Does the Universe have a Memory?

Some Speculations on Quantum Mechanics

[CrazY ThOughts of an OlD man]

Einstein

1. Did not accept QM as Final Theory

2. Searched for a Unified (Geometric Theory)

Standard Model of Elementary Particles (Gauge Theory)

Attempt to combine QM & GR (String Theory, M-Theory ...)

Modify GR to QM framework? [Orthodox]

or "QM " GR "? [Maverick]

Penrose

String Theory

As Mathematics

Not yet fully rigorous but has led to remarkable mathematical results

Beautiful, powerful Mathematics of 21st Century (Witten)

Dualities Non-linear Fourier Transform?

As Physics

Is it the physics of 21st Century?

How much further needs to be done?

What will ultimate theory look like?

Uses vast mathematical structure

Is this the way God created the Universe??

Fields Medal
Perhaps there is a simpler way of looking at things?

Perhaps M-theory is so complex because we just use all tools at our disposal. Consider Ptolemy epicycles, Kepler, Platonic solids. Replaced by Newton inverse square law + calculus.

Can we take a step back & discard some basic assumption? (like Einstein did with space + time)

Perhaps we can find "simple" geometric theory (incorporating GR) which is very difficult to solve and M-theory arises from our best attempts.

Perhaps QM emerges from such a theory (perhaps in some approximation) (compare with Newtonian gravity as an approx of Einstein GR)

1) Any such theory has to agree with experiments.

2) Should be as "simple" as possible [Occam's razor]

3) Should (eventually) seem "natural"

4) Would have been approved of by Einstein.
A Universe with Memory

What basic assumption should we discard?

Continuity of space-time?

Discrete model? (very drastic, calculus too useful)

Causality?

Strong form: present determines future

Basic assumption?

Classical mechanics: position + velocity → dynamics

Quantum mechanics: state in Hilbert space → evolution

Relation to experiment: source of philosophical difficulties

Weak form of causality

Past & present determine future

Memory

1. Can we develop physical theory on this basis?

2. What kind of mathematics would we need?

3. How would it relate to standard physics (classical & quantum)?

4. Is this much too drastic - hopeless?

Clearly "memory" must be very short term

On scale relevant to QM

(perhaps this "scale" is related to Planck constant?)
Perhaps ignorance of our past explains Heisenberg uncertainty?

What will replace differential equations?

Consider simple example of dynamics path \( x(t) \) in \( \mathbb{R}^3 \) evolving in time

Ordinary differential equation \( \frac{dx}{dt} = F(x,t) \)

Generalize to retarded differential in which \( \frac{dx}{db} \) depends not just on \( x \) at time \( t \) but on \( x(s) \) for all \( s \leq t \)

Such theory exists but very difficult even for "simple equations"

J. Hale \textit{Functional Differential Equations} Springer 1971

Many possibilities for type of dependence on past

These have arisen in many applied problems (ex. control theory)

Simplest example

\[
\frac{dx}{dt} = F(t, x(t), x(t-t))
\]

for some fixed constant \( t > 0 \)
**Differential - Difference Eqns**

If taken seriously as a model for physics, it incorporates a fundamental length scale \( y \) (Good Physics)

[Shared idea with discrete models]

But preserves continuity (Calculation)

Math. Theory: Existence, uniqueness of solution proved under suitable technical restrictions

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**Even simpler model**

Difference equations with parameters

\[ f(x(t), x(t-y)) = 0 \]

Family of difference eqns

Parameter (initial conditions) choice of function \( x(t) \) in interval \( 0 \leq t \leq y \)

But matching at ends

"Quantization"

If we replace derivatives \( \frac{dx}{dt} \)

By finite differences \( \frac{x(t) - x(t-y)}{y} \)

We have "universal" way to discretize eqns of classical physics and as \( y \to 0 \) we recover classical limit (feature of QM with \( y = 0 \)?)
RELATION TO WORK OF CONNES?

