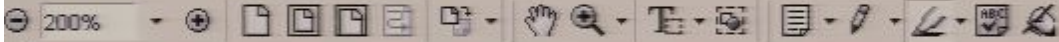
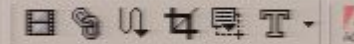


Title: Many Worlds

Date: Oct 03, 2006 09:00 AM

URL: <http://pirsa.org/06100002>

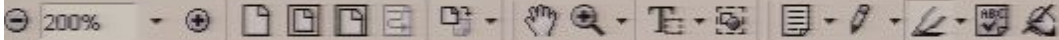
Abstract: TBA

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The many worlds theory takes unitary quantum mechanics, without collapse, to be a complete theory. To explain our experiences three additional observations are needed:

1. Given the pure quantum state of the universe, any subsystem of it can always be assigned a quantum state of its own, the **relative state**, which is in general mixed.

Let  $\mathcal{H}$  be the Hilbert space of the universe, and suppose that the universe has a (pure) quantum state  $|\Psi\rangle$ . Consider a division of the universe into two subsystems  $\mathcal{H} = \mathcal{H}_1 \otimes \mathcal{H}_2$ . We can think of  $\mathcal{H}_1$  as a space associated with a given physical system, and  $\mathcal{H}_2$  with the "rest of the universe". Take a basis  $\{|\psi_i\rangle\}$  in  $\mathcal{H}_1$  and a basis  $\{|\phi_j\rangle\}$  in  $\mathcal{H}_2$ . The state of the universe  $|\Psi\rangle$  can be written in terms of these bases



The state of the universe  $|\Psi\rangle$  can be written in terms of these bases as:

$$|\Psi\rangle = \sum_{ij} \lambda_{ij} |\psi_i\rangle \otimes |\phi_j\rangle \quad (1)$$

put

$$\mu_i = \sum_j |\lambda_{ij}|^2, \quad \mu_i \geq 0, \quad \sum_i \mu_i = 1 \quad (2)$$

Define

$$|E_i\rangle = \sum_j \frac{\lambda_{ij}}{\sqrt{\mu_i}} |\phi_j\rangle \quad (3)$$

then  $|\Psi\rangle$  can be rewritten as:

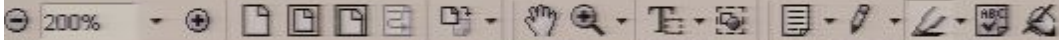
$$|\Psi\rangle = \sum_i \sqrt{\mu_i} |\psi_i\rangle \otimes |E_i\rangle \quad (4)$$

where the  $|E_i\rangle$  need not be orthogonal nor form a basis, so the expansion (4) is not, in general, a bi-orthogonal decomposition. The relative state of the system 2 is the mixture on  $\mathcal{H}_2$  given by  $\rho_2 = \sum_i \mu_i |E_i\rangle \langle E_i|$ , and each individual  $|E_i\rangle$  is the state of the rest of the universe relative to the state  $|\psi_i\rangle$  of the system. Everett calls each term  $|\psi_i\rangle \otimes |E_i\rangle$  in the global superposition (4) a branch, or a



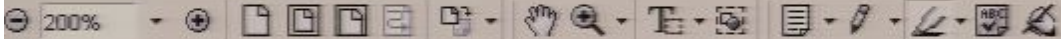
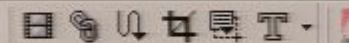
2. In the many worlds theory **environmental decoherence** (see e.g. Joos, Zeh & Kiefer 2003) is the key to solving the so-called preferred basis problem (i.e. roughly the question why our experience is associated with some particular coarse grained states). It can be shown that decoherence yields coarse grained branches that are defined in terms of the decoherent states and this is just enough to explain our usual quasi-classical experience. (At least let's assume here that this is the case).

