Title: Observer Localization in Multiverse Theories

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Abstract: The progression of theories suggested for our world, from ego- to geo- to helio-centric models to universe and multiverse theories and beyond, shows one tendency: The size of the described worlds increases, with humans being expelled from their center to ever more remote and random locations. If pushed too far, a potential theory of everything (TOE) is actually more a theories of nothing (TON). Indeed such theories have already been developed. I show that including observer localization into such theories is necessary and sufficient to avoid this problem. I develop a quantitative recipe to identify TOEs and distinguish them from TONs and theories in-between. This precisely shows what the problem is with some recently suggested universal TOEs.

Observer Localization in Multiverse Theories

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Topic of This Talk

- information-theoretic and computational approach for addressing the philosophical problem of judging theories (of everything) in physics.
- Slides (over)simplify & focus on the core problem and solution idea.
- Classical models in physics are essentially differential equations describing the time-evolution of some aspects of the world.
- A Theory of Everything (ToE) models the whole universe or multiverse, which should include initial conditions.
- I will argue, it can be crucial to also localize the observer, i.e. to augment the ToE with a model of the properties of the observer, even for non-quantum-mechanical phenomena.
- I call a ToE with observer localization, a Complete ToE (CToE).

THEORIES OF SOMETHING, EVERYTHING & NOTHING

- A number of models have been suggested for our world.
- They range from generally accepted to increasingly speculative to apparently bogus.
- For the purpose of this work it doesn't matter where you personally draw the line.
- The following (in)sane models will help to make clear the necessity of observer localization.

What is a Theory or Model

- By theory I mean a model which can explain ≈ describe ≈ predict ≈ compress our observations.

- deterministic theory/model + initial conditions = compact representation of observation sequence = bit string.

- Example: Newton mechanics maps initial planet positions+velocities into a time-series of planet positions.

- Stochastic model = probability distribution over observation strings.

Egocentric Model

A young child believes it is the center of the world.

+ Localization is trivial. It's always at coordinate (0,0,0).

– Cannot explain similarity of self and other humans.

Geocentric Model

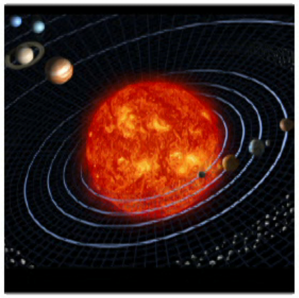
Human race and Earth is at the center of the universe.

+ Leads to understanding & well-functioning society.

– Why am I this particular person and not any other?

– Complex epicycle model for planets.

Heliocentric Model



Sun is at the center of the solar system / universe.

+ Simpler and better model of celestial motions.

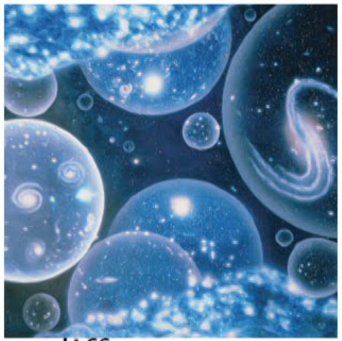
– Why are we on planet 3 ?

Our Observable Universe

described by standard model + general relativity

+ Describes all known phenomena in our universe.
– Does not explain why are we in this solar system in this galaxy.

Large Universes & Multiverse Theories



Many theories (can be argued to) imply a multitude of essentially disconnected universes (in the conventional sense), often each with their own (quite different) characteristics.

- String theory: Different compactifications lead to different universes.
- Inflation: Universe much larger than visible part. Regions differ. Like the infinite fantasia land from the NeverEnding Story, where everything happens somewhere.
- Oscillating universe (Wheeler): a new big bang follows the assumed big crunch, and this repeats indefinitely.
- Baby universes (Smolin) Every black hole recursively produces new universes on the "other side" with quite different properties.
- Quantum universes (Everett): many-worlds interpretation of quantum mechanics postulates that the wave function doesn't collapse but the universe splits (decoheres) into different branches, one for each possible outcome of a measurement.

The Universal Universe

General recipe: If theory X contains some unexplained elements Y (quantum or compactification or parameter or other indeterminism), postulate that every realization of Y results in its own universe, and we just happen to live in one of them.

Often the anthropic principle is used in some hand-waving way to argue why we are in this and not that universe.

