Personal Identity and Uncertainty in the Everett Interpretation of Quantum Mechanics Zhonghao Lu

ABSTRACT

The deterministic nature of EQM (the Everett Interpretation of Quantum Mechanics) seems to be inconsistent to the use of probability in EQM, giving rise to what is known as the "incoherence problem". In this paper, I explore approaches to solve the incoherence problem of EQM via pre*measurement uncertainty*. Previous discussions on the validity of pre-measurement uncertainty have leaned heavily on intricate aspects of the theory of semantics and reference, the embrace of either 4-dimensionalism or 3-dimensionalism of personhood, or the ontology of EQM. In this paper, I argue that, regardless of the adoption of whether 3-dimensionalism or 4-dimensionalism of personhood, the overlapping view or the divergence view of the ontology of EQM, the premeasurement uncertainty approach to the incoherence problem of EQM can only archive success while contradicting fundamental principles of physicalism. I also use the divergence view of EQM as an example to illustrate my analyses.

1. The Incoherence Problem

The Everett Interpretation of Quantum Mechanics (EQM) is a deterministic physical theory, but it also involves probability via the Born Rule. ¹ The deterministic nature of EQM seems to be

¹ See Saunders (2010a) for an overall introduction. In (1957) Everett attempts to reconstruct the Born Rule in section 5, while assuming full determinism as the underlying principle of Quantum Mechanics.

inconsistent with the use of probability in EQM. This has been called the "incoherence problem" of EQM (Saunders and Wallace 2008a).

Consider the simplest branching process with only two branches. Image an observer, Aristotle, measuring the *z*-spin of an electron in a state of superposition of different z-spins. The initial state of the entire system is represented by $\frac{1}{\sqrt{2}}(|\uparrow\rangle+|\downarrow\rangle)\otimes|Aristotle\,0\rangle$, where $\frac{1}{\sqrt{2}}(|\uparrow\rangle+|\downarrow\rangle)$ represents the initial state of the electron, and Aristotle 0) is the initial state of Aristotle. After the measurement, the state of the whole system evolves into $\frac{1}{\sqrt{2}}|\uparrow\rangle\otimes|Aristotle\uparrow\rangle+$ $\frac{1}{\sqrt{2}}|\downarrow\rangle\otimes|Aristotle\downarrow\rangle$, where $|Aristotle\uparrow\rangle$ (or $|Aristotle\downarrow\rangle$) signifies the state of Aristotle seeing the z-spin is up (or down). From an "outside" viewpoint, all branches equally exist after the measurement, and both the probabilities of Aristotle seeing the z-spin is up and Aristotle seeing the z-spin is down are 1. But from an "inside" viewpoint, one can only obtain a one single result after the measurement. Consequently, according to the Born rule, both the probabilities of Aristotle seeing the z-spin is up and seeing the zspin is down are 1/2 (Tegmark 1998).

In a deterministic theory, the following principle is commonly held true:

Ignorance: In order to make propositions such as "the probability that event E happens is p" meaningful in a deterministic universe, we must be ignorant of some facts about E.

Ignorance is commonly acknowledged in classical physics. In the background of classical mechanics as a deterministic physical theory, whether it will be raining tomorrow is determined by the physical state of a given moment *s*. But we cannot discern which physical state it is among a vast array of similar physical states {*s*'}. This is the basis for discussions involving probability in classical mechanics. Loosely speaking, if the measure of all states {*s*'} is *A*, and the measure of those states in {*s*'} that lead to tomorrow's rain is *B*, then the probability that it will rain tomorrow is *B*/*A* given the

physical state is *s*. This probability arises from our ignorance of the precise physical state of this moment.

In this paper I shall explore one line to solve the incoherence problem via pre-measurement uncertainty. I shall focus on Saunders and Wallace's proposal that some kind of pre-measurement uncertainty, which comes from the lack of specific indexical knowledge of observers, can resolve the incoherence problem in EQM (Saunders 1998, 2010, Wallace 2005, 2006, 2012, Saunders and Wallace 2008a, 2008b). According to Saunders and Wallace, even though Aristotle knows that the state of the entire system will be $\frac{1}{\sqrt{2}}|\uparrow\rangle\otimes|Aristotle\uparrow\rangle+\frac{1}{\sqrt{2}}|\downarrow\rangle\otimes|Aristotle\downarrow\rangle$, he remains uncertain of which person in the future he is identical to. This solution is based on the Lewis's account of personal identity (D. Lewis 1976, 1983). This approach is criticized based on theory of semantics and reference by P. Lewis (2007) and Tappenden (2008). In this paper, I will investigate the validity of the pre-measurement uncertainty approach to the incoherence problem and its consequences, while maintaining a more charitable position on the debate in language and semantics.

Pre-measurement uncertainty is not the only attempt to resolve the incoherence problem. Some authors favor *post-measurement uncertainty* to explain probability in EQM. For instance, Vaidman (1998) proposes that, imaging Aristotle is blindfolded during the measurement, he would be uncertain who he is identical to after the measurement until he sees the results of the measurement. ² Tappenden (2011) argues that this, combined with Sider (1996)'s account of personal identity, explains the use of probability in EQM. Moreover, Papineau (1996) and Tappenden (2000) reject *Ignorance* as the foundation for understanding probability in EQM.³ Although I do not find their suggestions unproblematic, this paper will solely

² This approach is furthered developed in McQueen and Vaidman (2019).

³ Instead, in a recent publication, Tappenden (2023) embraces premeasurement uncertainty. However, it bears more similarity to Tappenden's previous approach that rejects *Ignorance*, and remains to be justified whether it truly qualifies as a "pre-measurement uncertainty" approach. For this reason, I do not include Tappenden's recent approach in this paper.

focus on pre-measurement uncertainty.

