ACHIEVING THE WORLD SUSTAINABLE DEVELOPMENT GOALS

ROLE OF KAUFFMAN'S ECONOMIC WEBS AND QUANTUM MODELS

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COMPLEXITY THEORY : UNDERLYING BEAUTY

Scientists' greatest pleasure comes from theories that derive the solution to some deep puzzle from a small set of simple principles in a surprising way. These explanations are called "beautiful" or "elegant." Historical examples are Kepler's explanation of complex planetary motions as simple ellipses, Bohr's explanation of the periodic table of the elements in terms of electron shells, and Watson and Crick's double helix. Einstein famously said that he did not need experimental confirmation of his general theory of relativity because it "was so beautiful it had to be true. (John Naughton)

UN SDGS: (SUSTAINABLE DEVELOPMENT GOALS)

- 17 Goals from ending poverty and hunger, fighting inequality and exclusion, to reducing climate change and promoting peace and justice. (169 targets and associated indicators to be achieved by 2030)
- Requires transformational change in financing models, technology applications and economic thinking and models leading to shifts in public policy.
- Nothing less than a fundamental rethinking of the way we understand the world and how we relate to it and with each other.
- From where can we get some new insights and inspiration ? Interest in complexity theory and quantum modeling.

MY JOURNEY INTO COMPLEXITY

- 1989 paper on Entropy and the Economic process at CEHI
- 1994 Search for a theory of SD at IISD leads to visit to Santa Fe. Becomes familiar with work of Kauffman , Arthur, Holland, Gellman and others.
- 1996 Joined UNDP : global development
- Continues work on socio-ecological systems including visiting professorship at Waterloo 2001.
- 2009 : While in GoC visits Stu at the Inst of Biocomplexity in Calgary, and after an engaging conversation invited Stu to Ottawa . GoC ; IDRC etc. To see policy makers view of economic webs, subs and comps, adj possible.
- 2010. Conference at Santa Fe on missing dimensions of economic growth theory : Hidalgo and Haussman (Harvard) participated. Arthur and Romer declined.
- My interest in all of this a practitioner scholar looking to catalyze development transformation to meet the SDGs. (2/3 of poor live in MICs)

ECONOMIC WEBS

- From *competitive general equilibrium* theory of economic growth to the economy as a *collective autocatalytic set* with *no entailing laws*.
- Ideas of supra-critical state (like the global economy which adds value and generates jobs internally) to sub critical states (like Caribbean economies based mainly on tourism or Alberta based on export of oil, timber, wheat, beef).
- Evolution of economy is likened to the evolution of the biosphere : we do not know ; *cannot know* what new product, service or production capacity will emerge in the future.
- Industrial Revolution as combinatorial explosion and sudden take off (Koppl et al 2018)
- Limited value to policy except as heuristics. No testable hypothesis.

ECONOMIC WEBS 2

- Product space complexity and economic growth (Haussmann and Hidalgo)
- The evolution of order from atoms to economies (in *Why Information Grows* Hidalgo 2017)
- Previous efforts to explain growth: institutions, geography, technology, diversity and psychology. Brings in the sciences of information, networks and complexity.
- In Complexity Economics (Arthur) : quotes Kauffman as asking: Why do you guys do everything at equilibrium? What would it be like to do economics out of equilibrium (Arthur likened that to : what would physics be like if the gravitational force were suspended ?)
- Arthur (Nature of Technology (what is and how it evolves); Koppl et al (combinatorial model) provide very useful insights into technology/economic system evolution.

CAN UNPREDICTABLE EVOLUTIONARY ECONOMIC SYSTEMS BE TREATED WITH MATHEMATICAL TOOLS

- Kauffman and Longo (2011) and Kauffman (2017) argue for the end a physics world view of economic growth (whether classical or quantum physics). For classical physics the arguments seem stronger than for quantum physics which needs deeper analysis.
- For example path integral (Feynman-Dirac) can treat a multidimensional system with infinite degrees of freedom. But whether path integral can be done over stochastically evolving state space itself remains an open question (some would argue). Might this provide an operational interface between natural and social worlds?
- Baaquie (2018) (student of Feynman) has used path integral in a new way to develop a theory of the firm which might be applicable to a "creative evolutionary economy"

WHY QUANTUM-LIKE MODELLING IS REQUIRED IN ECONOMIC SCIENCE?