Connes showed standard model comes out very simply using a simple non-commutative geometry involving 2 copies of space-time one with usual algebra of C-valued functions the other having algebra of quaternion-valued functions.

Eqn involving \( x(t) \) and \( x(t') \) \( \Rightarrow \) 2 copies with different roles involve spinors at \( x(t) \) scalars at \( x(t') \) ?

RELATION TO QM

Can we associate to past history of particle \( x(s) \) for \( s \leq t \) a vector \( u(t) \) in Hilbert space that evolves (perhaps approx) according to Schrödinger eqn as time moves? If so then we have memory \( \Rightarrow \) quantum state and ignorance of past = \( \ldots \) quantum state \( \Rightarrow \) uncertainty inability to perform retrospective experiments
Such a theory does not involve linear superposition.

Principle (except as approx.)

"Disposes" of Schrödinger's cat!

Raises question.

How much can we predict if we know a little of our past?

Provides a more satisfactory explanation of quantum uncertainty.

A possible way for passage:

Past → State

Given trajectory $x(t)$ in curved space-time

Consider it as moving light-source and take propagation of light

Gives solution of wave-equation "natural"

But lots of problems to investigate including

1) Relation of Hamiltonian to Eqs. of motion of $x(t)$

2) Wave Eqn. → Schrödinger Eqn (Dirac Eqn)

3) Divergencies
ULTIMATE PICTURE

BASIC EQUATIONS NON-LINEAR RETARDED

FIELD EQUATIONS ON CURVED SPACE-TIME

WHAT EINSTEIN WAS SEARCHING FOR

A PRECISE PRESCRIPTION OF THE

PASSAGE TO QFT [PERHAPS WITH

SOME APPROXIMATION]

PROPAGATION OF GRAVITATIONAL FIELD

SOPHISTICATED MATHS OF M-THEORY

EMERGING FROM SOME USE OF

"NON-LINEAR FOURIER MODES" TO

ANALYZE THE BASIC EQUATIONS

DUALITIES

HIGHER DIMENSIONAL STORY EMERGING FROM

4-DIMENSIONS AS WAY TO TREAT THE

WHAT WOULD BE GAINED?

IS THIS JUST A FANCY WAY TO

DRESS UP QM \\ QFT?

1) PHILOSOPHICAL SIMPLIFICATION AND

BETTER UNDERSTANDING OF THE RELATION

OF THEORY TO EXPERIMENT

2) SIMPLER, MORE RIGOROUS

MATHEMATICAL FOUNDATION

3) UNDERSTANDING OF WHAT

M-THEORY REALLY IS

4) POSSIBILITY OF SOME SMALL DEVIATION

FROM QM CAPABLE OF EXPERIMENTAL

VERIFICATION

5) STIMULUS TO BETTER MATHEMATICAL

UNDERSTANDING OF THE BASIC EQUATIONS
PROBLEMS AHEAD

1) EXPLORE VARIOUS FORMS OF RETARDED DIFFERENCES IN PHYSICAL CONTEXT

2) EXAMINE VARIOUS ARGUMENTS & EXPERIMENTS USED TO SUPPORT QM
   a) TWO SLIT EXPERIMENT
   b) BELL'S INEQUALITY
   c) EPR EXPERIMENT (QUANTUM ENTANGLEMENT)

3) UNDERSTAND ROLE OF COMPLEX NUMBERS IN QM [PENROSE]

4) EXTEND TO FIELD THEORY (PARTIAL DIFFERENTIAL DIFFERENCE EQUATIONS)

PRINCIPLES DISCARDED

[AT FUNDAMENTAL LEVEL]

1. TIME REVERSIBILITY

2. DUALITY BETWEEN POSITION & MOMENTUM

PRINCIPLES PRESERVED

1. GEOMETRICAL DESCRIPTION

2. USE OF CALCULUS

OK BY EINSTEIN!