Schrödinger's Cat Without Limits

But why stop there, when the configurations of superpositions can even be extended into the physical structure of the eye of the observer [20], a superposition of one that saw the photon and one that did not, and even to the nervous system and further on to the neural correlates of consciousness in the brain, with nothing to prevent superpositions of conscious feelings, a superposition of one that was happy to see the photon and one that was not, Figure 2.7?

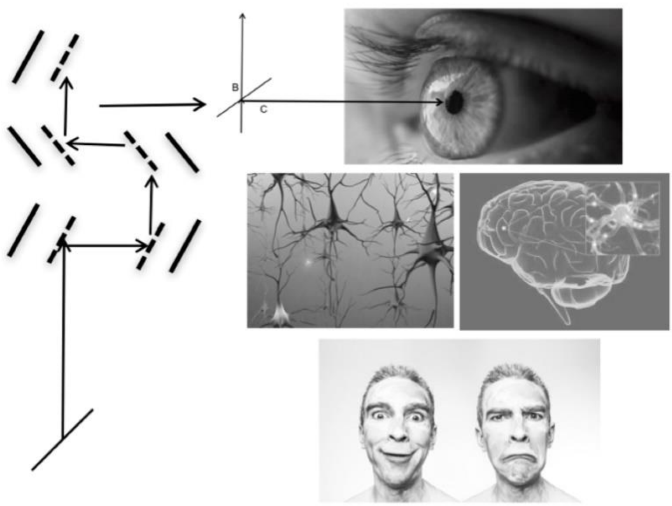

Figure 2.7: But why stop with the mirrors, when the configurations of superpositions can even be extended into the physical structure of the eye of the observer, to the nervous system, to the neural correlates of consciousness in the brain, and with nothing to prevent even superpositions of conscious feelings?

If we consider that there must be a momentum recoil for a system with finite mass, then any wave-packet will experience recoil at sufficient intensity. This would indicate that a mirror can go into superpositions of different locations. In a unitary world, there would be no boundaries to the superposition principle, any object, no matter how large, can go into a superposition of different locations [21]. One can extend the NOON photon state to an entangled matter state $|\psi\rangle = (|N\rangle|0\rangle + |0\rangle|N\rangle)/\sqrt{2}$. Consider that if N is made large enough the state could approach that of a *quantum locomotive*,

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|\text{Locomotive}\rangle|0\rangle + |0\rangle|\text{Locomotive}\rangle).$$

Such an entangled locomotive state is possible in an all-unitary theory, although it would be uncharted territory from our experience. The state might be represented as in Figure 2.8, for which the entire state of the train is traveling on the left track with the right track unoccupied, in superposition with the train on the right track with the left track unoccupied. No worries if such an extreme macroscopic object even shattered a mirror, as the superpositions unitarily would simply continue to be extended. The magnitude of its quantum of action would overwhelm that of Planck's constant and any associated decoherence would still be operating unitarily. Nothing is violated as long as there is no measurement process. However, there is no such measurement process in a unitary world, not even a single photon entering the eye of an observer allows him to fixate his location unitarily.

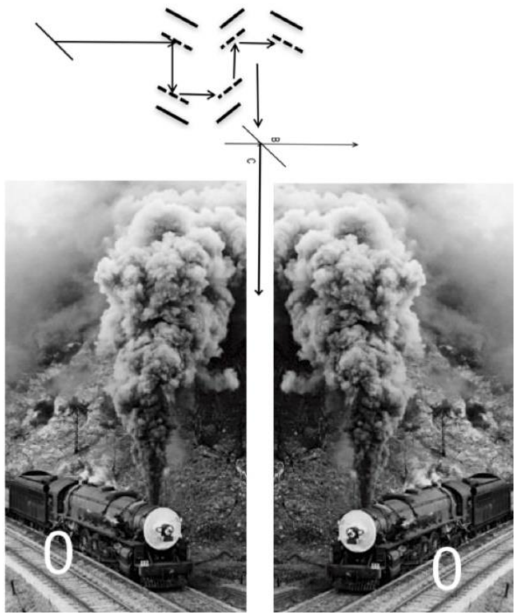

Figure 2.8: A quantum locomotive superposition via two interferometer paths represented by the empty and occupied train tracks, giving the two classical possibilities of the locomotive.

