Title: Observers as Primitives

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Abstract: Let us suppose that we are trying to build a physical theory of the universe, in order to do so, we have to introduce some primitive notions, on which the theory will be based upon. We explore possible candidates that can be considered to be such "primitives": for example, the structure of the spacetime, or quantum states. However, the examples can be given such that show that these notions are not as objective as we would want them to be. The concept of objectivity, on the other hand, is closedly linked to that one of "an observer", thus, we can at least assign it as a primitive of the theory. Now agents are themselves physical systems, and we should take this into account when we specify the ground rules of what they can do. On the one hand, we take agents and their communication as a primitive of the theory and then see which concepts can be derived from there. On the other hand, we treat agents as quantum systems themselves and investigate what kind of logic applies to their interpersonal reasoning; for that, as a guiding example we use the Frauchiger-Renner thought experiment {1,2}.

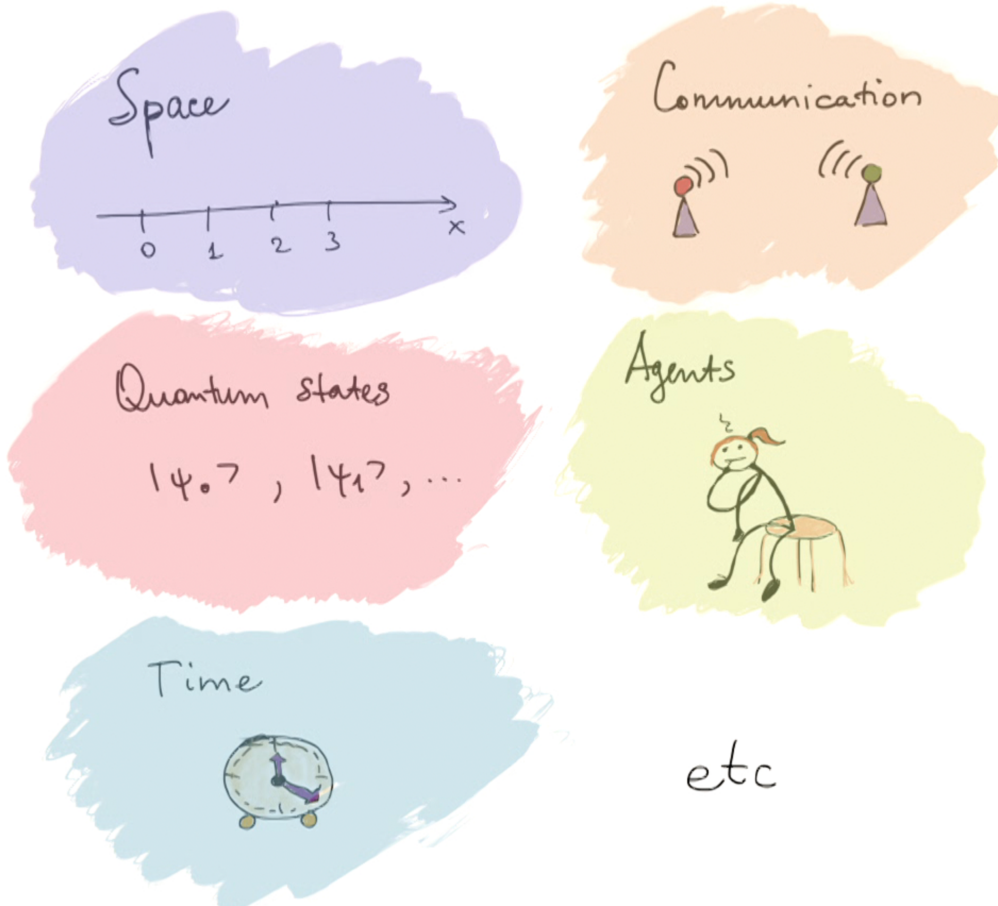
Observers as primitives

Nuriya Nurgalieva, Lídia del Rio, Laura Burri, Renato Renner

ETH Zurich

Foundations of Quantum Mechanics workshop
Perimeter Institute, Canada

Constructing a theory



Factorization as a primitive

Example[1]:

- $\mathcal{H} = \bigotimes_p \mathcal{H}_p$

[1] ChunJun Cao, Sean M. Carroll: "Space from Hilbert Space: Recovering Geometry from Bulk Entanglement", 2016, Phys. Rev. D 95, 024031 (2017)

