**LIVING IN CONFIGURATION SPACE**

**I. INTRODUCTION**

Natural Selection has produced living beings that universally perceive they live in a 3-dimensional spatial environment well described by classical physics. However, during the late 1800’s and early 1900’s it became progressively more apparent that there were critical physical phenomena that could not be understood within this framework. About one hundred years ago, after intense intellectual effort, quantum mechanics (QM) opened the door to deeper understanding. For example, the existence of stable Structures such as tables, chairs, and humans, was no longer fundamentally mysterious. However, the mathematical formulation of QM requires configuration space (CS), a space of very high dimensionality that is not perceived [1, 2].

While QM produces extremely accurate quantitative descriptions, there is no generally agreed fundamental interpretation of the theory[3]. Most frequently, interpretive proposals involve a primary 3-D space of our manifest image, a separate CS of variable status depending on a myriad of details, and complex methods of translation between the two [3, 4]. At the other extreme QM is taken at its word, with CS being the fundamental space and the 3D space we experience being derivative or emergent [1, 5-7].

This paper follows the latter path, giving a concrete demonstration that the perception of space may not accurately reflect its underlying geometry [8, 9]. It presents a nuts-and-bolts elaboration of Albert’s recognition [1] that the Hamiltonian can be the source of 3-D perceptions for inhabitant CS. First it is shown that the general form of the Schrödinger wave function of any Structure that move in a manner consistent with preserving its integrity and functionality is the product of two terms. One describes the free translational and rotational motion of the entire Structure in directions defined by a special 3-D subspace of CS, a different subspace for each Structure. That motion becomes progressively more classical as the mass of the Structure increases. It is classical for Structures big enough to be alive. The second term describes the high-dimensional, always quantum mechanical, internal dynamics of the Structure. Next, the paper shows how the classical, 3-D, manifest image emerges within CS from interactions between the Structures. Finally, life with our evolutionary and intellectual perceptions of the world is discussed.

**II. QUANTUM MECHANICS OF STRUCTURES**

**A. Structures**

The dynamics of non-relativistic quantum mechanics are described by the Schrödinger equation, shown in Eq. 1 for a world of pairwise interactions.

are the potential energy functions of the interactions; ; and has 3 spatial second derivatives. is the wave function (WF), a complex valued function on CS. While in classical mechanics one naturally deals with the motion of “particles”, that is less clear in QM. However, the Schrödinger equation is built from “components” with different masses, kinetic energies, and interaction, each component described in a 3-dimensional subspace of CS. That nomenclature will be adopted -- interacting 3-dimensional “components” that form Structures of higher dimensionality in CS.

The CS coordinate axes of the *ith* component are , with basis vectors **.** The coordinate values of all the components, , define the position of the system point, ***SP*** in CS. Motion of the ***SP*** gives the trajectory of the changing configuration of the coordinate values of all components. In classical mechanics the ***SP*** is a single point. Quantum mechanically, the Schrödinger equation defines a family of trajectories given by the probability current[[1]](#footnote-1). Thus, the ***SP*** extends over the region of support (ROS) for the WF in CS[[2]](#footnote-2). The potentials in Eq. 1 are time independent and so describe a stable potential energy terrain in CS on which the WF and the corresponding ***SP*** evolve.

Structures containing multiple components can be formed by attractive potentials of the general form shown in Figure 1, with specific shapes and magnitudes dependent on the types of components. The potential is infinite when . As increases the potential decreases, becoming negative, and finally becoming 0.

**Figure 1**. Representative Attractive Potential. See text for details.



Imagine a world containing *G* total components, a subset N*k* of which are connected to each other through chains of interactions that have values of corresponding to negative potential energy. If each has sufficiently low kinetic energy the components are bound together, forming Structurek.[[3]](#footnote-3) Assume for the moment that all other components have coordinate values such that they do not interact with any of the components. Thus, Structure*k* will behave independently.