2. Personal Identity and Ontological Structure

Some attempts to understand EQM aim to distinguish different ontological structures of a *world* in order to address the debate of uncertainty. For instance, Wilson (2012) argues that the mathematical structure of EQM itself does not decide between the overlapping view or divergence view.⁴ Following this line of thought, adopting the divergence view can avoid the problem posed by Saunders and Wallace's approach to solving the incoherence problem. This claim relies on a deep metaphysical understanding of EQM, say, there can be deep and important differences in whether there can be multiple qualitatively identical "worlds" corresponding to one state in EQM, and that we should take the identity of worlds in EQM very seriously. However, I find this perspective misleading as it may undermine the very spirit of EQM that we do not need any additional structures or postulations of quantum mechanics. The common-sense 4-dimensional world we inhabit merely emerges from the quantum state, which is not primary in the ontology of EQM. As Wallace cites Dennett:

Dennett's criterion: A macro-object is a pattern, and the existence of a pattern as a real thing depends on the usefulness—in particular, the explanatory power and predictive reliability—of theories which admit that pattern in their ontology. (Wallace 2003, 93)

⁴ If different histories in EQM are not overlapped in the past, say, they are quantitatively identical but numerically different in the past, EQM should be thought of in terms of divergence; either way if they are numerically identical in the past, it should be thought of in terms of fission. Wilson (2013) further claims that the mathematical structure of EQM remains neutral regarding the view of Individualism, which regards an Everett world (a branch in Saunders and Wallace's terminology) as a metaphysically possible world, or the view of Collectivism, which regards an Everett multiverse (everything described by the quantum state of the universe) is as a metaphysically possible world.

The same applies to a *world* in EQM. The existence of a world is approximate, and could be vague and indefinite in EQM (Wallace 2002, 2003, 2010, 2012). Following this line, there is no deep philosophical inquiry to be made-regarding the identity of physical objects in EQM, at least nothing deeper than the identity of physical objects in classic mechanics. The identity of physical objects or *worlds* is not a deep truth underlying the *prima facia* structure of EQM, as Wallace once puts in this way:

There is a concept of transtemporal identity for patterns, but again it is only approximate. To say that a pattern P_2 at time t_2 is the same pattern as some pattern P_1 at time t_1 is to say something like " P_2 is causally determined largely by P_1 and there is a continuous sequence of gradually changing patterns between them"—but this concept will not be fundamental or exact and may sometimes break down. (Wallace 2003, 95-96)

Consequently, the distinction between overlapped histories and divergent histories is merely a superficial artifact. If adopting the divergence view of EQM can avoid the problem that the overlapping view has in order to solve the incoherence problem, then there must be a substantial difference between understanding one branch in EQM as one world or multiple qualitatively identical but numerically different worlds. We would need to introduce additional structures (possibly only metaphysical rather than physical) to EQM, if we want to find any deep differences between them.⁵ I shall discuss the divergence view in section 4. Although the divergence view may have its own problems, the aim of this paper is not to reject it. In section 4 I shall argue that my analyses in this paper apply to the divergence view as well, and supporters of the divergence view will face the same dilemma.

Although there may be no deep ontological questions within EQM, it is still legitimate to inquire whether one *person* is identical to another within the framework of EQM. While it might be

⁵ Wallace (2012, 287) also argues that the difference between overlapping histories and divergent histories is not meaningful for a similar reason.

commonly agreed that personal identity supervenes on the physical reality from a physicalism viewpoint, it is not *part* of our physical theories. As a result, it remains to be investigated *how* personal identity supervenes on the physical reality, as it allows for the development of different theories of personal identity within the framework of classic mechanics as the background. This inquiry differs from the question "divergence or not" mentioned earlier. Taking personal identity seriously does not necessarily burden the ontology of the underlying physical theory.

Personal identity, as I shall discuss in the following sections, is forms the very core of pre-measurement uncertainty in EQM. I will introduce the Lewis's account of personal identity in section 2 and Saunders and Wallace's solution of the incoherence problem involving pre-measurement uncertainty in section 3. I then will delve into P. Lewis and Tappenden's objection to Saunders and Wallace based on concerns related to reference and semantics. While maintaining a charitable perspective on the debates, I will propose another objection that there are no facts to be uncertain of in a common reading of Saunders and Wallace's proposal. In section 4, I will present a modified view that suggests the existence of multiple qualitatively identical but numerically different mental states that supervene on one physical state before the branching. The modified view can withstand the objections just mentioned. In Section 5, I further argue that this revised view cannot be consistent with physicalism and be successful to address the incoherence problem at the same time, unless we introduce some hidden variables into EQM. Finally, in section 6 I discuss the "divergence" view" of EQM, which provides a concrete example that illustrates the analyses presented in section 5.

3. The Lewisian Account of Personal Identity

The Lewisian account of personal identity, developed by D. Lewis (1976, 1983), is an attempt to preserve personal identity as a definite and transitive relation despite Parfit's destructive

arguments through Parfit's *personal fission* thought experiment (1984, 245-280).

By virtue of the obvious analogy between the brain splitting case and branching in EQM, I will use the branching case in EQM to illustrate both the Parfitian account and the Lewisian account of personal identity here. In our scenario, the quantum state after branching is $\frac{1}{\sqrt{2}}|\uparrow\rangle\otimes|$ Aristotle $\uparrow\rangle+\frac{1}{\sqrt{2}}|\downarrow\rangle\otimes|$ Aristotle $\downarrow\rangle$. Let us denote the person represented by |Aristotle $\uparrow\rangle$ (or |Aristotle $\downarrow\rangle$) as Aristotle \uparrow (or Aristotle \downarrow), and the person represented by |Aristotle0) before the branching as Aristotle0.

According to Parfit, if we maintain that personal identity is a transitive⁶ and definite⁷ relation, Aristotle⁰ can only be identical to at most one of Aristotle[↑] and Aristotle[↓] since Aristotle[↑] and Aristotle cannot interact with each other after branching, and they are distinct agents making their separate decisions. Consequently, Aristotle0 cannot be identical to both Aristotle[↑] and Aristotle[↓], as it would contradict the transitivity of personal identity. Hence, Aristotle0 is identical to only one of Aristotle \uparrow and Aristotle \downarrow . If we uphold personal identity as a definite relation, given that the branching is highly symmetric, whether Aristotle0 is identical to Aristotle↑ or Aristotle↓ can only depend on some rather trivial differences between them. Parfit claims that such trivial relations cannot be of significant philosophical importance. Therefore, either there does not exist such a relation as personal identity which is definite and transitive, or such a relation is trivial and lacks significance.