Factorization Problem

$$|\Psi_{00}\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$$

$$\phi_A : \mathcal{H}_A \otimes \mathcal{H}_{\overline{A}} \to \mathcal{H}, |i\rangle \otimes |j\rangle \mapsto |ij\rangle$$

$$|\Psi_{00}\rangle \simeq \frac{1}{\sqrt{2}}(|0\rangle_A \otimes |0\rangle_{\overline{A}} + |1\rangle_A \otimes |1\rangle_{\overline{A}})$$

$$\phi_B : \mathcal{H}_B \otimes \mathcal{H}_{\overline{B}} \to \mathcal{H}, |i\rangle \otimes |j\rangle \mapsto |\Psi_{ij}\rangle$$

$$|\Psi_{00}\rangle \simeq |0\rangle_B \otimes |0\rangle_{\overline{B}}$$

$$\rho_A = \frac{1}{2}\mathbb{I}_A \qquad \rho_B = |0\rangle\langle 0|_B$$

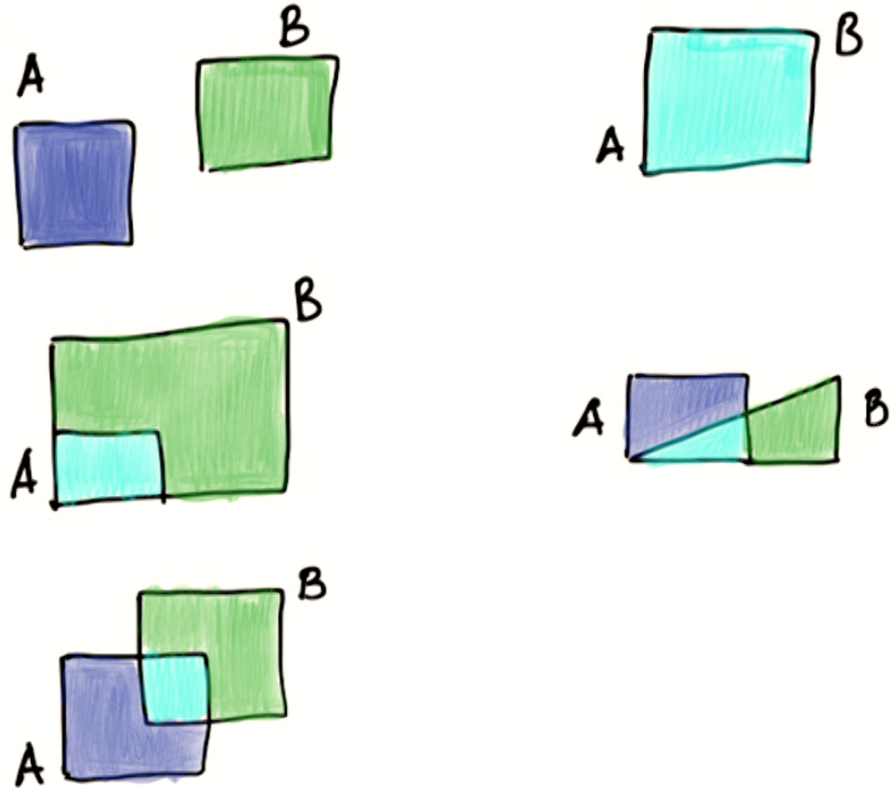
Factorization Problem[2]

Agents do not know their isometries ϕ_A, ϕ_B; they need to reconstruct $\phi_B^{-1} \circ \phi_A : \mathcal{H}_A \otimes \mathcal{H}_{\overline{A}} \to \mathcal{H}_B \otimes \mathcal{H}_{\overline{B}}$.