**B. Structural Integrity, Three-Dimensional Motion, and the Wave Function**

The components that comprise Structure*k* can undergo different types of motions consistent with the constraints of their mutual interactions. These include, for example, thermal fluctuations (phonons) and small internal motions required for the biochemistry of life. What about large-scale motions that preserve Structure*k*’s functional integrity? Such motions must leave each *ij* term in the potential energy in Eq.1 unchanged. Suppose that the configuration changes such that , and similarly for *y* and *z*. Equating the before and after the motion:

Keeping only the first order terms in the :

for all

One way the potentials are unchanged is if , etc. By fixing it is evident that all must be equal, and that they need not be infinitesimal. Similarly, for and . These 3 sets of displacements can differ, call them , and . Therefore, all vectors that describe the integrity/function-preserving displacements of Structure*k* are of the form:

where ; ; and are orthogonal unit vectors spanning the 3-dimensional subspace, call it , containing all vectors . The ***SP*** of Structurek can move to and maintain its integrity. Complex calculations are not required for Structure*k* to make such a move. Baseball players and baseballs always get it right. The Appendix describes a second class of structure/function preserving motions that involve correlated infinitesimal changes in { in Eq. 2. These describe rotations about axes consisting of the vectors **.**

The subspace has another important characteristic. Consider two components of Structure*k*, one with coordinate values and the other in their respective subspaces. Projecting the position of the first onto the basis vector gives:

and similarly for and **.**

The normalizes the projection so that it is independent of the unknown number of components of the Structure. Projection of the coordinate values of the second component yields corresponding results. The difference in the coordinate values after projection into the 3-dimensional subspace is . Thus, there is a Pythagorean distance between the projected positions of the two components, the square of which is just the argument of the potential function, so that the interaction appears as we naturally perceive it in 3 dimensions.

However, the 3-D relationships of the projected position are mathematical, not physical. To see this, note that locations in are given by:

for arbitrary *a, b,* and *c.* Thus, the coordinate values for all components are identical, so all the potential functions of Eq.1 have , making the potentials infinite. in where the potential is infinite so nothing physical can be present.

Figure 2 illustrates the foregoing concepts for the most complex Structure that can be conveniently depicted—a pair of 1-dimensional components interacting with the attractive potential of Figure 1. X1 and X2 indicate the orthogonal axes of CS, with the 1-dimensional ***D*** subspace, basis vector**,** bisecting the angle between them. The vertical axis gives the potential, ***V12***. The potential terrain, indicated by the blue dashed lines, has minima on both sides of ***D***, the near side corresponding to coordinate values where *x*1> *x*2 and the far side to *x*1< *x*2. The potential is infinite for points in ***D*** as required by Eq. 5. The green disc shows the ***SP***, with the red ***d*** vectors from ***D*** showing the directions of its unrestricted motion. The purple arrow indicates the internal motions of the ***SP*** [[4]](#footnote-4). To get an appreciation of the scale, note that the purple internal configuration typically represents inter-atomic distances, while the free motion of the ***SP*** in the trough in the ***d*** direction is unbounded.

Figure 2. CS for Two Interacting Components Moving in One Dimension. See text for details.



Extending Figure 2 to Structures with an arbitrary number of higher dimensional components is straightforward but difficult to visualize. Imagine Structurek of Nk three dimensional components. Its corresponding ***D***k is a 3-dimensional “ridge” of infinite potential (Eq. 5) through its 3Nk dimensional subspace of CS. ***D***k is surrounded by a high-dimensional negative potential region in which the ***SP***/ROS is located. The general form of the WF for the motion of Structurek is obtained by transforming the “natural” basis of Structurek’s subspace to a set employing the three basis vectors of  **, ,** plus 3Nk-3 additional orthogonal bases vectors.[[5]](#footnote-5). In this basis, by construction coordinate values associated with the 3 basis vectors of ***Dk*** do not appear in the potential. The WF becomes the product of two terms. The first, , is that of a “free” component translating and rotating in the 3 dimensions of ***Dk***.[[6]](#footnote-6) ; while the second, , involves the remaining 3Nk-3 transformed dimensions describing the internal configuration of Structure*k*. Thus, the WF of Structurek is [[7]](#footnote-7), with describing its overall position and its high-dimensional morphology in CS. This WF is the CS description of tables and chairs.

**C. Classical is Quantum**

All Structures must have a WF of the general form of if they maintain their functional integrity. As the number of components of a Structure increases above 2, the coordinate transformation discussed in the previous section initially increases in complexity[[8]](#footnote-8). However, as Nk increases the 3 basis vectors of the space become progressively closer to orthogonality with the standard basis vectors of CS. Equation 3 shows that the projection of one on the other is , which is about 10-12 for a modest Structure with Avogadro’s number of components. Thus, if a structure has enough components, to an excellent approximation its WF can be described using the 3-dimensional basis of in conjunction with the original coordinates of CS.

