A Quantum-Inspired Model for Human-Automation Trust in Air Traffic Control derived from Functional Magnetic Resonance Imaging

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Background

- Expected Increased in Air Traffic.
- Increased Automation Support for Controllers. E.g. Digital Assistant.
- Human-Automation Trust governs how Controllers use their tools.
- Trust is a crucial but under-studied human factor in ATM.

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Research Problems

- Traditional cognitive models have not been able to fully reflect controller trusting behaviour.
- Antecedents of human-automation trust have not been identified.
- Objective data on human-automation trust has been difficult to obtain.

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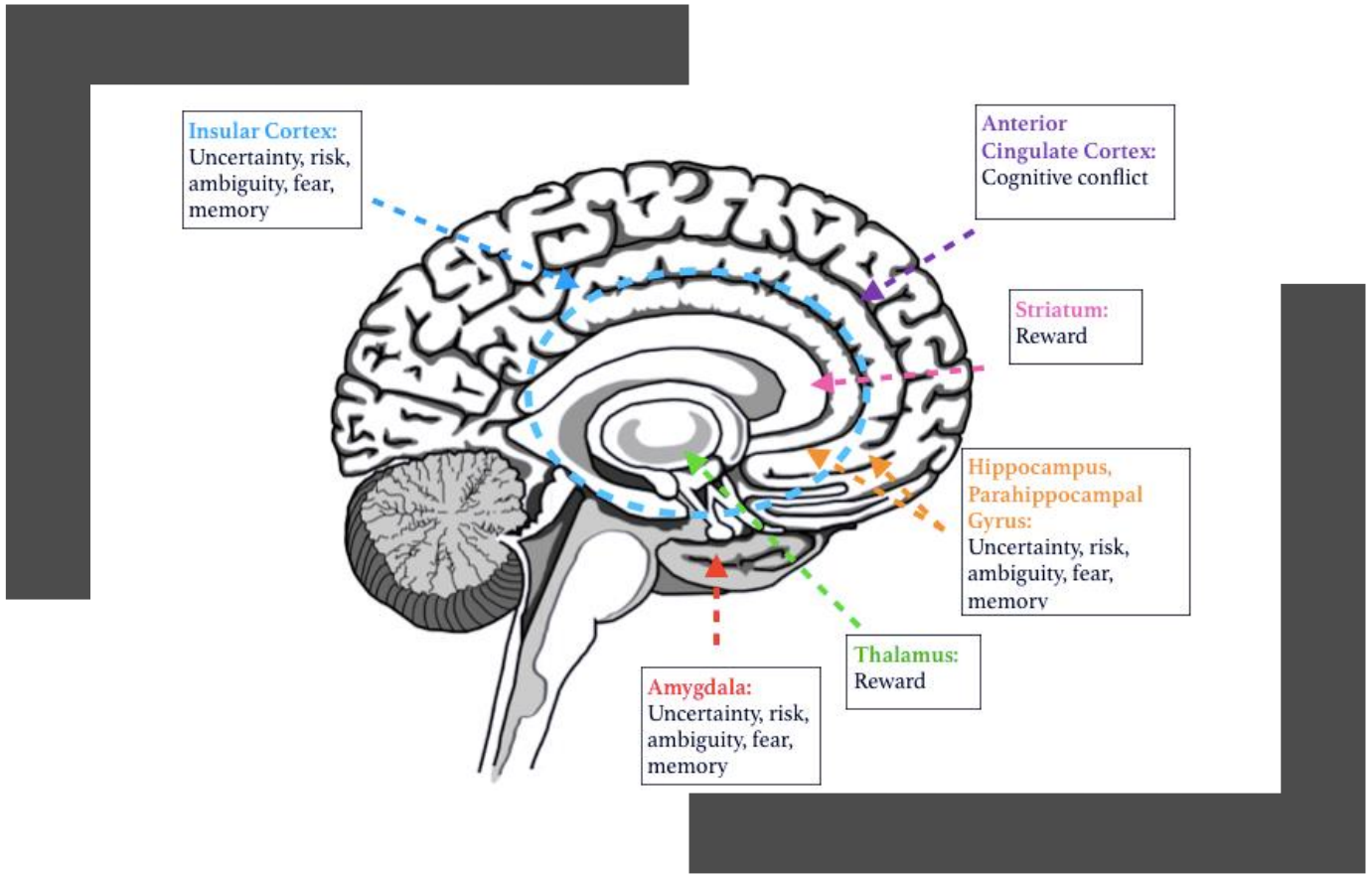
Motivation