The Lewisian account of personal identity seeks to preserve the definiteness and transitivity of personal identity by positing the existence of (at least) two persons both before and after branching: They coincide before branching, but diverge afterwards. In the case of EQM, there are *already* two persons present before branching: Aristotle0 \uparrow and Aristotle0 \downarrow . Aristotle0 \uparrow (or Aristotle0 \downarrow) is identical

⁶ Namely, if person A is identical to person B, and person A is identical to person C, then person A is identical to person C.

⁷ *Personal identity is a definite relation* means that it does not admit of degree. We cannot say that person A is 50% identical to person B.

to Aristotle \uparrow (or Aristotle \downarrow), but Aristotle0 \uparrow is not identical to Aristotle0 \downarrow , hence the definiteness and transitivity of personal identity can be preserved.



Figure 1. Branching process according to David Lewis. C₁ and C₂ represents two 4-dimensional persons. *S* represents a person stage (the quantum state of which is |Aristotle0)) shared by both C₁ and C₂.⁸

It is important to notice the original Lewisian account has a 4dimensionalism nature. According to Lewis's account, a person is a 4-dimensional entity rather than a 3-dimensional entity. The claim that Aristotle0 \uparrow is identical to Aristotle \uparrow is not of *temporal identity*, but merely a trivial claim that Aristotle0 \uparrow is identical to *itself*. As the same 4-dimensional entity, Aristotle \uparrow is simply an alternative name of Aristotle0 \uparrow . Lewis calls the 3-dimensional slice of a 4-dimensional continuant as a 4-dimensional person a *person-stage*, which is usually understood as a fully-present *person* in 3-dimensionalism. A person, as a 4-dimensional entity according to Lewis, is an aggregate of person-stages that belong to different times.⁹ In the scenario of this paper, there is only one person-stage before the branching and two person-stages after the branching. Since the quantum states |Aristotle0 \rangle , |Aristotle \uparrow ⟩, and |Aristotle \downarrow ⟩ are all (approximately, of course) 3-dimensional, we can use them to

⁸ This figure is adapted from David Lewis's original figure in (1976, 25).

⁹ "A continuant person is an aggregate of person-stages, each one I-related to all the rest (and to itself). (It does not matter what sort of "aggregate." I prefer a mereological sum, so that the stages are literally parts of the continuant. But a class of stages would do as well, or a sequence or ordering of stages, or a suitable function from moments or stretches of time to stages.)" (D. Lewis 1976, 22)

represent the corresponding person-stages for convenience. These three person-stages can constitute at least two (4-dimensional) persons: { $|Aristotle0\rangle$, $|Aristotle\uparrow\rangle$ } (C_1 in Figure 1) and { $|Aristotle0\rangle$, $|Aristotle\downarrow\rangle\}$ (*C*² in Figure 1).¹⁰ The claim that there are already two persons present before branching means that, prior to the branching, the present 3-dimensional person-stage |Aristotle)belongs to two 4dimensional persons. One ({|Aristotle0}, |Aristotle^)}) is identical to the only person who contains |Aristotle[†]}, while the other is identical to the only person who contains $|Aristotle\downarrow\rangle$.¹¹ These identity relations between the 4-dimensional persons are transitive, but the identity relations between the 3-dimensional persons (Lewis calls it *I-relation*, namely, two person-stages are in I-relation if, and only if, there is at least one person containing them) can be intransitive. Both the person-stages represented by |Aristotle[†]) and $|Aristotle\downarrow\rangle$ share the I-relation with $|Aristotle0\rangle$, but $|Aristotle\uparrow\rangle$ does not share the I-relation with $|Aristotle\downarrow\rangle$.

3. Saunders and Wallace's Lewisian solution to the Incoherence Problem and its objections

Saunders and Wallace (2008a) utilize the Lewisian account as the foundation of pre-measurement uncertainty in EQM. Before the branching, Aristotle may be fully aware that the quantum state after branching will be $\frac{1}{\sqrt{2}}|\uparrow\rangle\otimes|$ Aristotle $\uparrow\rangle+\frac{1}{\sqrt{2}}|\downarrow\rangle\otimes|$ Aristotle $\downarrow\rangle$, but he lacks knowledge of whether he is Aristotle0 \uparrow or Aristotle0 \downarrow . As a result, he is uncertain whether he will observe the electron in state $|\uparrow\rangle$ or $|\downarrow\rangle$. There are no *internal* ways of distinguishing between Aristotle0 \uparrow and Aristotle0 \downarrow before the branching (though we can distinguish them through an external definition), for they are

¹⁰ For simplicity, I have only included two typical person-stages for each person.

¹¹ I assume that there is only one person who contains $|Aristotle\uparrow\rangle$ (or $|Aristotle\downarrow\rangle$) as its 3-dimensional part for simplicity. Strictly speaking, there can be an infinite number of persons containing $|Aristotle\uparrow\rangle$ (or $|Aristotle\downarrow\rangle$) considering the possible infinite occurrences of branching in the future. However, this assumption will not affect results in this paper.

physically identical up to the moment of branching. If this is true, then there can be some *subjective uncertainty* in EQM, although the evolution of the quantum state is deterministic. Aristotle is ignorant of *who he is* before branching.