Take this to the extreme (Schmidhuber, Tegmark):
Universal Universe consists of every computable/mathematical universe.

Since our universe seems computable/mathematical, then it is contained in the universal universe, so we have a ToE already in our hands !

Epistemology: Bit-String Ontology

- All observations can be coded as a bit-string,
  e.g. camera image in robots or optic nerve signal in humans.

- Classical epistemology operates on a much higher conceptual level and therefore requires stronger (and hence more disputable) philosophical presuppositions.

- We assume
  a temporal bit-string of increasing length is the only observation;

- all higher ontologies are constructed from it
  and are pure "imagination".

All-a-Carte Models

are even simpler ways of obtaining ToEs

- Discretize our observable space-time universe at e.g. Planck level, and code it into a huge finite bit string o.
- Think of a digital high resolution 3D movie of the universe from the big bang to the big crunch.
- Now define infinite bit string:

  u := Infinite sequence of random bits (fair coin tosses), or

  u := Champernowne's number $= 0.1\,10\,11\,100\,101\,110\,111 \ldots$, or

  $u := \boxed{\sqrt{2}} \equiv \boxed{1.01101010000010011110011001100111111110011\ldots}$

String u contains o (actually infinitely often) $\Longrightarrow$ u is a perfect ToE.

[Reminiscent of Boltzmann's idea: in a sufficiently large random universe,]
[there exist low entropy regions that resemble our own universe.]

... but something doesn't seem right here ...

PREDICTIVE POWER & OBSERVER LOCALIZATION

- Some models seem bogus, others solid, and some are borderline.
- Many now accepted theories have once been regarded as insane.

$\Longrightarrow$ scientific community or general public as a judge is problematic and can lead to endless discussions.

- Examples: Historic geo$\leftrightarrow$heliocentric battle.
  Ongoing discussion of whether string theory is a ToE or more a ToN.
- Problem: Line of sanity differs for different people and different historical times.
- Standard (pseudo)justifications: Authority, Bible, Popper, Anthropic
- This talk: rational criterion whether a ToE makes sense or not.

Intuitive Sanity Status of Some Models

- Moving the Earth out of the center of the Universe was (and for some even still is) insane.
- The Standard Model + Gravity is accepted by nearly all physicists as the closest approximation to a ToE so far.
- Only outside physics, often by opponents of reductionism, this view has been criticized.
- Some respectable researchers including Nobel Laureates go further and take String Theory and even some Multiverse Theories serious.
- Universal ToE also has a few serious proponents.
- All-a-Carte Models seem clearly bogus.

Trend: Size of Worlds Increases

The progression of theories suggested for our world, from ego- to geo- to helio-centric models to universe and multiverse theories and beyond, shows one trend:

– The size of the described worlds increases, with humans being expelled from their center to ever more remote and random locations.

+ More accurate and comprehensive models of the world.

o First, larger model is ridiculed, later accepted. Can this go on forever? Will Multiverse, Universal Universe & All-a-Carte become accepted?

Rigorous scientific justification?

Predictive Power of Multiverse Theories

- Multiverse models: explain existence of our universe, but have reduced predictive power:
- Need to know in which Universe we are to make testable predictions Inflation: where, String theory: which compactification, SM+G: 20 parameters, baby universes: which, ...
- Anthropic arguments are not convincing! (Smolin 2004)
- Universal Universe: perfect ToE, but need to know which program generates **our** observable Universe to make testable predictions.
- All-a-Carte Models: Useless ToE, except o in u has been localized. But localization of o in u requires specification of whole o itself.

Predictive Power of 'Small' Historic Models

- The loss of predictive power when enlarging a Universe to a Multiverse model has nothing to do with Multiverses per se.
- Indeed, distinction between Universe and Multiverse is not absolute.
- Egocentric models can be used directly for prediction.
- Geocentric model: Need to localize yourself out of 10^{10} humans.
- Heliocentric model: Need also to know on which planet we are in order to predict celestial movement.
- (Assume deterministic) Universe model: need to know which is our Sun out of 10^{22} stars.

Conclusion

- We lose something (some predictive power) when progressing to too large Universe and Multiverse models.
- Localizing yourself can be important to make predictions. If pushed to the extreme, ToE becomes trivial but localization infeasible.