- Economy is not a standard general equilibrium system, where given the full knowledge of initial conditions future evolution can be predicted fully
- There is inherent randomness OR uncertainty which is not simply epistemic but ONTIC
- Standard Bayesian rational models fail to capture such inherent uncertainty, since Bayesian updating model is based on upgrading incomplete knowledge through new information set
- Quantum theory holds that Nature herself does not allow more fuller description of a system than allowed by Uncertainty principle: *this limitation is not resolved by fine tuning measurement apparatus*
- We live in a world of radical uncertainty

ADVENT OF QUANTUM MODELLING

We must be careful not to prematurely propose any physical theory of Quantum Brain

Though certainly neural networks are been studied from Quantum theory perspective

- Behavioral finance literature () observed anomalies in human decision making which can not be explained from Neoclassical decision theory perspective (constrained utility maximization, OR, even bounded rationality model)
- Some noted and numerously observed anomalies are:

Failure of sure thing principle, order effects, disjunction and conjunction fallacies

- so basic are these assumptions that whole of neoclassical decision theory, and standard Game theory is based on them
- Cognitive scientists and economists () have observed regular violations of such principles in human choices under uncertainty
- Why standard models cant fix them?

FAILURE OF NEOCLASSICAL AND LIMITATIONS OF BEHAVIORAL MODELS

The emerging paradigm of Quantum-like modelling in social sciences is different from both schools

Behavioral economics models no doubt extends the utility formulation, say inequity aversion / prospect theory models do propose more general utility functions, but there is no coherent theory which can resolve multiple decision paradoxes

- Even dealing with probabilistic modelling UNCERTAINTY is never defined well in neoclassical regime
- There are non trivial events in economy which can not be given a priori probability distributions
- In Quantum theory superposition of different Eigen values in a given basis describes the state of a system before any measurement is done, such superposition reflects the underlying uncertainty
- Hence in Quantum-like modelling any initial belief state of an agent is described by superposition of basis states, which describes the inherent uncertainty *(in the speak of quantum information theory this is a superposition of I0> and I1> states)*
- Superposition is then the starting point of Quantum-like modelling

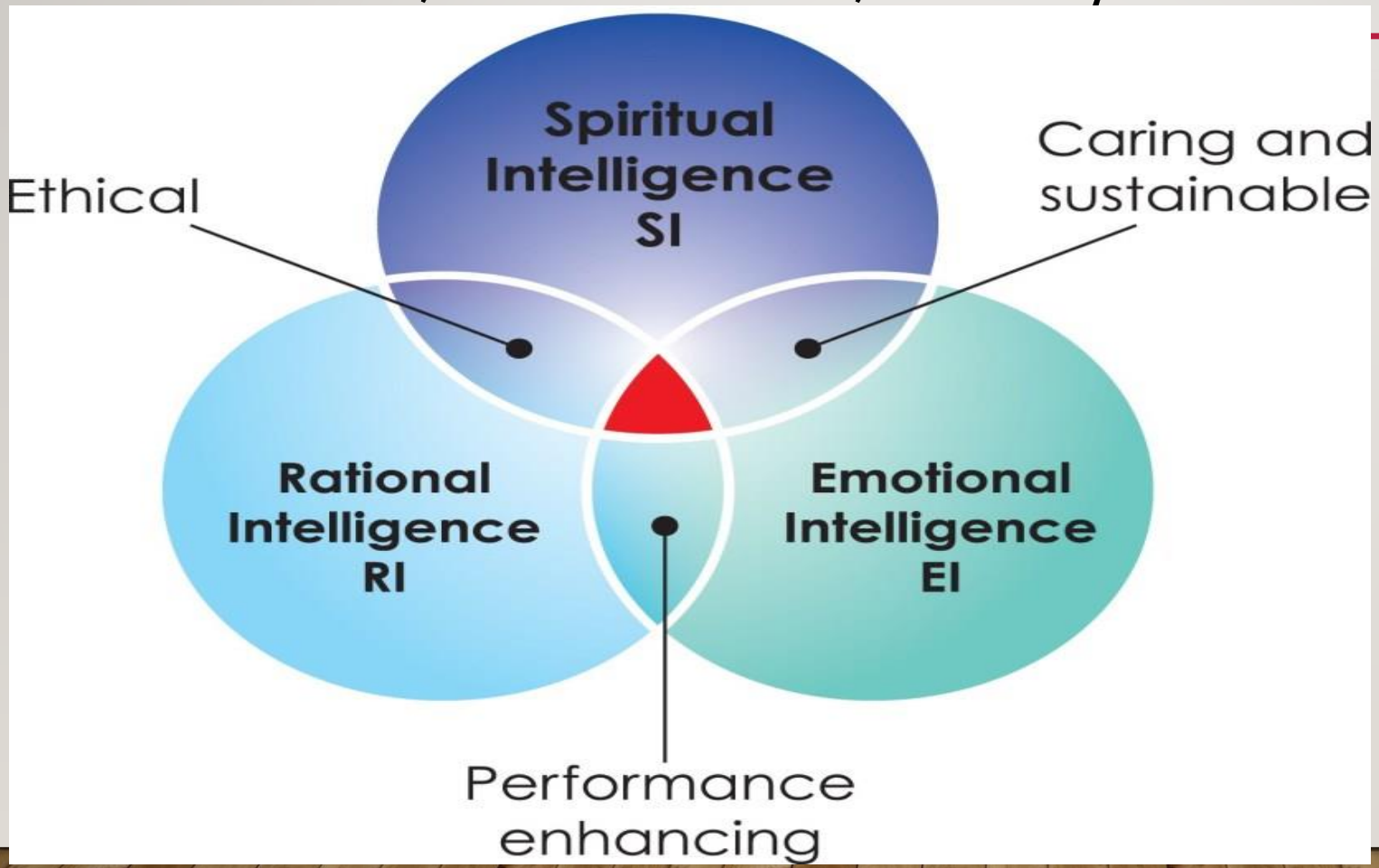
WHICH AREAS THEN THIS NEW PARADIGM CONTRIBUTING TO?