This solution is objected by P. Lewis $(2007)^{12}$ and Tappenden (2008). They argue that, even if the Lewisian account is correct, neither Aristotle0[↑] nor Aristotle0[↓] could successfully refer to themselves before the branching. Aristotle0[↑] and Aristotle0[↓] can only successfully refer to the single person stage represented by Aristotle0) before branching, which is commonly shared by all persons in this scene. Consequently, they conclude that it makes no sense to claim that Aristotle0[↑] is ignorant of some indexical information about himself, as the utterance "I do not know whether I am Aristotle0 \uparrow or Aristotle0 \downarrow " fails to express that "Aristotle0 \uparrow does not know whether Aristotle $0\uparrow$ is Aristotle $0\uparrow$ or Aristotle $0\downarrow''$. In other words, their argument goes as follows: Before the branching, any singular terms in Aristotle0[†]'s expressions cannot singularly refer to Aristotle0[↑] but instead refer to all persons who supervene on |Aristotle0) at the same time; thus, the incoherence problem cannot be solved along this line. As P. Lewis argues that

In particular, I cannot wonder further whether my use of the pronoun 'she' when pointing at the observer picks out she \uparrow or she \downarrow ; since she \uparrow and she \downarrow coincide at the moment, I am pointing at both of them. (P. Lewis 2007, 6) (P. Lewis's use of "she \uparrow " and "she \downarrow " is the same as the use of "Aristotle0 \uparrow " or "Aristotle0 \downarrow " in this paper.)

Tappenden also objects that

But HydraUP and HydraDOWN cannot each indexically refer to her own body via an utterance of 'This is my body' which has a single token sited in a single body-stage at time *T* prior to

¹² P. Lewis did not cite Saunders and Wallace (2008a) in (2007) since it was not published yet by that time. But P. Lewis did argue against a similar line of solution presented in Saunders (1998) and Wallace (2006).

branching, because that single body-stage is common to the world-tube bodies of both HydraUP and HydraDOWN. (Tappenden 2008, 311) (Tappenden's use of "HydraUP" and "HydraDOWN" is the same as the use of "Aristotle0[†]" or "Aristotle0[‡]" in this paper.)

Saunders and Wallace attempt to develop a set of semantic rules where one single utterance can be paraphrased as two different propositions to address the objections (Saunders and Wallace 2008a, 295-296). I do not want to meddle with the somewhat murky issues of language and semantics here. Whether an utterance can successfully refer is, unsurprisingly, sensitive to the contexts in which it is uttered and the semantic rules we apply. I shall remain neutral in the debate about semantics. Instead, I shall argue that, under some general restrictions, which I shall explicate in the following, there are no *facts* in EQM to be uncertain of. Whether our language can express our uncertainty is one thing, but whether there is *anything* to be uncertain of is another thing.

4. Two versions of the solution

In D. Lewis's original writing, the claim that there are two persons before branching is a trivial one. There are no mysterious, or philosophical deep facts behind this claim that require investigation. In D. Lewis's original scene, and also in Saunders and Wallace's discussions, there exists only one 3-dimensional personstage before branching. To assert that there are two persons *present* before the branching simply means that there are two different ways to combine this particular 3-dimensional person-stage with other person-stages to constitute a 4-dimensional person.¹³ Before the

¹³ Tappenden (2023) misconstrues Saunders and Wallace's approach as it "reject(s) the concept of splitting, which is arguably Everett's key idea." Everett is not concerned about personhood or personal identity. Saunders and Wallace do not challenge Everett's idea of split that "the observer state 'branches' into a number of different states. Each branch represents a different outcome of the measurement and the corresponding eigenstate for the object-system state. All branches exist simultaneously in the superposition after any given sequence of

branching, Aristotle's internal mental state and thinking process is single. If Aristotle can be uncertain of something, he must be unaware of some facts. When Aristotle feels uncertain whether he is Aristotle0 \uparrow or Aristotle0 \downarrow in his mind, there should be some facts that determine whether this thinking belongs to Aristotle0 \uparrow or Aristotle0 \downarrow .¹⁴ However, it appears that this determination is merely a matter of our choice. It is Aristotle0 \uparrow who is uncertain if we choose to combine the person-stage before the branching with some person-stages that observe the *z*-spin of the electron as up, and it is Aristotle0 \downarrow who is uncertain if we choose to combine the personstage before the branching with some person-stages that observe-the *z*-spin of the electron as down. To put it more ironically, it is Aristotle0 \uparrow who is uncertain if we choose that the thought which feels uncertain belongs to Aristotle0 \uparrow , and it is Aristotle0 \downarrow who is

observations. (1957, 459)" in (2008). Saunders and Wallace do not alter Everett's conceptual framework as a physical theory; they only introduce 4-dimensionalism and an account of personal identity into EQM.

¹⁴ Saunders and Wallace propose that there are two or more thoughts of Aristotle before the branching, as they write: "If persons are continuants, we do better to attribute thoughts and utterances at t to continuants *C* at *t*. That is, thoughts or utterances are attributed ordered pairs $\langle C, t \rangle$ or slices of persons $\langle C, S \rangle$, $S \in C$ not to temporal parts *S*. This is to apply whether or not there is branching. In the absence of branching we obtain the standard worm-theory view; in the presence of branching conclude that there are two or more thoughts or utterances expressed at *t*, one for each of the continuants that overlap at that time.

Is it to be objected that thoughts or utterances have an irreducibly significance? We may grant the point that their tokenings are purely events - and as such, indeed, are identical - but the content of thoughts utterances is another thing altogether. On even the most timid forms of externalism, or functionalism for that matter, meanings are context-dependent. sentences produced pre-branching are likely to play different semantic each person subsequently, and likewise their component terms." (2008a, 295)

They consider *thoughts* as external entities. Their intention is to convey that there exist two or more contents within the agent's single thinking process in mind. Here I use *"thinking"* as the mental process and state in mind in this paper. As the subsequent argument unfolds, however, it is a matter of our choice to decide the semantic content of Aristotle's thinking (according to semantic externalism, as Saunders and Wallace advocate).

uncertain if we choose that the thought which feels uncertain belongs to Aristotle0↓. There is something not decided here, and fairly we can say there is some kind of *indeterminacy*, however such indeterminacy does not come from any further unknown facts, but only from a choice that remains to be made by us. This is not a kind of uncertainty.

