameter interpolation with presets located at fixed intervals along a slider [6]. Todoroff describes a system for interpolating granular synthesis parameters using 2D and 3D control input and a fixed geometric layout of parameter sets [16]. More recent work includes a 3D implementation of field-based interpolation using a breakpoint editor to define time varying trajectories [18, 17].

Choi et al. employ genetic algorithms to optimise a mapping from the synthesis parameter space to a three dimensional gestural control space [5]. Goudeseune later applies 'simplical mapping' to a similar problem [7]. Rovan et al. describe a system for controlling additive synthesis using

[1]AudioMulch is distributed as shareware and can be downloaded from http://www.audiomulch.com

bilinear interpolation between four of nine analysis-derived models representing an expressive timbre subspace [12].

Of significant interest here is the work of Momeni and Wessel whose approach "gives emphasis to software tools that provide for the simple and intuitive geometric organisation of sound material" [9]. They describe a generalised system supporting the spatial arrangement of objects (sounds and numerical parameter values) each of which influence a global field using a Gaussian kernel. They also present a range of applications developed with this system.

Watson offers a wide ranging introduction to classical surface interpolation approaches including discussions of the characteristics of various methods [19]. Goudeseune reviews the (in)appropriateness of many classical interpolators for musical applications citing properties such as discontinuities and overshoot [7]. Spain and Polfreman discuss the limitations of gravitational field models for interpolation and propose a parameter interpolation model based on physical light mixing [15]. Van Nort et al. introduce the application of Regularised Spline with Tension (RST) interpolation for 2-to-many and 3-to-many mappings. They also note some relevant mathematical formalisms and use these to to compare RST against several other interpolated mapping schemes, including some of those cited above [11].

2.2 The overSYTE Preset Interpolator

OverSYTE (figure 1) is a real-time performance granulator developed by the author in 1995 to support improvised processing of instrumental and vocal performers. The user interface includes a number of on screen sliders for controlling various parameters of the granulation process. Support for storing and recalling named presets is provided. Of relevance to the present discussion is a feature called the *preset interpolator*: a rectangular region of the screen with drop-down lists at each corner allowing a different preset (or the current parameter values) to be associated with each corner. Clicking and dragging the mouse cursor within the region articulates an interpolation between the four presets using bilinear interpolation. A checklist allows selection of a subset of parameters to participate in the interpolation.

The preset interpolator is an important feature of overSYTE, facilitating interesting multiparametric modulations controlled only by the mouse. An unexpected feature of this type of interpolation interface, also noted by Momeni and Wessel, is that novel parameter combinations are often found at intermediate locations on the surface. In spite of the musical expressivity of the preset interpolator it's limitations are clear: it allows working with at most four presets at a time, and the geometry is fixed to a rectangle, severely limiting the possibility of designing a musical space. It is clear that an intuitive interpolation interface which overcomes these limitations is highly desirable.

3. THE METASURFACE

The Metasurface (figure 2) has been implemented for the AudioMulch real-time musical signal processing environment, the successor to overSYTE. The Metasurface offers the same baseline functionality as the overSYTE preset interpolator, the main improvement being that instead of using four presets placed at the corners of a square, the Metasurface supports placing an arbitrary number of presets anywhere on the surface. As a consequence, detailed surfaces with user defined geometry may be specified. Points are inserted on

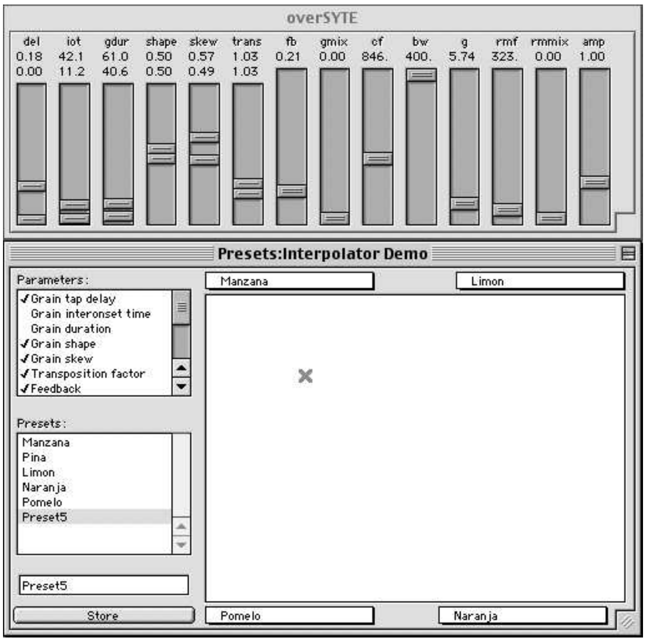

Figure 1: The overSYTE preset interpolator circa 1995.

the surface using drag-and-drop and their locations can be altered using direct manipulation. Separate edit and interpolate modes dictate whether dragging the mouse performs interpolation or moves points on the surface.