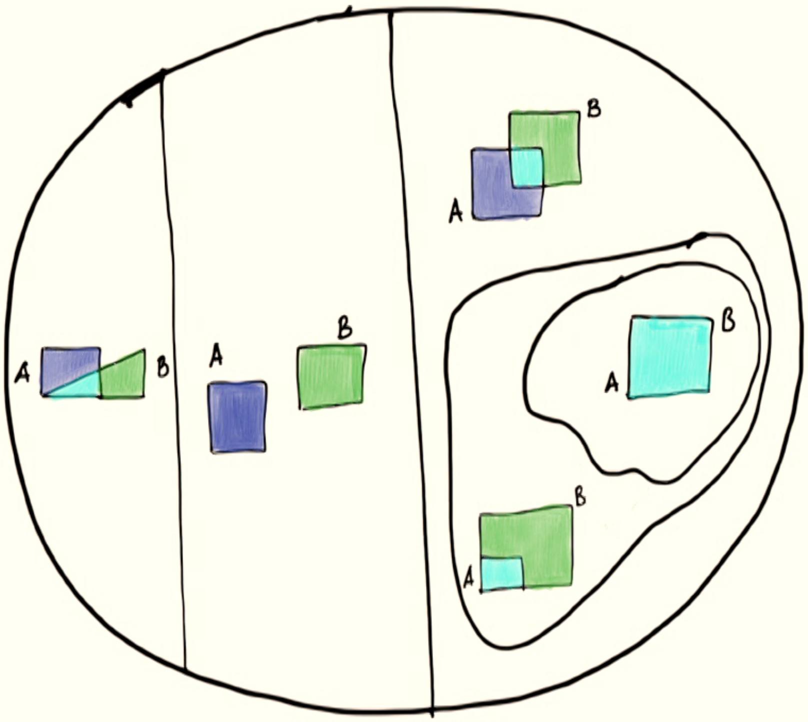
Two scenarios: device-dependent and device-independent.

[2] Laura Burri: Hilbert Space Factorization and Locality, 2018, Bachelor Thesis, ETH Zurich, to be published on arXiv

Factorization Problem



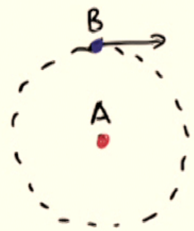
Factorization Problem



Communication between agents as a primitive[3]

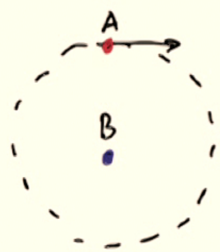
$\Delta t > 1\ \mathrm{sec}$ $\quad \Delta t' > 1\ \mathrm{sec}$

$\Delta t < 1\ \mathrm{sec}$ $\quad \Delta t' < 1\ \mathrm{sec}$



$\Delta t_A < 1\ \mathrm{sec}$ $\quad \Delta t_A' = 1\ \mathrm{sec}$

$\Delta t_B > 1\ \mathrm{sec}$ $\quad \Delta t_B' = 1\ \mathrm{sec}$



$\Delta t_A > 1\ \mathrm{sec}$ $\quad \Delta t_A' = 1\ \mathrm{sec}$

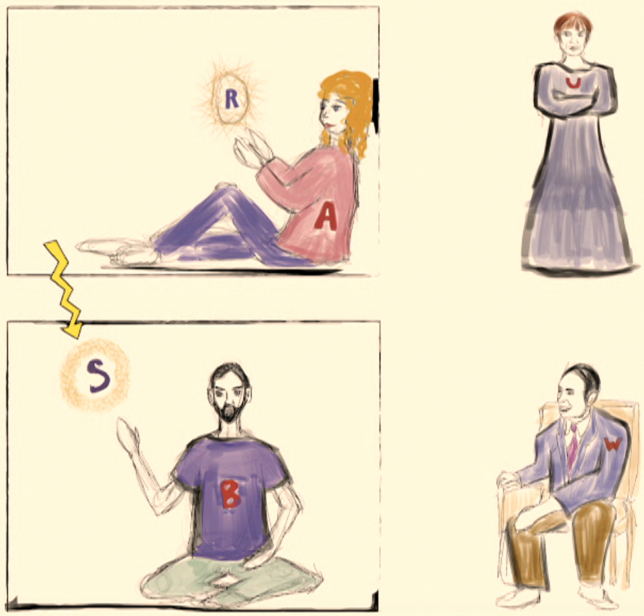
$\Delta t_B < 1\ \mathrm{sec}$ $\quad \Delta t_B' = 1\ \mathrm{sec}$

[3] Hardy L. Operational general relativity: Possibilistic, probabilistic, and quantum. arXiv preprint arXiv:1608.06940, 2016

Agents as a primitive

Now agents are quantum systems. What logic should they use?

Frauchiger-Renner thought experiment[4]



[4] Frauchiger, D. Renner, R. Quantum theory cannot consistently describe the use of itself (2016). Latest version used by the authors https://foundations.ethz.ch/wp-content/uploads/2018/04/renner.pdf. arXiv:1604.07422.