However, with just a few modifications, I will present another version of Saunders and Wallace's solution. If there is more than one 3-dimensional entity which supervenes on one single physical state |Aristotle0), the previous objections can be addressed. For instance, two 3-dimensional that there are person-stages, suppose $(Aristotle0\uparrow)_3$ and $(Aristotle0\downarrow)_3$ before the branching, and both of them supervene on |Aristotle0). Namely, there is only one singular physical body as Aristotle before branching, but there are multiple mental states, or some other 3-dimensional entities, that supervene on |Aristotle0).¹⁵¹⁶ By having two or more minds that think before branching, which are *qualitatively* identical but *numerically* different, the objection presented in the previous paragraph can be resolved. Before the branching, neither thinking can tell which mental state it belongs to, as both share the same contents. But there are some further facts, though might be unobservable in principle, that can determine which mental state it belongs to.

¹⁵ The requirement that there is only one physical body as Aristotle before the branching can be relinquished if we introduce multiple qualitatively identical "worlds" or multiple physical states before the branching, with each mind of Aristotle situated in a distinct world. I shall discuss this approach in section 3 and 4. However, the claim that there are multiple mental states as Aristotle before the branching, which is more essential, shall remain unchanged.

¹⁶ The term "3-dimensional" might be a bit perplexing when applied to a mental state. In this context, I'm employing the term "3-dimensional" in a broad sense for the sake of convenience, aligning it with the terminology of 3-dimensionalism and 4-dimensionalism. A 3-dimensional person-stage is momentary, while a 4-dimensional person is not. From an eternalist perspective, one might uphold that there exists an overarching mental state for a person throughout all time, with their momentary mental states serving as partial "sub-states" of this ultimate mental state. I do not know who exactly uphold this view, but it is important to make a distinction here. Here, I call a mental state 3-dimensional in the sense that it is momentary.

P. Lewis and Tappenden's objection concerning reference and semantics can also be resolved. While there is only one singular "physical" utterance, namely, only one string of voices is uttered, this utterance is reflected in two numerically different mental states. When Aristotle utters "I do not know whether I will be Aristotle↑ or Aristotle↓ after the branching", this utterance can be translated into different propositions for different minds. Hence, the pronoun "I" can refer to different entities before the branching. (Aristotle0↑)₃ is uncertain whether (Aristotle0↑)₃ will be Aristotle↑ or Aristotle↓, and similarly, (Aristotle0↓)₃ is uncertain whether (Aristotle0↓)₃ will be Aristotle0↓)₃ will be Aristotle1↓ or Aristotle↓.

This revised solution is similar to some kind of the "Many Minds Interpretation of Quantum Mechanics" (MMI) . (Albert and Lower 1988, Lockwood 1996a, 1996b) MMI posits the existence of *indefinite minds* which supervene on one singular physical state of ourselves. Some early advocates of MMI do not aim to address the incoherence problem via pre-measurement uncertainty; for instance, Lockwood does not offer any account of personal identity in Lockwood's MMI theory, and rejects *Ignorance* as a necessary requirement. Lockwood claims that the idea of multiple minds supervening on one physical state itself is consistent with physicalism.¹⁷ However, in the next section, I shall argue that this option is inconsistent with physicalism if we intend to utilize it as a means to resolve the incoherence problem by pre-measurement uncertainty.

3 5. The Problem of Supervenience

As we have duplicated the person-stages in the previous section, the so-called "I-relation" between different person-stages is now reestablished as a definite and one-to-one relation. Adopting 3dimensionalism or 4-dimensionalism will not influence the conclusions in the following sections. For the simplicity of notations, I will use the notions in 3-dimensionalism from now on. If adopting

¹⁷ As Lockwood writes that "The assumption no more carries any dualistic implications than the conventional assumptions, which even physicalists allow themselves, about what it is like to be in such states." (1996a, 184)

3-dimensionalism, there are already two persons Aristotle0 \uparrow and Aristotle0 \downarrow before the branching or more. If adopting 4dimensionalism, the argumentation can be restored by replacing "Aristotle0 \uparrow " and "Aristotle0 \downarrow " with 3-dimensional person-stages "(Aristotle0 \uparrow)₃" and "(Aristotle0 \downarrow)₃", and replacing "personal identity relation" with "I-relation". This notation shift is purely for convenience, and does not imply an adoption of either the 3dimensionalism view or the 4-dimensionalism view of personal identity.

I use the term '*physicalism*' to represent the view that human persons are *in essence* physical things.¹⁸ Providing a comprehensive and elaborate definition here is both impossible and unnecessary. Instead, I present a relatively weak criterion of physicalism. According to this viewpoint, a human person is essentially a physical entity, and their personal identity can be *determined* if the physical state of the whole universe is determined and can in principle be deduced from the latter. It is reasonable to demand that the following requirement be fulfilled under physicalism

Supervenience: The personal identity relations in a possible universe ¹⁹ w' are the same as the personal identity relations in a possible universe w, if w and w' are physically identical. (In simple terms, personal identity in a universe supervenes on its physical state.)

This requirement is sufficiently lenient as it does not require that we can simply "read off" personal identity relations from the physical

¹⁸ Peter van Inwagen (2014, 225) defines *physicalism* as the thesis that "human persons are physical things". My definition is weaker as it allows some room to interpret what is "in essence" physical. These definitions, though not very precise, suffice for the purpose of my argument here.

¹⁹ In the terminology of EQM, the term "universe" refers to the entirety of physical existences described by the formulation of Quantum Mechanics. On the other hand, the term "world" is used to denote a specific branch in the universe under decoherence. Therefore, in this paper, I use the term "possible universe" instead of "possible world".

state. Such requirement does not even exclude the possibility that the personal identity relations supervene on physical states *nonlocally*. For example, if person A and B supervene on local physical states $|A\rangle$ and $|B\rangle$ respectively, whether A is identical to B may not be determined by the properties of $|A\rangle$ and $|B\rangle$ themselves. Donald (1997, 8) has suggested that a mind in MMI supervenes on the entire history, which implies that the non-locality of personal identity relations concerning physical states. Nevertheless, physicalism cannot be upheld if *Supervenience* is not satisfied.