3. **Probabilities:** this is our subject. The major problem of the many worlds theory (as construed above) is how to account for the probabilistic content of standard quantum mechanics, that is, Born's rule. The problem arises because the Everett-DeWitt branching is unrelated to the quantum probability. In a finite



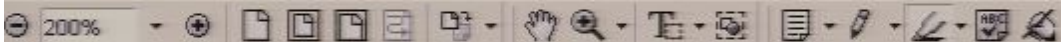
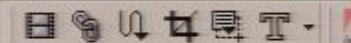
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where  $|\Phi_0\rangle$  is the 'ready' state of the apparatus, then the Hamiltonian evolves the state so that after the  $N$  measurements the final state is the superposition

$$|\Psi^N\rangle = \sum_{i_1, i_2, \dots, i_N} \mu_{i_1} \mu_{i_2} \dots \mu_{i_N} |\psi_{i_1}\rangle \otimes \dots \otimes |\psi_{i_N}\rangle \otimes |\Phi_{i_1}\rangle \otimes \dots \otimes |\Phi_{i_N}\rangle. \quad (6)$$

Where the  $|\Phi_{i_k}\rangle$  are the pointer states (or the memory states) of the apparatus, associated with the  $|\psi_{i_k}\rangle$  states of the system. The apparatus states are assumed to be of the kind described by decoherence theory.

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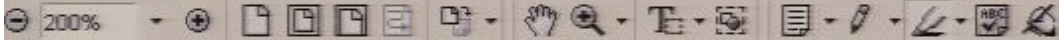
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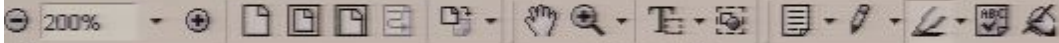
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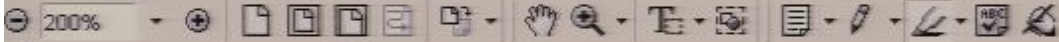
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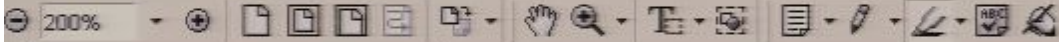


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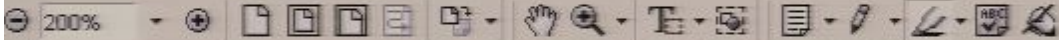
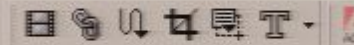
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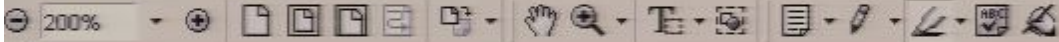
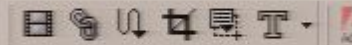
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$$|\phi^\infty\rangle = |\phi\rangle \otimes \dots \otimes |\phi\rangle \otimes \dots \tag{7}$$

Let  $|\psi_k\rangle$  be the eigenstates of the operator  $\mathcal{O}$  on  $\mathcal{H}$ . Define for positive integers  $N$  and  $k$  the operator  $P_k^N$  on  $\mathcal{H}^N = \mathcal{H} \otimes \dots \otimes \mathcal{H}$  ( $N$  copies) by

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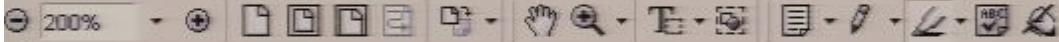


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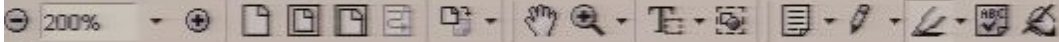
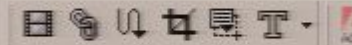
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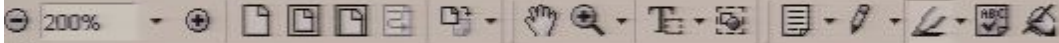
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bookmarks