$\Longrightarrow$ A Complete ToE requires model of universe & observer.

- Example: If and only if we know we were in the center of universe $u = 001011011$, we can predict that we will 'see' $o = 1011$ when 'looking' to the right.
- Cf. Egocentric model $u = 1011$ needs no extra specification.

Need to balance model complexity & observer localization complexity ...

COMPLETE TOES (CTOES)

need specification of

(i)	initial conditions	}	deterministic ToE in conventional sense
(e)	state evolution		
(l)	localization of observer	}	required for CToE
(n)	random noise	}	for stochastic models
(o)	perception ability of observer	}	explained later

We will ignore noise (n) and perception ability (o) in the following and resume to these issues later.

Next we need a way to compare ToEs ...

Predictive Power and Falsifiability

- Whatever the intermediary guiding principles for designing theories/models (elegance, symmetries, tractability, consistency), the ultimate judge is predictive success.
- Unfortunately we can never be sure whether a given theory makes correct predictions in the future.
- Example: Grue Emerald Paradox:
  Theory 1: All emeralds are green.
  Theory 2: All emeralds found till y2020 are green & thereafter blue.
- Both theories are equally consistent with the observations.
  Popper's falsifiability principle doesn't help.
- Solution: Ockham's razor: take simplest theory consistent with data.

Ockham's Razor

- ... tells us to choose the simpler among two otherwise equally good theories.
- ... is the most important principle in science
- ... maybe is even the definition of science

- One can show that simpler theories indeed more likely lead to correct predictions.

- For a discussion in the context of theories in physics, see Gell-Mann's (1994) book.

Quantification of Simplicity/Complexity

- Roughly, the complexity of a theory can be defined as the number of symbols one needs to write down the theory.
- More precisely, write down a program for the state evolution together with the initial conditions which reproduces the observation/data, and define the complexity of the theory as the size in bits of the file that contains the program.
- Identify theories with programs and write Length(q) for the length=complexity of program=theory q.
- Keywords: Kolmogorov complexity & Solomonoff induction, Minimum Description/Message Length principle, Overfitting & regularization in statistics (bias$\leftrightarrow$variance trade-off).

CToE Selection Principle – Informally

Among two CToEs, select the one that has shorter overall length

$$\text{Length}(i) + \text{Length}(e) + \text{Length}(l)$$

- Length/Complexity of Theory:
  All-a-Carte $<$ Universal $<$ Multiverse $<$ Universe.

- Length/Complexity of Localizing Observer:
  All-a-Carte $\gg$ Universal $>$ Multiverse $>$ Universe.

$\Longrightarrow$ All-a-Carte Model does *not* minimize above expression.

- Universal Universe is nearly as good as Multiverse.

Localization Within our Universe

- So far we have only localized our Universe in the Multiverse, but not ourselves in the Universe.
- Assume the $\sim 10^{11} \times 10^{11}$ stars in our Universe are somehow indexed. In order to localize our Sun we only need its index, which can be coded in about $\log_2(10^{11} \times 10^{11}) \approx 73$ bits.
- To localize earth among the 8 planets needs 3 bits.
- To localize yourself among 7 billion humans needs 33 bits.
- These localization penalties are tiny compared to the difference in predictive power of the various theories (ego/geo/helio/cosmo).
- This explains and justifies theories of large universes in which we occupy a random location.

(C)ToE – Formalization

- UTM = Universal Turing Machine = general-purpose computer.
- UTM takes a program coded as a finite binary string $q \in \{0,1\}^*$, executes it and outputs binary string $u \in \{0,1\}^\infty$.

$$\text{UTM}(q) = u_1^q u_2^q u_3^q \ldots =: u_{1:\infty}^q$$

- Formal ToE: $u_{1:\infty}^q$ will be the Universe (or Multiverse) generated by ToE candidate q. (high-resolution 3D movie of the whole Universe from big bang to big crunch)

$\Longrightarrow$ q incorporates initial condition (i) and state evolution (e).

Observational Process & Complete ToE

- Consider human in Universe u observing $o \equiv o_{1:\infty}$=parts of the world
  Observation is direct and classical. Think of
  a video camera mounted on a robot recording o.