As the number of components increases the mass increases, and the mass associated with the 3-dimensional motions described by approaches the total mass of the Structure. Thus, highly localized, very stable, wave packets for the large-scale 3-D motion can exist. For example, if for a 1 Kg Structure were initially localized to an atomic diameter, 1 å, the “velocity” of spread of the wave packet would be ~ 0.5x10-24 M/sec[[9]](#footnote-9). To provide a reference for this, after a time equal to the age of the universe the wave packed would have spread to ~ 1 μM*.* Thus, as the number of its components increases the 3-dimensional behavior of a Structure becomes progressively more classical—3-D motion with a well-defined position. On the other hand, the behavior of the internal motions of the Structure described by remain fully quantum mechanical no matter the dimensionality and total mass[[10]](#footnote-10). This is the continuous quantum-classical transition.

**D. Hierarchies**

Finally, note that the discussion of Structures started with 3-dimensional components in their individual subspaces of CS. Linking them with interactions produced Structures with an arbitrarily large number of components, but always with free motion in 3 dimensions. Therefore, who can say that the components initially imagined in a Structure were not Structures themselves, ones with sufficient binding energy to keep them from being disturbed when incorporated into the larger-scale Structure? This is the hierarchical, combinatorial formation of the Structures we are familiar with—tables made from atoms, which are made from nucleons and electrons, which are made from ……..

**III. GENERATING THE 3-DIMENSIONAL, CLASSICAL, MANIFEST IMAGE**

CS as described thus far is a lonely place—non-interacting Structures inhabiting separate, high-dimensional, orthogonal subspaces. However, since they are free to rotate and translate within their subspaces according to vectors from their individual 3-dimensional ***D*** subspace, Structures can explore their environment.[[11]](#footnote-11) Eventually the coordinate values of some components of an explorer become similar enough to the coordinate values of some components of another Structure so that they interact. These interactions are essential for living Structures, providing access to food, opportunities for reproduction and friendship, but also danger. They provide the leverage by which natural selection produces and refines the 3D spatial perception and mobility of living structures.

While the details of these encounters are complex, the essential features for the present discussion are that a living Structure exploring the world[[12]](#footnote-12) will perceive its interactions at positions in the 3-dimensional subspace of CS defined by the motions it is free to undertake. Moreover, will be such that its quantum mechanical exploratory motions are effectively classical, even for tiny living structures such as single cell microbes[[13]](#footnote-13). Each explorer will interact with the other Structures in the world and experience them as being located relative to its 3-dimensional motions, which are orthogonal to those of the other explorers because they are described by vectors from different ***D*** subspaces. However, all explorers will perceive the same 3-D spatial relationships among the Structures they encounter, correcting for motion that may have occurred if the encounter times are different. Explorers that have sufficient mental capability to remember (squirrels) and possibly record (humans) their motions will be able to produce mental/physical maps of their perceived 3-D world. If the explorers communicate and compare their maps, they will find them to be identical, including the locations of themselves, the other explorers, tables, chairs, and nuts. Therefore, each will perceive itself to be a 3-D Structure in the same 3-D space inhabited by all. This is their shared 3-dimensional, classical manifest image.

**IV. LIVING WITH DUAL PERCEPTIONS**

What should live Structures, with their perception of living in a 3-D world, do after developing QM, with its requirement that everything including themselves be described in CS? The suggestion explored here is that they should intellectually realize that their perceptions are described completely by QM, and that that should be the basis of their scientific thinking. Dividing the world into “macroscopic” classical and “microscopic” quantum features is a productive computational approximation, but is misleading for metaphysical considerations.

After performing a fully QM analysis, a physicist can determine the 3-dimensional behavior s/he will perceive by projecting the calculated coordinates of each component into the world’s 3-dimensional subspace[[14]](#footnote-14) as in Eq. 4. Thus, for the ith component:

where are the basis vectors of . This mapping is the inverse of that originally used by the Structures who developed the concept of CS for classical and then quantum mechanics. The reciprocal mathematical relationship makes it evident that the Structures’ perceived 3-D world is a subspace of CS, not a separate space.