comments

signatures

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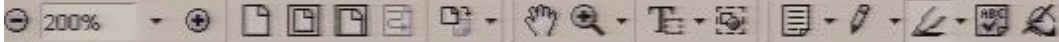
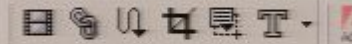
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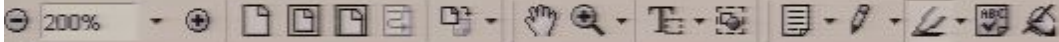
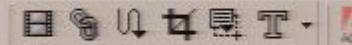
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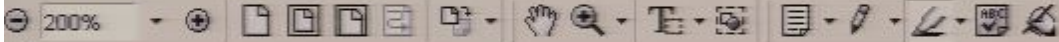
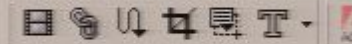
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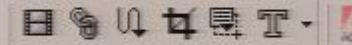
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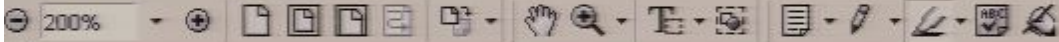
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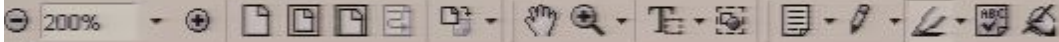
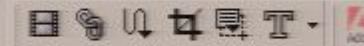
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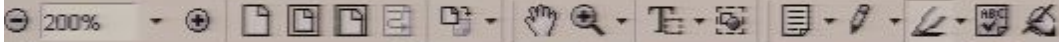
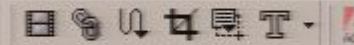


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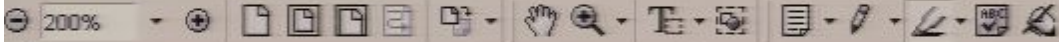
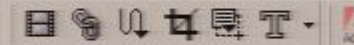
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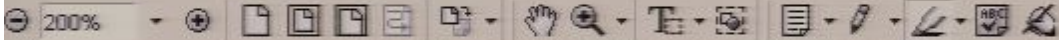
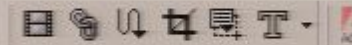
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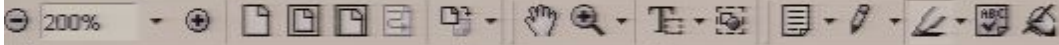
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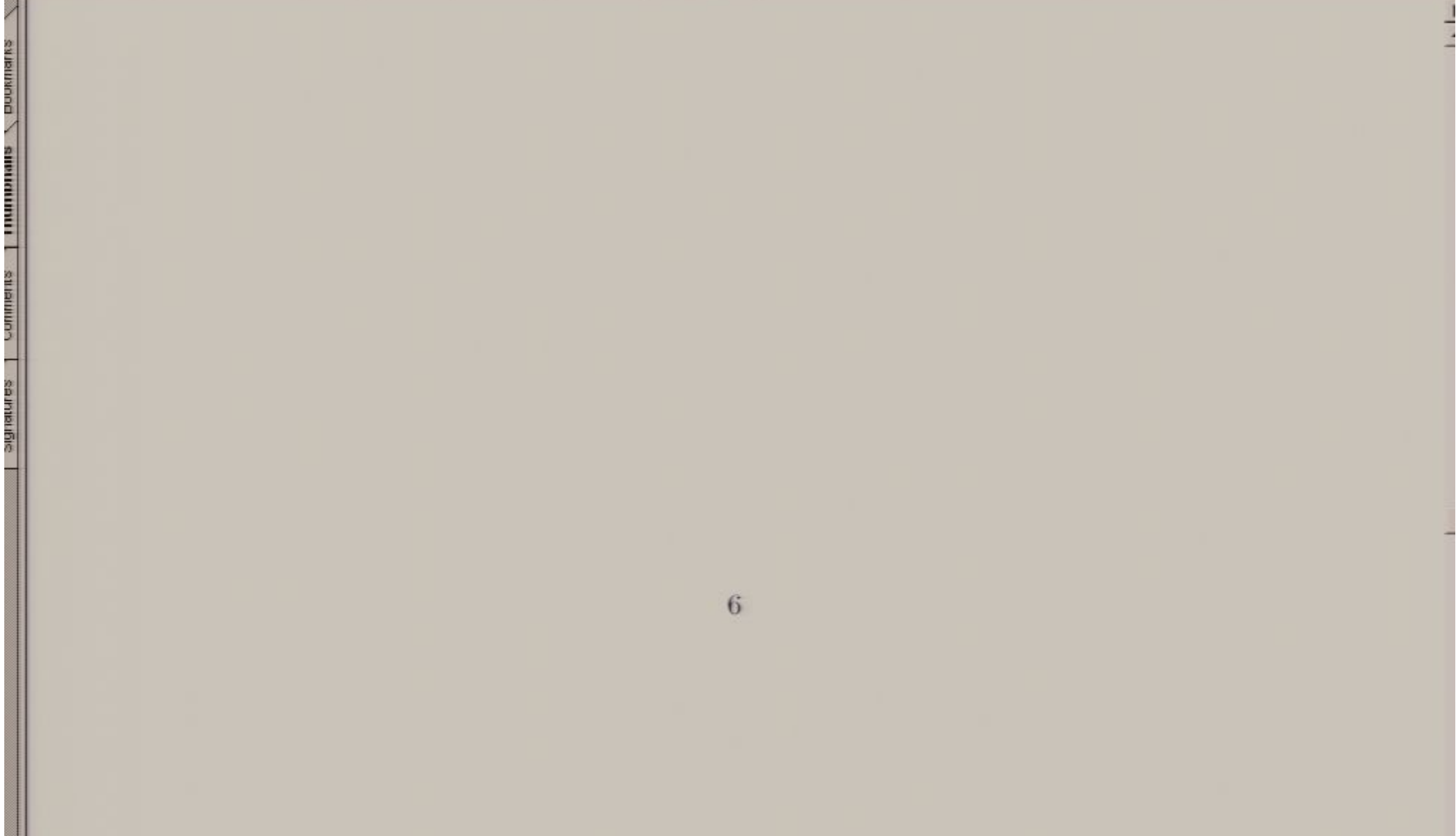
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So what are the problems?