The modified view presented in the previous section does not necessarily contradict physicalism. As we discussed earlier, physicalism does not necessarily require that only one mental entity can supervene on one single physical human body, as argued by Lockwood. However, to solve the incoherence problem via premeasurement uncertainty, a specific kind of identity relation between persons before and after branching is needed. This requires more than that multiple mental states supervene on one physical state.

The quantum state before the branching is represented by $\frac{1}{\sqrt{2}}(|\uparrow\rangle+|\downarrow\rangle)\otimes|$ Aristotle 0). Following the discussions in the previous section, both Aristotle0 \uparrow and Aristotle0 \downarrow supervene on |Aristotle0 \rangle approximately.²⁰ |Aristotle0 \rangle represents one single physical state and at least two numerically different mental states, which correspond to different persons (or person-stages). Various accounts can be proposed to explain how these mental states supervene on the physical state. The simplest option is that they directly supervene on |Aristotle0 \rangle without any further fine-grained characterizations. We can suppose that Aristotle0 \uparrow before branching is identical to Aristotle \downarrow , without loss of generality. This relation as personal identity is either *deterministic* or *indeterministic*. In a deterministic scenario, *which person after branching Aristotle0\uparrow is <i>identical to* is fully determined by all facts (both physical and non-

²⁰ |Aristotle0⟩ is an *instantaneous* physical state. Here, the term "approximately" implies that, strictly speaking, Aristotle0↑ and Aristotle0↓ may supervene on the physical states over a small period of time.

physical) before branching. In this case, no physical facts can fully explain how this relation is determined. All we know about the relations among Aristotle0[↑], Aristotle0[↓], and |Aristotle0[↓] is the *bare* fact that both Aristotle0 \uparrow and Aristotle0 \downarrow supervene on |Aristotle0 \downarrow =, but there are no physical facts to distinguish Aristotle⁰ and Aristotle0↓from their physical structures or to ground the fact that Aristotle0[↑] is identical to one person supervening on one specific physical state while Aristotle0↓ is identical to another. Consequently, non-physical facts must come into play to determine the relations of those states. If, in a different universe, we have these non-physical facts different while keeping the physical state of the universe the same, we would arrive at a different result regarding whether Aristotle¹ is identical to Aristotle¹. This, however, contradicts Supervenience.

If this relation is indeterministic (as suggested by Albert and Lower (1988) that personal identity in EQM is *irreducibly probabilistic*), it would immediately violate *Supervenience*. The claim that it is indeterministic that Aristotle0 \uparrow is identical to Aristotle \uparrow entails that in a possible universe, this proposition is false, which contradicts *Supervenience*.

The failure of the previous solution indicates the necessity of providing a more *fine-grained* account of how different persons supervene on their physical states. This suggests that we should attempt to divide the state |Aristotle0)into different parts in its mathematical formulation, each representing (or supervened by) a different person. For instance, we can rewrite the state before branching as follows:

 $\frac{1}{\sqrt{2}}(|\uparrow\rangle+|\downarrow\rangle) \otimes |\text{Aristotle 0}\rangle$ $= \frac{1}{\sqrt{2}}(|\uparrow\rangle+|\downarrow\rangle) \otimes \frac{1}{2} |\text{Aristotle 0}(\uparrow)\rangle + \frac{1}{\sqrt{2}}(|\uparrow\rangle+|\downarrow\rangle) \otimes \frac{1}{2} |\text{Aristotle 0}(\downarrow)\rangle$ where Aristotle0↑ supervenes on the state |Aristotle 0(†)⟩, and Aristotle0↓ supervenes on the state |Aristotle 0(↓)⟩. Treating these as functions over a subset of the overall direct product of configuration spaces in the formulation of Quantum Mechanics²¹,

²¹ The quantum state of *n* particles, known as the "wave function", is a function $\sim 17 \sim$

 $|Aristotle 0(\uparrow)\rangle$ and $|Aristotle 0(\downarrow)\rangle$ should have the same value to symmetry. In other words, Aristotle0 \uparrow and Aristotle0 \downarrow are qualitatively identical, so we should expect that $|Aristotle 0(\uparrow)\rangle$, and $|Aristotle 0(\downarrow)\rangle$ have the same value. One might suggest that since $|Aristotle\uparrow\rangle$ and $|Aristotle\downarrow\rangle$ are different, $|Aristotle0(\uparrow)\rangle$ and $|Aristotle 0(\downarrow)\rangle$ should have different values accordingly. This proposal implies *teleology* or *fatalism*, making it hardly plausible. Suppose Aristotle does not measure the *z*-spin of an electron, but rather the sum of z-spins of two electrons and the state |Aristotle 0) keeps fixed; it seems that how different mental states supervene on Aristotle 0) should not be influenced by which measurement is going to be performed later. Furthermore, to distinguish $|Aristotle 0(\downarrow)\rangle$ and $|Aristotle 0(\downarrow)\rangle$ as different physical states, we ought to offer a different understanding of what a physical state is according to its mathematical formulation. This might require developing a new mathematical formulation of QM to differentiate mathematically. For instance, could envision them we reformulating QM as a kind of *fiber bundle* theory, where |Aristotle $0(\uparrow)$) and |Aristotle $0(\downarrow)$) represent different fibers upon the same element |Aristotle0) in the base space, or some other alternative approach.

In section 4, I will discuss a proposal that this can be achieved without introducing any additional mathematical structures, only through a shift of metaphysics. Following this line, it is not necessary to propose that multiple mental states supervene on one physical state; Instead, they may supervene on different physical states or different "worlds". However, even if we can distinguish |Aristotle $0(\uparrow)$ and |Aristotle $0(\downarrow)$ based on their mathematical forms, the challenge of *Supervenience* remains. Physical facts alone cannot ground why the person supervening on |Aristotle $0(\uparrow)$ is identical to the person who supervenes on |Aristotle $0(\uparrow)$ rather than |Aristotle \downarrow , given that |Aristotle $0(\uparrow)$ and |Aristotle $0(\downarrow)$ have the same value. The formulation of a fiber bundle theory still lacks sufficient asymmetry to determine the relation, and the analysis

defined over the direct product of n configuration spaces of the background space manifold.

presented in previous paragraphs can be equally applied here.