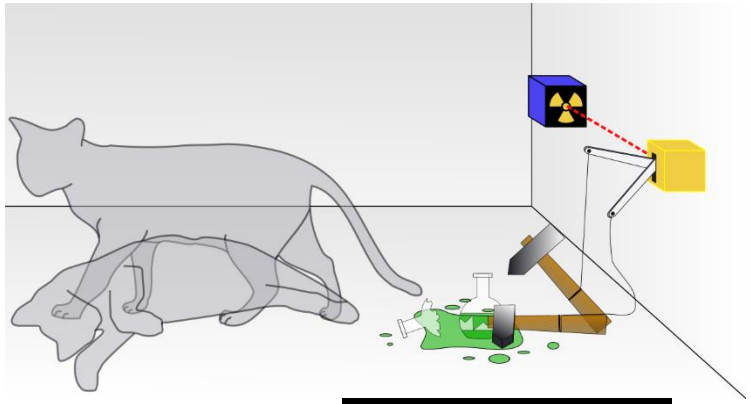


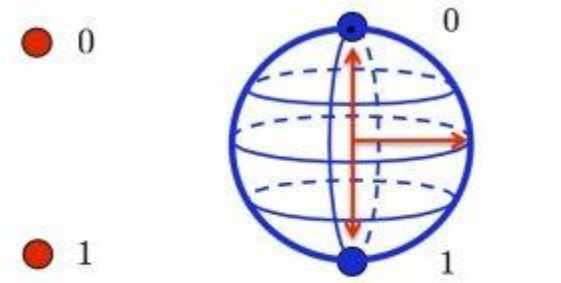
Recent neuroimaging studies on human-human trust have demonstrated a deeper understanding of the fundamentals of trust.

Key Finding: Trust and Distrust are neither pure polar opposites, nor independent constructs.

The Quantum Aspect

- Quantum cognition models have proven to increase robustness in decision theory, perception of semantics, and memory among other cognitive concepts.
- Largely due to the Principle of Superposition, which juxtaposes 2 or more (cognitive) states together to better describe human behaviour. E.g. Schroedinger's Cat.
- In computing terms, the quantum bits are 1 and 0 at the same time, as compared to either 1 or 0 in traditional probability theory.





Proposed Quantum Model

- $|00\rangle$, as pure distrust
- $|11\rangle$, as pure trust
- $|01\rangle$, as reciprocal trust
- $|10\rangle$, as reciprocal distrust

$$|\psi\rangle = \alpha|00\rangle + \beta|11\rangle + \gamma|01\rangle - \gamma|10\rangle$$

By Born Rule, $|\alpha|^2 + |\beta|^2 + 2\,|\gamma|^2 = 1$

Classification of Brain Regions wrt Trust

Pure Trust	Pure Distrust	Reciprocal Trust	Reciprocal Distrust
Putamen and Nucleus Accumbens	Insular Cortex and Amygdala	ACC and PCC	ACC and PCC

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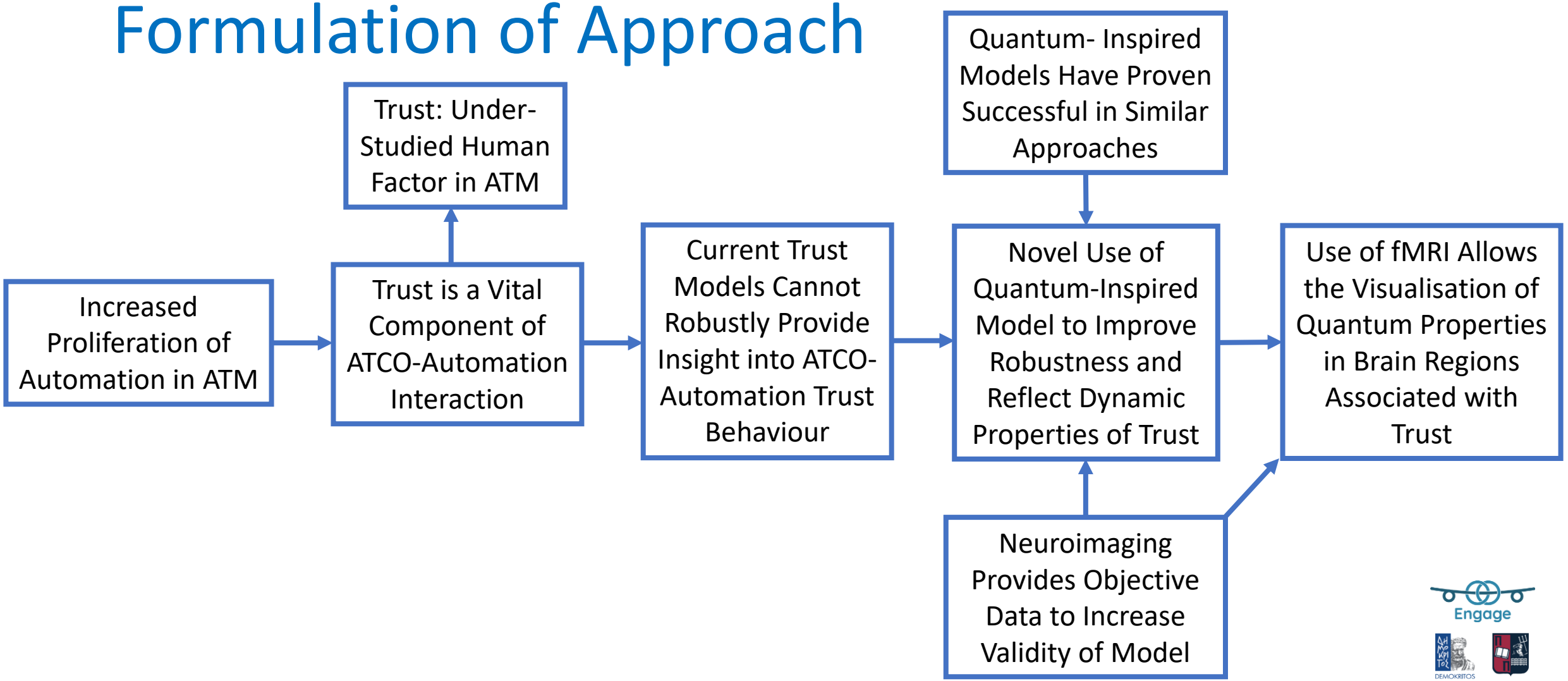
Formulation of Approach