1. Philosophical question: what does it mean for an agent to have preferences when all the options are equally realized?
2. The devil is in the details. One major axiom of ALL authors is probabilistic and NOT decision-theoretic. Namely the **non contextuality of probability**. (Implicitly assumed by Deutsch, and explicitly by Wallace, who in one paper calls it Measurement Neutrality, and in another Equivalence)

Non Contextuality is a probabilistic assumption (not a rationality assumption) both in the classical and in the quantum framework.

It was called by Keynes a judgment of irrelevance. Consider a case of a flip of a coin and throw of a die. The 'standard model' is to take the probability space as the Cartesian product

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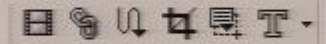
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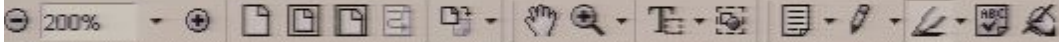
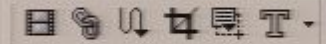
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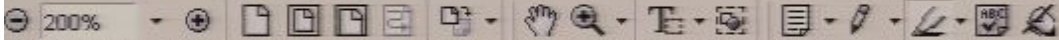
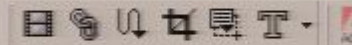
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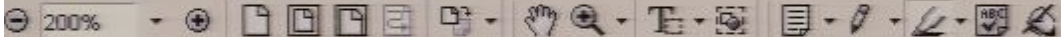
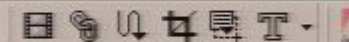
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define the probability of HEADS, whether the die is rolled or not.

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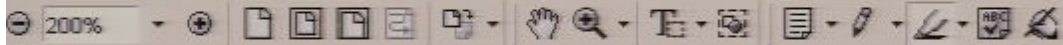
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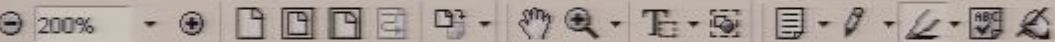
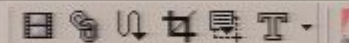
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