The coordinate values of the components in CS evolve according to the family of probability current trajectories of the ***SP***, as described in Section IIA. Therefore, the projections of Eq. 6 should be performed in a trajectory-specific manner to preserve correlations. Variations among the projected trajectories provide a 3-D view of the QM uncertainties. If the mass of a Structure is high enough the variations related to overall position will be small and the projection will reveal classically behaving tables, chairs, and physicists; while the uncertainties related to the internal motions will generally provide a 3-D view of quantum mechanical behavior. In some situations, such as Structures with a small number of components, correlations between the trajectories produce the 3-D view of entanglement and non-local behavior. Recall however that this description of what a physicist would naturally perceive from a QM calculation is just a mathematical projection into the subspace of CS, which Eq. 5 shows must be empty. The perceived masses, interactions, and 3-D dynamics of the projected points originate from the Schrödinger equation in high-dimensional CS where the Structures live.

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**APPENDIX: CONFUGURATION CHANGES AT CONSTANT POTENTIAL ENERGY**

The potential energy is given by:

Suppose that the configuration changes so that etc. Then to keep the potential energy constant for all interactions one needs:

to first order in all :

for all .

**Linear Translation**. One solution is for , etc. If one fixes it is immediately evident that all as discussed in Eq. 2 and the subsequent development of the subspaces, Eq.3.

**Rotations.** What about general solutions with etc.? Suppose only one term in Eq. A2 has non-zero Then there is no general solution. However, if one assumes that two of the terms have non-zero , for example all but the others can be non-zero, one finds:

Where is an infinitesimal rotation angle around the axis of ***D****[[15]](#footnote-15)*. Similarly, one finds and respectively when all and when all . Rotations around an arbitrary axis in CS can be built from sums of these three.

In conclusion, no matter how many components a Structure contains, and therefore no matter the dimensionality of CS, the only changes in configuration maintain its integrity are 3-dimensional translations along, or rotations about, vectors in the subspace.

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1. In the Bohmian interpretation of QM one of these trajectories, whose identity is unknowable, describes the evolving true state of the system. This interpretation becomes very attractive given Section 4. [↑](#footnote-ref-1)
2. The extent of the ***SP*** is the source of the statistical nature of QM. Superpositions of WFs can produce disjoint ***SP***s. [↑](#footnote-ref-2)
3. Structures are not stable in classical mechanics but are in QM. [↑](#footnote-ref-3)
4. Due to superpositions this may be on both sides of the potential wall. [↑](#footnote-ref-4)
5. This generally requires some complex re-assignment of mass and potentials to the coordinates. [↑](#footnote-ref-5)
6. A system with a single component is automatically restricted to 3-D motion. [↑](#footnote-ref-6)
7. Note that for points in ***Dk***, so that the full WF is also 0 there, as required by Eq. 4. [↑](#footnote-ref-7)
8. The transformation for two component structures like the hydrogen atom is straightforward. [↑](#footnote-ref-8)
9. For a 1kg mass initially confined to 1 å, the spreading velocity of is 0.5x10-24 M/sec. The spreading velocity for a 100 ng amoeba in a vacuum with initially localized to 1μM is 0.5x10-18 M/sec. [↑](#footnote-ref-9)
10. A bridge designer is concerned with in the high-mass (classical) limit to fit beams together, while the metallurgist developing new bridge building materials is focused on tweaking the QM behavior of . Further, a CCD detector has both a well-defined position, and the QM internal behavior required for its function. [↑](#footnote-ref-10)
11. Undergoing these motions requires auxiliary systems (which may also be Structures) such as arms and legs, rocket thrusters, walkways, and boats etc., which can be described within the framework of Eq. 1. These complex details can be imagined for present purposes. [↑](#footnote-ref-11)
12. Particles that mimic photons could be added to speed up the mapping process since direct interaction among Structures would not be necessary if each can interact with the “photons”. [↑](#footnote-ref-12)
13. Consider a tiny living structure such as an amoeba. If it were in a vacuum, footnote 9 shows that would spread at a velocity of 5x10-18 M/sec if it initially were localized to 1μM. In a living environment with continuous interactions with the surrounding liquid, spreading will be substantially less. For comparison, the swimming velocity of the amoeba is on the order of 10-5 M/sec, 13 orders of magnitude higher than the vacuum spreading. Classical mechanics would describe this very well, so the amoeba experiences a 3-D classical world. Notice that the internal functions of the amoeba described quantum mechanically by are not affected by the fluid environment, with the exception, of course, of defined interaction portals for food and waste etc. [↑](#footnote-ref-13)
14. Defined as in Eq. 3, with the sum extended to the full (but unknowable) G components of the world. [↑](#footnote-ref-14)
15. This is a general solution for Structures regardless of component number. For Structures of with up to 4 components other solutions may exist. [↑](#footnote-ref-15)