- Let $s \in \{0,1\}^*$ be program that extracts obs. o^{sq} from universe u^q:

$$\text{UTM}(s, u^q_{1:\infty}) = o^{sq}_{1:\infty}$$

- Program s contains all information about the location and
  orientation and perception abilities of the observer/camera,

$\Longrightarrow$ q specifies not only item (l) but also item (o).

A *Complete* ToE (CToE) consists of a specification of a (ToE,Subject) pair (q, s). Since it includes s it is a *Subjective* ToE.

CToE Selection Principle – Formally

- Let $o_{1:t}^{true}$ be true past observation (whole life experience).
- The observation sequence $o_{1:\infty}^{sq}$ generated by a correct CToE must be consistent with the true observations $o_{1:t}^{true}$

$\Longrightarrow$ Among a given set of perfect $o_{1:t}^{sq} = o_{1:t}^{true}$ CToEs $\{(q,s)\}$ select the one of smallest Length(q) + Length(s). Formally ...

$$(q^*, s^*) := \arg\min_{q,s}\{\text{Length}(q) + \text{Length}(s) : o_{1:t}^{sq} = o_{1:t}^{true}\}$$

where $o_{1:\infty}^{sq} = \text{UTM}(s, \text{UTM}(q))$.

The selected CToE (q^*, s^*) can and should then be used for forecasting future observations via ...$o_{t+1:\infty}^{forecast} = \text{UTM}(s^*, u_{1:\infty}^{q^*})$.

Universal ToE - Formalization

generates all computable universes

q	UTM(q)					
ϵ	u_1^ϵ	u_2^ϵ	u_3^ϵ	u_4^ϵ	u_5^ϵ	$\cdots$
0	u_1^0	u_2^0	u_3^0	u_4^0	$\cdots$	$\cdots$
1	u_1^1	u_2^1	u_3^1	$\cdots$	$\cdots$	
00	u_1^{00}	u_2^{00}	$\cdots$	$\cdots$		
$\vdots$	$\vdots$	$\vdots$	$\vdots$			

Each row corresponds to one universe.

(Schmidhuber, 2000)

Linearize by dovetailing in diagonal serpentines:

$$\breve{u}_{1:\infty} := u_1^\epsilon u_1^0 u_2^\epsilon u_3^\epsilon u_2^0 u_1^1 u_1^{00} u_2^1 u_3^0 u_4^\epsilon u_5^\epsilon u_4^0 u_3^1 u_2^{00} ...$$

Not hard to construct an explicit program $\breve{q}$ for UTM that computes $\breve{u}_{1:\infty} = u_{1:\infty}^{\breve{q}} = \text{UTM}(\breve{q})$.

Extensions to More Realistic Models

Partial&approximate theories: E.g. Newton only predicts planetary positions approximately, but not phenomena involving light.
Solution: Add Length(b), where b are bits that are not or wrongly predicted.

Probabilistic theories: (E.g. QM) Replace programs (q, s) by probability distributions $(s(o|u), q(u))$, and (Shannon) code noise in $\log 1/p(o)$ bits.
$p(o) := \sum_u s(o|u)q(u)$. Cf. two-part MDL.

Theories with parameters: Code parameters to suitable finite accuracy.
For smooth parametric models, a parameter accuracy of $O(1/\sqrt{n})$ is needed, which requires $\frac{1}{2}\log n + O(1)$ bits per parameter.

Infinite/continuous universes: *(a) All separable spaces* have a countable characterization, e.g. rational points in $I\!R^4$. *(b) Loewenheim-Skolem* theorem (an apparent paradox) implies that Zermelo-Fraenkel set theory (ZFC) has a countable model. – And all physics is separable and formalizable in ZFC.

Assumptions

(i) Bit-string ontology: The observers' raw experience of the world can be cast into a single temporal binary sequence o. All other physical and epistemological concepts are derived.

(ii) Realism: There exists an objective world independent of any particular observer in it.

(iii) Computable universe: The world is computable, i.e. there exists an algorithm (a finite binary string) which, when executed, outputs the entire space-time universe.

(iv) Computable observer process:
The observer is a computable process within the objective world.

(v) Ockham's razor principle:
Choose the simplest theory consistent with the observations.

