SIMULATION PRODUCTS AND THE MULTI-SENSORY INTERACTIVE PERIODIC TABLE

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ABSTRACT

The Multi-Sensory Interactive Periodic Table (MSIPT) is described as a *simulation product* for the perceptualization of electron configurations, atomic radii, orbital structures, and chemical bonds of the elements comprising the periodic table. A simulation product is defined as an interactive output representation from a data-centric sonification model, and is used to illustrate the form and structure of various elements through sound synthesis. First, a brief overview of the frameworks and possibilities inherent within this approach is addressed, which is then followed by a discussion of MSIPT. It is concluded that a simulation product provides a robust and self-contained method for communicating multi-faceted structures through sound.

1. INTRODUCTION

A sonification model is a system with a set of instructions that determine how acoustic phenomena are generated in response to user stimulation [2]. That is, a "model space" bisects the data space and the sound space in this framework. This model space consists of the dynamic architectures that are needed to translate coordinates in the data space to perceptual artifacts that can be heard by the listener, as shown in **Figure 1**. The current study aims to apply this sonification model approach to the level of an interactive product, the Multi-Sensory Interactive Periodic Table (MSIPT).

The sound spaces of MSIPT come from interaction-based mediators that form the model space. That is, the model space is a kind of tool box that allows similar sonic artifacts to emerge from multiple data sources. In this case, the electron configurations, ionic radii, and orbital structures of the specific atoms undergo the same transformations, which underlines the reproducibility and generalizability of the simulation product. In addition, the model itself is dimensionally independent: it can be used for both simple and complex atomic structures. This streamlines the product's mapping process, thereby reducing the amount of time needed to 'learn the language' of these atomic structures, and heightens the listener's ability to discern salient differences between the elements' structures. Simulation products, then, are self-contained, interactive, sonification model systems. This provides a many-to-one paradigm between the data space and the sound space: many different types of underlying data can be transformed by the same model.

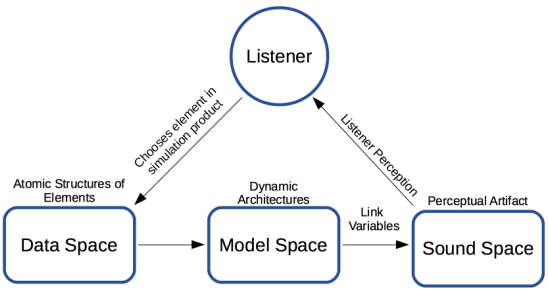

Figure 1: The conceptual framework of a simulation product.

2. THE DATA SPACE – ATOMIC STRUCTURE

Atoms comprise all matter within our universe, and define the nature and properties inherent to our existence. An atom is made up of a positively charged central nucleus surrounded by one or more negatively charged electrons, which occupy a distinct space, or orbital, dependent upon their energies. During the late 19^{th} and early 20^{th} centuries, scientists made significant leaps towards our current understanding of atomic structure, and further illuminated how the electron configuration, or the distribution of electrons within the orbitals of the atoms of an element, defines the chemical properties of the given element.

Physicists discovered the dual nature of light as both a particle (with mass and a precise position in space) and a wave (without mass or a fixed position), while chemists accumulated information on the properties, reactions, and atomic masses of the elements. The physical observation of light as both a particle and a wave led to the development of the quantum-mechanical model of the atom, which describes an atom's structure based upon the atom having specific quantities of energy that result from allowed frequencies of its electrons' wavelike motion. Based on this model, the position of an atom's electrons is known within a certain probability to occupy specific orbitals around the nucleus, and the electrons are distributed consecutively from lowest to highest orbital energy. This is the foundation of the electron configuration for each element comprising the periodic table, with each element (and thus each electron) containing a different configuration and thus a different set of "quantum" numbers n, l, m_l, and m_s, which dictate the relative size, shape and orientation of the orbitals respectively

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occupied by the electrons, and the electron spin itself [6].

The sound space of MSIPT is directly linked to quantum numbers. The principle quantum number n gives the size of the orbital, and its distance from the nucleus, thus directly corresponding with the atomic radius. As n decreases, the energy also decreases, thus the probability that the electron is close to the nucleus is greater. Visually, n corresponds with a given row in the periodic table, beginning with n=1 for the first row, n=2 for the second row, etc. Subsequently, the angular momentum quantum number l gives the energy sublevel, or shape of the orbital occupied by one or more electrons. These sublevels, or shells, are distinguished by the letters s (for spherical orbital), p (for 3 two-lobed orbitals), d (for 5 multilobed orbitals), and f (for more complex orbital structure). Furthermore, the magnetic quantum number m_l gives the 3-dimensional orientation of the orbital in the space around the nucleus. Finally, the spin quantum number m_s is a property of the electron itself, not the orbital, as it corresponds with the two directions of the electron's field, and applies only to multi-electron elements (every element except Hydrogen) to describe the number of electrons within a given orbital (0, 1, or 2).

3. THE MODEL AND SOUND SPACE

MSIPT uses sonic scale representations to model electron configurations and orbitals. The orbitals themselves are denoted by a single pitch, and the location of the orbital is localized around the nucleus – in this case, the user – using 3d ambisonics.

The tremolo rates of the specific sounds imply the amount of electrons in a specific lobe within an orbital. A faster tremolo rate suggests a higher energy level, which implies that there are more electrons in an orbital. This corresponds with the spin quantum number (m_s), which reflects the principle that an atomic orbital can hold a maximum of two electrons, which must have opposing spins.