Each preset has an associated colour to provide a visual cue about the sonic properties of different areas of the surface. Colours are smoothly interpolated across the surface to provide feedback about the surface's curvature. Initially the colours are random, however they may be altered by the user to express specific colour/sound associations. Although the coloured representation may sometimes have low perceptual correlation with the sonic output, it was deemed adequate given the difficulties of visualising an arbitrary N-dimensional parameter space.

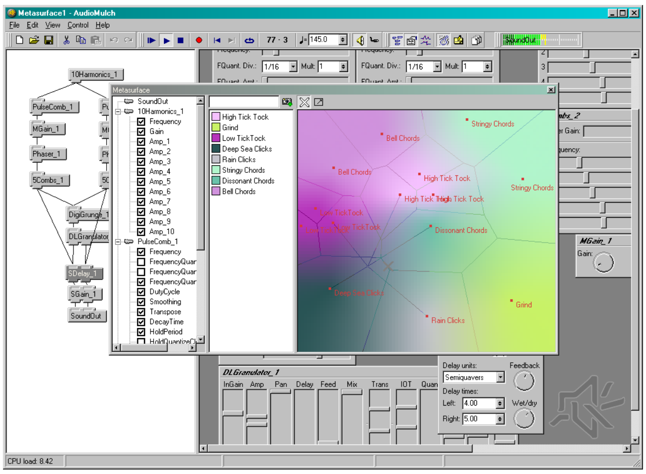

Figure 2: The Metasurface and AudioMulch.

3.1 Natural Neighbour Interpolation

The Metasurface employs natural neighbour interpolation [14], a method based on Voronoi tessellation, to smoothly interpolate between parameter values associated with each point on the surface. Voronoi tesselation can be defined as "The partitioning of a plane with n points into n convex polygons such that each polygon contains exactly one point and every point in a given polygon is closer to its central point than to any other" [21]. A description of the natural neighbour interpolation technique follows:

Given a set of data points distributed on a plane, natural neighbour interpolation computes the interpolated value for a given point X as the weighted sum of the points which are natural neighbours of X. Where the natural neighbours can be intuitively understood as those points which would be adjacent to X in a Voronoi tessellation of the point set including X. Figure 3 depicts in black a Voronoi tessellation of the points A through E. The gray region marks the new Voronoi cell which would be present if the point X were included in the tessellation. The weights of points A through E used to compute the interpolated value of X are respectively the areas of the gray region intersecting each original cell of A through E and are also known as the natural neighbour coordinates of X.

The surface formed by natural neighbour interpolation has the useful properties of being continuous (C^0) everywhere and passing through all data points without any overshoot. For users this has the advantage of behaving as one would intuitively expect: continuous control inputs result in continuous interpolated values lying between the values of neighbouring data points. Moreover, the interpolated surface is continuously differentiable (C^1) everywhere except at the data points, providing smoother interpolation than if (for example) a bilinear interpolation of the Delaunay triangulation were used.

Other useful properties of natural neighbour interpolation are that it only requires the points to be placed, it doesn't require tension values or point 'gravity' to specify the region of influence of each point. Natural neighbour interpolation is local, irrespective of scale, allowing the level of detail to be easily varied across the surface. Local influence also means that interpolated values are computed using a local point set, resulting in bounded computational cost independent of the total number of points on the surface.

3.2 Natural Neighbour Implementation

The Metasurface is implemented using a Voronoi/Delaunay mesh data structure which supports rapid insertion and removal of nodes [10]. Interactive movement of data points is implemented by removing and reinserting nodes in the mesh. Caching of the most recently addressed mesh location limits the average computational cost of moving a point by the number of natural neighbours of the old and new point locations, allowing large meshes to be edited. To perform interpolation, natural neighbour coordinates are computed according to the method described in [13] using an algorithm for calculating circumtriangles of a point which takes advantage of the structure of the mesh.