Summary

- Respectable researchers have dismissed and embraced each single model of the world discussed above
  – at different times in history and concurrently,
  – often based on unscientific arguments.
- I presented a more serious treatment of world model selection.
- I introduced and discussed the usefulness of a theory formally in terms of predictive power based on model *and* observer localization complexity.
- Outlook: Compute and compare complexities of concrete theories, e.g. compare SM+G with String Theory.

Thanks! Questions? Details:

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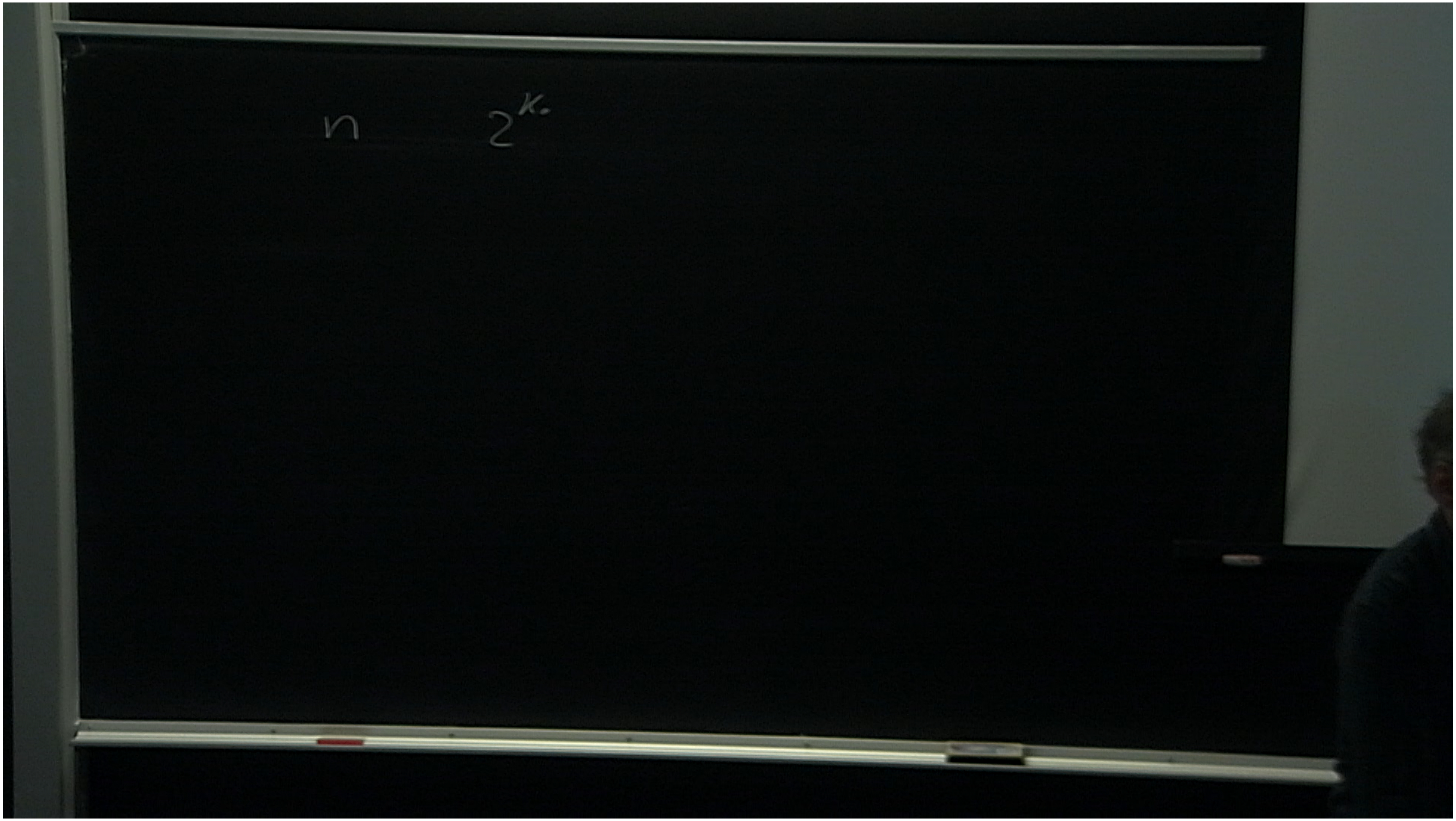
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