What aspects of the world around us prevent the occurrence of superpositions to qualify it as mesoscopic or macroscopic; e.g., numbers of particles or magnitudes of particular quantities? A flux qubit built from a SQUID (superconducting quantum interference device) supports superpositions of clockwise and counter-clockwise supercurrents involving billions of electrons; however, only at most a few thousand electrons are found to be distinguished when passing from one branch of the superposition to the other [22]. Interferometry has been achieved with macromolecules, beginning with diffraction of fullerenes, and since extended to higher masses in the range $10^3 - 10^{10}$ amu (where 1 amu ≈ mass of the hydrogen atom) [23] [24] [25] [26], though this is several orders of magnitude smaller than has been achieved in ultra-cold atom experiments. By applying optical pulses on a freely falling Bose-Einstein condensate of $\sim 10^5$ ultracold rubidium atoms, a superposition of wave-packets separated by a distance of 54 cm was realized [27] [28] [29]. Perfect siliconcrystal neutron quantum optical experiments have achieved a coherent massive object with a separation of 9.5 cm enclosing an area of 100 cm^2, allowing enough room for a human hand to reach through the two branches [30] [31].

Yet all of these observed phenomena are still consistent with a quantum unitary world. Will new physics appear as these experiments are scaled up still further into the world around us or is our world completely unitary? In Chapter 3, we will develop the requirements for distinguishing unitary from non-unitary processes and the implications for the quantum measurement problem.

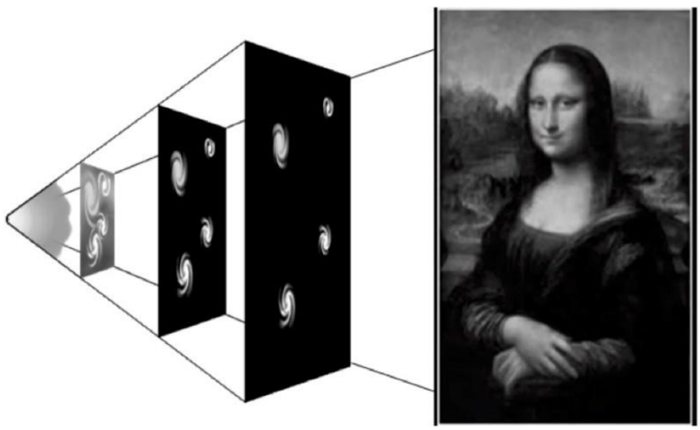

Figure 2.9: Have all the aspects of our surroundings emerged unitarily from the initial expansion of the universe at the big bang?

Mona Lisa

A unitary world also leads to the conclusion that all aspects of our surroundings emerged unitarily from the initial evolution at the big bang. However, many aspects of what we observe would be puzzling if this were the case. Observations of the cosmic microwave background (CMB) and our local universe are consistent with a picture that the universe was initially hot and opaque, then cooled over several hundred thousand years until light decoupled, leaving a nearly isotropic CMB that embodies the afterglow of the big bang. An early inflationary phase of accelerating expansion would account for how the current universe can be nearly isotropic if the pieces of what we observe were not in causal contact when the photons were first emitted. The end result is a universe that is spatially flat at an age of $\sim$ 14 billion years since the big bang with an accelerating expansion and consisting not only of atoms (i.e., hydrogen and helium) but also cold *dark matter* and *dark energy* [32]. The early conditions of the universe on large cosmological scales some hundred thousand years after the big bang are revealed in the measured temperature distribution of the nearly uniform CMB [33]. The structure of the universe is much more complex and diverse at the smaller spatial scales we see all around us. Nevertheless, a corresponding unitary description of the universe would be described by a wave function $|\Psi\rangle$ governed by the Schrödinger equation even if the resultant probabilities for many events were not high [34].

Applied to the universe as whole, a *no-boundary* initial condition of the universe was proposed by Hartle and Hawking [35]. However, would all the delicate balances of the initial phases of the wave function of the universe remain intact to account for the world we see around us, without exceptions, not even for the seemingly historical accidents and multitude of developments streaming from our civilizations, including the inevitability of even the Mona Lisa, and Leonardo and Leonardo's mother, and the silk merchant who commissioned the Mona Lisa, etc., Figure 2.9 [36]? Unitarity would then even have led to all of the theories of the quantum measurement problem reviewed in Chapter 4, some of which predict that this same universe is non-unitary. However, these are high-level products in the hierarchy of complexity of our cultures and suggest a purposeful design and possibly that intelligence with the capability of non-unitary intention has appeared. Or alternatively, can all of this complexity be mimicked by unitary processes even if only in an emergent manner [34]? These questions form the main theme of this book.

The reader should now be familiar with the concepts of interference, reversibility, and entanglement that are inherent in unitary evolution. The reader with a less technical background should now proceed to the Introduction of Chapter 3. Although a detailed understanding of the mathematics of Chapter 3 is not a prerequisite for continuing to Chapter 4, the general results in Chapter 3 should be understood. After becoming familiar with the Introduction of Chapter 3, the less technical reader should proceed through the majority of the remaining material in Chapters 4, 5, 6, and 7, while omitting detailed technical aspects found within one section or another, which are generally not required to proceed through the remainder of the book.