As Barrett (1999, 185-206) suggests, giving a deterministic law of such identity mentioned above leads to some form of *hidden variable theories*. Such hidden variable theories are *ad hoc* if their acceptance is only for solving the issues of personal identity, implying that we have special *connecting rules* for mental entities, but not for all physical objects. Moreover, it remains challenging to determine how such connecting rules could be. For example, if we label |Aristotle↑⟩ with a hidden variable "↑", it could indicate a form of *fatalism* that Aristotle *must* measure the *z*-spin of the electron before branching; If Aristotle chooses to measure the x-spin of the electron instead, the hidden variable "↑" would hardly be effective in determining the personal identity relations. I shall elaborate this point in the next section with a particular example: the "divergence view" of EQM.

6. The Divergence View

Saunders (2010b) and Wilson (2012, 2013) have developed the so-called "divergence view" of EQM that there are multiple qualitatively identical but numerically different *worlds* before the branching. The motivation of Saunders's proposal is to avoid the problems of Saunders and Wallace's (2008) original solution to the incoherence problem, while the motivation of Wilson's proposal is probably to build a bridge between David Lewis's theory of possible world and EQM. Although Wilson claims that the choice between the divergence view and the overlapping view²² is neutral in terms of the mathematical structure of EQM (2012, 73; 2013, 713), their proposal requires a *deep* understanding of the ontology of EQM. It requires а substantial ontological difference whether $\frac{1}{\sqrt{2}}(|\uparrow\rangle+|\downarrow\rangle)\otimes|$ Aristotle 0) represents one world or two qualitatively different worlds. I do not engage in the debate of whether we should

²² In our scenario, for example, the view that there is only *one* world represented by the quantum state $\frac{1}{\sqrt{2}}(|\uparrow\rangle+|\downarrow\rangle)\otimes|$ Aristotle 0 \rangle , which has two different future branches, is attributed to the overlapping view.

accept the divergence view or the overlapping view in this paper. Instead, I argue that, supposing the divergence view is correct, the discussions presented in section 3 are still applicable to their proposal.

Saunders (2010) attempts to make some room for multiple 3dimensional persons before branching by proposing that histories in EQM which share the same past *diverge* rather than *overlap*.²³ Saunders uses an ordered pair (β , $|\alpha\rangle$) to represent a *person*, where β is what Saunders calls a momentary configuration (our |Aristotle0) is an example), and $|\alpha\rangle$ is an "entire history" consisting of β (*ibid.*, 191-192). In our case, there are at least two entire histories consisting of |Aristotle0⟩, whereas they consist |Aristotle↑⟩ and |Aristotle↓⟩ respectively. I call these histories $|\alpha\uparrow\rangle$ and $|\alpha\downarrow\rangle$ for convenience. It seems quite natural that (|Aristotle0⟩, $|\alpha\uparrow\rangle$) is identical to (|Aristotle↑⟩, $|\alpha\uparrow\rangle$) and that (|Aristotle0⟩, $|\alpha\downarrow\rangle$) is identical to (|Aristotle↓⟩, $|\alpha\downarrow\rangle$).

Following this line, there are multiple (3-dimensional) persons before the branching, and it seems that there can be some facts to ground Aristotle's curiosity "whether I am Aristotle0↑ or Aristotle0↓" before the branching. But this proposal still needs to be scrutinized following the analyses in sections 2.3 and 3. Again, if Aristotle is uncertain of whether he is (|Aristotle0⟩, $|\alpha\uparrow\rangle$) or (|Aristotle0⟩, $|\alpha\downarrow\rangle$), what facts remain unknown for Aristotle? The situation is similar to the discussion in section 2.3. Once again, he is (|Aristotle0⟩, $|\alpha\downarrow\rangle$) if we combine |Aristotle0⟩ with a *z*-spin up future, and he is (|Aristotle0⟩, $|\alpha\downarrow\rangle$) if we combine |Aristotle0⟩ with a *z*-spin down future. This is still a matter of choice rather than a kind of uncertainty.

This rejection might be too quick, and probably the core feature of the divergence view is overlooked. The proliferation of persons is grounded in the proliferation of *worlds*. This is more explicit in

²³ Saunders acknowledges to me that this is the motivation of Saunders's view on 20th Oct, 2022 in discussion session during the Research workshop of the Israeli Science Foundation: The Many-Worlds Interpretation of Quantum Mechanics at Tel Aviv University.

Wilson's writings that:

Then the two histories are exactly similar up to and including the penultimate projection operator, but differ on the final projection operator—they agree at all times up to t_{n-1} , but differ at t_n . The point at issue between the diverging and branching interpretations is whether the entities represented by the projection operators $\hat{P}_{\alpha_0}...\hat{P}_{\alpha_{n-1}}$ in $C_{\underline{\alpha}}$ are numerically identical to the entities represented by the projection operators $\hat{P}_{\alpha'_0}...\hat{P}_{\alpha'_{n-1}}$ in $C_{\underline{\alpha}'}$, or whether they are (numerically distinct) qualitative duplicates. Numerically identical entities give us overlapping worlds; qualitative duplicates give us diverging worlds. (Wilson 2012, 73)

Here Wilson uses symbols of consistent histories. $\hat{P}_{\alpha_0}...\hat{P}_{\alpha_{n-1}}$ and $\hat{P}_{\alpha_0'}...\hat{P}_{\alpha_{n-1}}$ represents the physical reality before the branching. $C_{\underline{\alpha}}$ and $C_{\underline{\alpha}'}$ represents the complete histories that are the same before the branching. $\hat{P}_{\alpha_0}...\hat{P}_{\alpha_{n-1}}$ and $\hat{P}_{\alpha_0'}...\hat{P}_{\alpha_{n-1}'}$ are exactly the same with respect to the mathematical formalism, and Wilson claims that they can be used to represent different ontological realities before the branching: they represent two worlds before the branching. Therefore, there can be two qualitatively identical but numerically different persons as Aristotle: Aristotle0 \uparrow or Aristotle0 \downarrow , who exist in different worlds respectively. Aristotle0 \uparrow will see the *z*-spin is up and the future observational result for Aristotle0 \downarrow will be down, making it reasonable for Aristotle to be uncertain whether he is Aristotle0 \downarrow .