3.3 Surface Topologies

Strictly speaking, natural neighbour interpolation is only defined inside the convex hull of all points. One way to make the interpolation defined across the whole rectangular

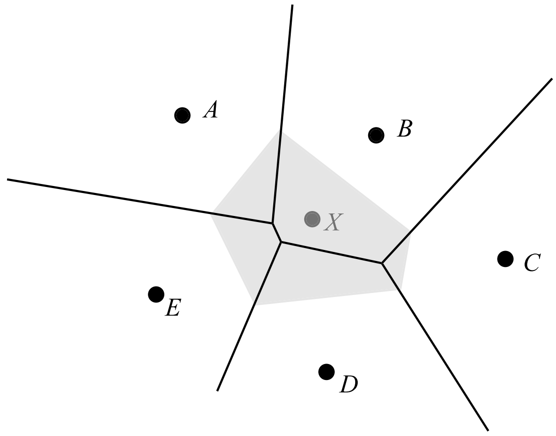

Figure 3: Natural neighbours of point *X*.

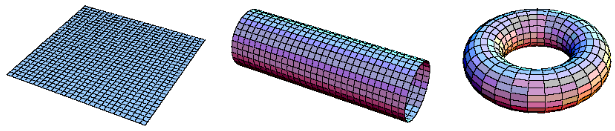

Figure 4: Possible topologies for the Metasurface: plane, cylinder and torus.

Metasurface is to duplicate all of the points to nine adjacent rectangles. By flipping the orientation of the duplicates in different combinations it is possible to create periodic surfaces in one dimension (cylinders) or in two dimensions (toroids), or aperiodic surfaces where point values extend to the boundaries of the surface (see figure 4).

Periodic surfaces suggest interesting possibilities when controlled by periodic controllers such as alpha wheels or trackballs. However the current implementation reflects the points around the edges of the Metasurface to give the impression of preset values extending from the outermost data points to the boundaries of the rectangular surface.

3.4 The AudioMulch Property Architecture

Architecturally, AudioMulch consists of a statically scheduled data flow network of signal generating and processing objects. Notifications are sent whenever objects are added or removed from the graph. The graph can be traversed at any time and individual properties corresponding to the synthesis parameters of each object may be inspected using a generalised reflection mechanism. The reflection mechanism is used for implementing persistence, automation and MIDI control. Properties implement a kind of passive Observer mechanism such that the GUI can easily be updated when property values change. Properties have an associated name, type, units of measure and allowable value range, all of which can be inspected at runtime. These features make it easy to implement a new modulation system like the Metasurface, which can easily scan the graph of signal processing objects to make preset snapshots and to restore interpolated values.

4. FUTURE WORK

The Metasurface has been released to the public, and as a result is only likely to change via incremental improvements such as adding variable damping of interpolation velocity, automated interpolation trajectories, and a work around for the discontinuity in the derivative at control points (for one possible solution to this see [8]). It is possible that the Metasurface could be reimplemented using the simplical spatial interpolation method employed by Goudeseune [7] however it is unclear whether the computational requirements of this method would support interactive surface design.

Another possible extension would be to implement a Metaspace in three or more dimensions using existing algorithms for n-dimensional natural neighbour interpolation [4, 20]. However the approach taken by Momeni and Wessel of composing multiple two dimensional surfaces may offer a more intuitive interface in practice [9].

Finally, data visualisation techniques could be applied to generate coloured and textured 'skins' to represent the composite parameter surface. One possible approach would be to generate descriptors for the sonic output at each pixel coordinate on the surface and visualise these descriptors to create an appearance which is correlated with the perceptual characteristics of the sounds at each location on the surface.

5. CONCLUSIONS

A graphical interface allowing the interactive design of two-to-many mappings called the Metasurface has been described. The Metasurface is easy to understand and use, even by musicians with little or no knowledge of mathematics or mapping theory. The degree of musical control provided by the Metasurface is significant and performance using a predefined mapping has been observed to facilitate musical expression by non-musicians.

The Metasurface employs Natural Neighbour interpolation, a local interpolation method based on Voronoi tessellation with a number of useful properties for designing surfaces, including: localised influence of data points, continuity (C^0 everywhere and C^1 everywhere except at data points), and support for varying point densities or levels of detail.

As noted in the introduction, the activity of mapping design and specification is of increasing interest to practitioners. It seems clear that work in the area of design support for mapping will continue to be a fruitful area of investigation. The Metasurface has been presented as one method for streamlining the process of designing and specifying mappings.

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