- Human decision theory in general, and financial and economic decision making under uncertainty in specific
- Fundamental economic theories like the celebrated Auman's theory of common knowledge which is another pillar of modern microeconomics : Signaling models
- Game theory
- Asset pricing theory
- Budding statistical firm theory

ACHIEVING THE SDGS BY 2030

- Just doing better what we have been doing so far will help but will not get us there. Speed, Scale and Sustainability of a different order.
- 4 interlinked revolutions need to be amplified (in addition to current)
- Leadership from managing to starting movements. Funding bold emerging leaders rather than projects or organizations. Uniting people around a common purpose (using social media); (Dulski, 2018. SU)
- Finance from billions to trillions : financial innovations, Fintech, blended finance, impact investments, development bonds, domestic financial mobilization, (Aid =150B; Private Sector AUM =200T)
- Large Scale Systems Change (LEP etc); Use Stories to energize movements
- Technology: Blockchain, AI, Societal Platforms.

TRANSPERSONAL LEADERSHIP (LEADING BEYOND THE EGO; J. KNIGHTS, 2018.)



PUSHING THE FRONTIERS

- Global Conference on **Frontier Technologies and Innovative Financing** for SDG achievement . Frontier Technologies =Artificial Intelligence, Blockchains, Big Data and Internet of things. Innovative Finance is to bridge the USD 2.5T annual gap. Date and Venue to be decided.
- O.P. Jindal Global University International Conference on **Complexity Theory and Quantum Modeling for Rethinking Public Policy** . Call for papers was sent to all of you. Can resend to those who might be interested.

EXPLANATIONS OF TERMS

- Epistemic randomness: where the concept of randomness arises from the lack of knowledge of all the factors impacting the system under measurement, if we could know all the factors we would have fully determined the trajectory of the system: standard classical physics thought/ later on Bayesian modelling was also built on this philosophy.
- Ontic randomness: there is irreducible randomness in the system, hence we can only compute probabilities of outcomes of measurements, not due to lack of knowledge or error in measurements but as a fundamental constraint. Orthodox quantum mechanics is based on this premise: also known as the Copenhagen interpretation.
- Can there be a role of this deep uncertainty in economic or social systems?

SOME EFFECTS

- Failure of sure thing principle: the standard decision theory logic holds that under full information irrelevant alternatives should not matter for final choice. However under uncertainty, real behavior does not follow the prediction, even in prisoners dilemma situation players may not choose the standard dominant Nash equilibrium strategy. Such deviant behavior can be described fruitfully via quantum like modelling of decision making.
- Order effects: if questions representing observables are presented in different orders to respondents then often the end results differ, non trivial to explain such behavior based on standard decision theory standpoint. Quantum decision theory can explain such effects if observables are provided proper operator representations.
- Failure of law of probability: this is the most striking violation, since it has been observed that under uncertainty context the familiar total probability law (which directly contributes Bayesian analysis) does not hold good many times (or say statistically), how every formula for total probability based on the square of the amplitude rule is fundamentally different, and there are interference terms which can explain such deviations.
- Other violations of standard probability laws can also be explained satisfactorily via quantum decision theory set up.

OPINION DYNAMICS

- Quantum decision model is used now to describe how opinions are formed in social systems, for example markets.
- Experiments are first performed based on the questions and responses by the agents in a market set up, and then probability of choosing / answering a specific option etc, is collected to see if such distributions can be described batter by quantum like models.
- The main challenge in such experiments are to compute the interference terms, where the phase factor can be more complicated than in standard quantum physics: it can be hyperbolic rather than trigonometric. This area is a very open and challenging area for explanation.