This possibility is discussed in section 3, where it is proposed that distinguishing different physical states before the branching would require some more fine-grained mathematical structures, such as *fiber bundle*. Wilson's approach does not require a different mathematical structure of EQM, but a different metaphysical structure of it. I do not intend to reject such metaphysical possibility here. However, we still need to address the question raised in section 3: Is personal identity here, as a relation, deterministic or indeterministic? For simplicity I suppose without loss of generality that the Aristotle that lies in the world $\hat{P}_{\alpha_0}...\hat{P}_{\alpha_{n-1}}$ is Aristotle0 \uparrow , and the Aristotle that lies in the world $\hat{P}_{\alpha'_0}...\hat{P}_{\alpha'_{n-1}}$ is Aristotle0 \downarrow . Suppose that $C_{\underline{\alpha}}$ is the branch where Aristotle sees the *z*-spin is up, and $C_{\underline{\alpha}'}$ is the branch where Aristotle sees the *z*-spin is down. If the relation (personal identity) is indeterministic, it would violate *Supervenience*. One might argue that the identity of worlds across time is indeterministic, and thus *Supervenience* is preserved: in each case, the identity of Aristotle strictly follows the identity of worlds. According to this view, if the world $\hat{P}_{\alpha_0}...\hat{P}_{\alpha_{n-1}}$ is identical (across time) to the world where Aristotle sees the *z*-spin is up, then Aristotle0 \uparrow is identical to Aristotle \uparrow , not Aristotle \downarrow . However, this introduces indeterminacy of the identity between worlds. Supporters of the divergence view cannot deny that this is an additional character that originally EQM does not have: indeterminacy.

If such relation (personal identity) is deterministic, it must be grounded in some physical facts that establish a deterministic connection between worlds (or the identity of worlds across time, in other words). In this case, $\hat{P}_{\alpha_0}...\hat{P}_{\alpha_{n-1}}$ is connected to the (future) world where Aristotle sees the *z*-spin is up, and $\hat{P}_{\alpha'_0}...\hat{P}_{\alpha'_{n-1}}$ is connected to the world where Aristotle sees the *z*-spin is down after the branching. This introduces *hidden variables* into EQM: each qualitatively identical world before the branching is labelled with a hidden variable to determine its future successor. This notion is termed "many-threads theory" by Barrett, as Barrett explains that:

That is, if one includes the global wave function in the state description of the worlds, then each world might be thought of as being described by a particular hidden-variable theory, where the preferred basis selects the always determinate physical quantity (the hidden variable), the local state of each world at a time gives the value of this quantity in that world, and the connection rule (together with the linear dynamics) determines, in so far as it is determined, how the quantity evolves in each world: a many-threads theory is ultimately just a hiddenvariable theory where one simultaneously considers all physically possible worlds. (Barrett 1999, 183-184)²⁴

Wilson (2012, 69) does acknowledge that "'Many worlds' or 'many minds' theories which posited additional fundamental structure would not be worth the price." It is not necessary to introduce hidden variables into the divergent view in discussing the ontology of EQM, so Wilson does not need to be concerned with that in (2012). However, this is indeed a problem if we want to solve the incoherence problem of EQM via pre-measurement uncertainty. If we want to avoid complicating EQM as a physical theory, we have to introduce a connection rule to determine the successor of different qualitatively identical persons before the branching, which leads to a violation of *Supervenience*. The introduction of the divergence view here serves as an illustration of the various possibilities discussed in section 3.

7. Results and Discussions

So far, I have examined approaches to solve the incoherence problem of EQM via pre-measurement uncertainty. Through a comprehensive analysis of Saunders and Wallace's solution based on David Lewis's account of personal identity, I have argued that the pre-measurement solution to the incoherence problem cannot be successful if only one mental state supervenes on each observer's physical state in EQM. This need not prove fatal to the premeasurement approach, if there can be multiple qualitatively identical but numerically different mental states supervening on each observer's physical state. However, the latter approach can only be successful while violating principles of physicalism. I use the "divergence view" of EQM as an example to illustrate my argumentation. As I have argued in section 6, this brings us back to old problems of EQM. Either we need to accept a form of "Many Worlds Theory" by introducing hidden variables into EQM, or we

²⁴ It seems to me that Wilson does not pay much attention to Barrett's alarm in Wilson's writings. Wilson only cites Barrett once in (2010) without mentioning this point. I am grateful to Shan Gao who reminds me of Barrett's writing.

have to develop a kind of "Many Minds Theory" that violates principles of physicalism. My analysis in this paper is impartial regarding the adoption of 3-dimensionalism or 4-dimensionalism, as well as the overlapping view or the divergence view of EQM. My argument also circumvents the debates on the theory of semantics and reference, upon which previous criticisms of Saunders and Wallace's proposal have rested.

An anonymous reviewer reminds me that "at the Tel Aviv conference²⁵ several participants argued for the introduction of hidden variables to Many Worlds theory and also for the introduction of objective probability, also distinctly non-Everettian." Indeed, this remains a possibility for EQM. However, after introducing non-Everettian elements into EQM, it still needs to be justified why EQM should be preferred over other interpretations of quantum mechanics. This may be encouraging news for those who favor post-measurement uncertainty or probability-withoutuncertainty in EQM, though I believe that those solutions have their own problems. Discussing these options goes beyond the scope of this paper. For those who are reluctant to complicate our physical theories by adding non-Everettian elements to EQM, embracing non-physicalism remains an option. In this sense, I believe that the Many Minds Interpretation (MMI) deserves more attention than it has received in literature today.

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²⁵ The Research workshop of the Israeli Science Foundation: The Many-Worlds Interpretation of Quantum Mechanics at Tel Aviv University in 18th-24th October, 2022.

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