Modal logic and Kripke structure[5][6]

- a set of propositions Φ
- a non-empty set of possible worlds Σ
- an interpretation $\pi : \Sigma \times \Phi \to \{\textbf{true}, \textbf{false}\}$
- a binary equivalence relation $\mathcal{K}_i$ on a set of possible worlds Σ: $(s, t) \in \mathcal{K}_i$ if agent i considers world t possible given his information in the world s
- $(M, s) \models K_i\phi \iff \forall t : (s, t) \in \mathcal{K}_i$ it holds that $(M, t) \models \phi$

[5] Fagin, R., Halpern, J. Y., Moses, Y. Vardi, M. Reasoning about knowledge (MIT press, 2004)

[6] Kripke, S. Semantical considerations of the modal logic (2007).

Distribution axiom

$$(M,s) \models (K_i\phi \wedge K_i(\phi \Rightarrow \psi)) \Rightarrow (M,s) \models K_i\psi$$

$\sim$ generalizes assumption **C**

Knowledge generalization rule

$$\text{if } (M, s) \models \phi \ \forall s \text{ then } \models K_i\phi \ \forall i.$$

$\sim$ covers the assumptions **Q** and **U** (common knowledge)

Positive and negative introspection axioms

$$(M,s) \models K_i\phi \Rightarrow (M,s) \models K_iK_i\phi \text{ (Positive Introspection)},$$
$$(M,s) \models \neg K_i\phi \Rightarrow (M,s) \models K_i\neg K_i\phi \text{ (Negative Introspection)}.$$

$\sim$ follow the assumption **S**

The final state

$$\sqrt{\tfrac{2}{3}}\,\underbrace{\frac{1}{\sqrt{2}}\left(|0\rangle_R|0\rangle_A+|1\rangle_R|1\rangle_A\right)}_{|fail\rangle_{RA}}|0\rangle_S|0\rangle_B+\tfrac{1}{\sqrt{3}}|1\rangle_R|1\rangle_A|1\rangle_S|1\rangle_B=$$

$$\tfrac{1}{\sqrt{3}}|0\rangle_R|0\rangle_A|0\rangle_S|0\rangle_B+\sqrt{\tfrac{2}{3}}|1\rangle_R|1\rangle_A\,\underbrace{\frac{1}{\sqrt{2}}\left(|0\rangle_S|0\rangle_B+|1\rangle_S|1\rangle_B\right)}_{|fail\rangle_{SB}}$$

The conclusions made by agents

$$|\psi\rangle_{RASB} = \sqrt{\frac{2}{3}}|fail\rangle_{RA}|0\rangle_S|0\rangle_B + \frac{1}{\sqrt{3}}|1\rangle_R|1\rangle_A|1\rangle_S|1\rangle_B$$

Ursula: "$u = ok \implies b = 1$"
Bob: "$b = 1 \implies a = 1$"

$$|\psi\rangle_{RASB} = \frac{1}{\sqrt{3}}|0\rangle_R|0\rangle_A|0\rangle_S|0\rangle_B + \sqrt{\frac{2}{3}}|1\rangle_R|1\rangle_A|fail\rangle_{SB}$$

Alice: "$a = 1 \implies w = fail$"

Epistemic modal logic in the experiment

- $(M,s) \models K_A(a=1 \implies w=\mathit{fail}) \quad \forall\ s$
- $(M,s) \models (a=1 \implies w=\mathit{fail}) \quad \forall\ s$
- $\models K_i(a=1 \implies w=\mathit{fail}) \quad \forall\ i$
- $\models K_i(u=\mathit{ok} \implies b=1)$,
  $\models K_i(b=1 \implies a=1)$,
  $\models K_i(a=1 \implies w=\mathit{fail}) \qquad \forall i$

Epistemic modal logic in the experiment

- $\models K_i(u = ok \implies w = fail) \quad \forall\, i$
- $(s, M) \models K_W[u = ok \wedge w = ok \wedge (u = ok \implies w = fail)]$
  $\Leftrightarrow\ (s, M) \models K_W[u = ok \wedge (u = ok \implies w = fail) \wedge w = ok]$
  $\Leftrightarrow\ (s, M) \models K_W[w = fail \wedge w = ok]$
- $(s, M) \models [w = ok \wedge w = fail]$

We do not have a sound logic system to analyze agents' reasoning when quantum measurements are involved!

Trust in the experiment

Definition (Trust)

We say that an agent i trusts an agent j (and denote it by $j \rightsquigarrow i$) if and only if

$$(M, s) \models K_i \; K_j \; \phi \implies K_i \; \phi,$$

for all ϕ, s.

Trust is not transitive!
Can be used for describing persistance of agents' memories over time.

Conclusions

- Take agents as primitives seriously and see how far we can get in deriving the rest of physics
- Model agents as physical systems to understand the limitations of things like common logic systems

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