Sonification models employ *link variables*, that is, the "glue which connects the model's dynamic processes to sound," [2] to mediate between the data and sound spaces. MSIPT employs some very basic forms of parameter mappings to serve as link variables; here, the mappings are designed to augment the efficiency of the translation between the data space and the sound space. A certain level of arbitrariness is built into the system, but this arbitrariness is virtually transparent in its sonic realizations. These realizations have the same function as "sketches" – they serve to illuminate the listener to the inner workings of atoms in a way that is unique to sound.

There are four characteristics of sound that are employed as link variables in MSIPT. The first three characteristics (loudness, pitch, and localization) are tied to an atom's first 3 quantum numbers (n, l, and m_l) which dictate the size, shape, and orientation respectively of the orbitals occupied by an atom's electrons. The fourth characteristic of sound (timbre) serves to underline the direct link between and an element's electron configuration and resultant physical and chemical properties by sonically differentiating between elements with different properties.

Loudness is used to portray the degree of attraction of the electrons to the nucleus by virtue of the closeness to the listener. That is, a sound that is louder, i.e. closer, to the listener implies that there is a stronger attraction to the nucleus. For example, although hydrogen and helium both have a single $1s$ orbital, helium has two electrons and protons surrounding its nucleus, whereas hydrogen only has one. This makes the helium orbital more strongly attracted to the nucleus, so it sounds almost twice as loud.

The second sound characteristic, pitch, involves a concomitant conceptualization of musical distance, and is associated with the element's respective orbital group. The pitch construction of MSIPT proceeds in a generative manner. The orbitals produced by the s group sound progressively lower octave tones from a selected fundamental, whereas the orbitals produced in the p, d, and f groups sound progressively higher tones that are near to each other in the harmonic series. This process can be represented as efficient voice leading through notes that share a common edge on a tuning lattice, or *Tonnetz*, as shown in **Figure 2**. This representation of voice leading through tuning lattices suggests gross contrasts between tones and chords, such as "near" or "far" [4]. That is, the audible distance between the notes used in carbon and nitrogen is much closer than that between the notes used in, say, carbon and silver.

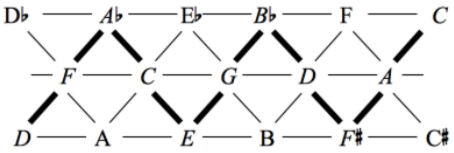

Figure 2: Voice leading path used in MSIPT.

The third characteristic of sound, localization, is associated with the sound source location of the orbital lobes around the listener. MSIPT's user is situated in the center of the atom, the nucleus, and the lobes' sound representations are distributed around the user using 3d ambisonics. An element with a stable octet of p orbitals will have three lobes, so the listener will hear sound come from the front and back, the sides, and the center.

The fourth musical characteristic, timbre, is associated with the class of element, specifically whether the element belongs to the alkali metals, alkaline earth metals, lanthanides, actinides, transition metals, elements of unknown properties, post-transition metals, metalloids, other nonmetals, halogens, or noble gases. Elemental class defines an element's physical and chemical properties and illuminates the nature of chemical bonding and reactivity. The listener can distinguish between the elements' natures as well as the underlying quantum mechanical evidence illuminated by the orbital group and degree of nuclear attraction through timbre. For instance, by acoustically differentiating the malleability, conductivity, and hardness of Iron (an alkaline earth metal) from the gaseous and unreactive nature of Neon (a halogen), the listener becomes aware of the respective properties of these elements.

4. CONCLUSION

The Multi-Sensory Interactive Periodic Table is a simulation product that allows the user to hear electron configurations, ionic radii, orbital structures, and chemical bonds of the elements found in the periodic table. Simulation products are sonification model systems that provide a self-contained method for many-to-one mappings between the data space, in this case the atomic structures, and the model space, which consists of the musical architectures that inform the sounding artifact. These architectures are made up of *link variables*, which are conceptual mediators that inform these mu-

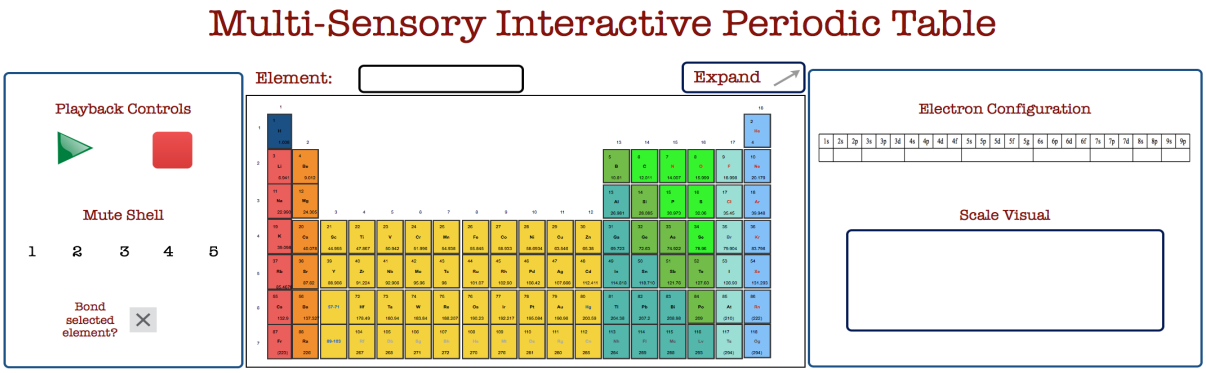

Figure 3: The User Interface for MSIPT.

sical architectures, and employ four characteristics of sound that together constitute the sound space.

By organizing the periodic table as a simulation product, the listener profits from a hitherto unused angle with regard to atomic structures. The many-to-one mapping system, coupled with the easily-learned, "sketch"-like sound language, provides the listener with a novel way to perceptualize the underlying trends found within the periodic table. It is intended for MSIPT to be employed in an educational setting, where this clear and novel sonic approach will be easily grasped by middle- and high-school students.

5. REFERENCES

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