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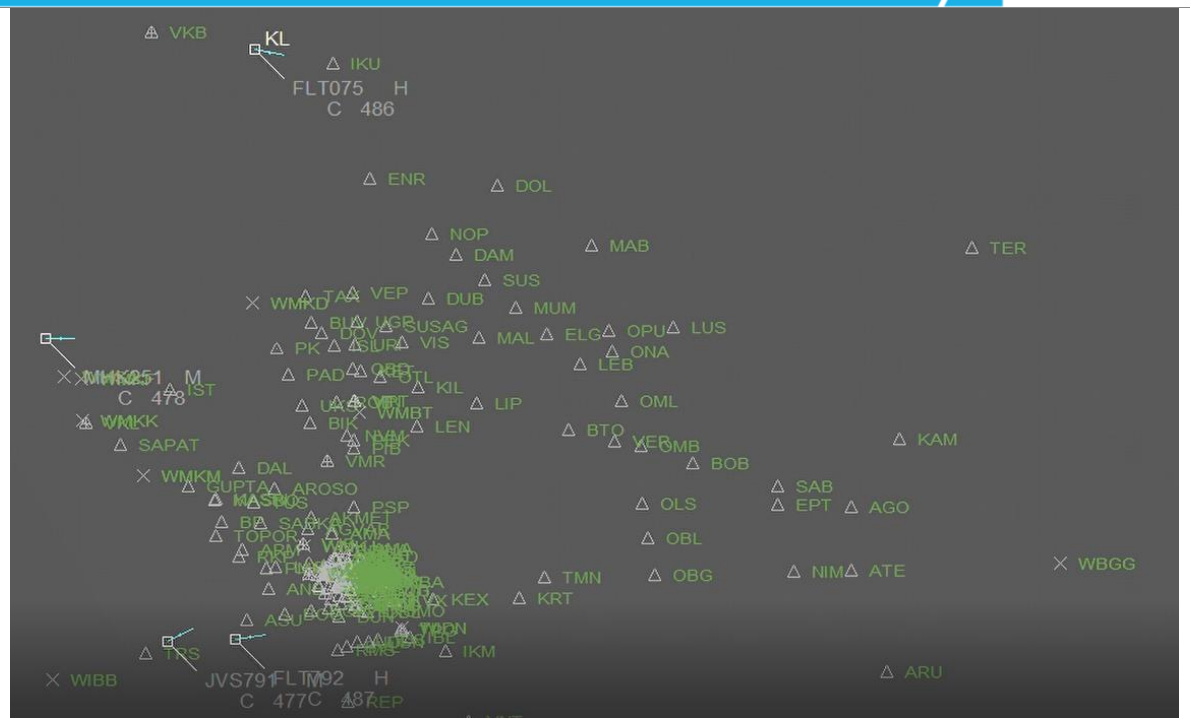
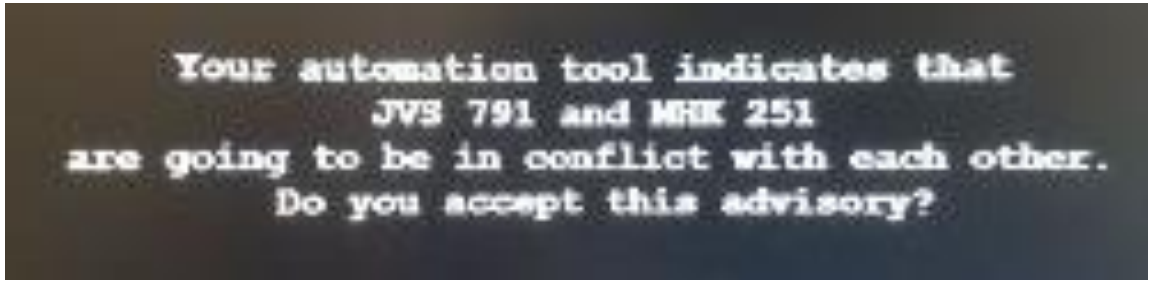


Methodology

- 4 experimental subjects (2 former ATCOs and 2 student ATCOs.)
- Each subject given 5 air traffic scenarios.

Conflict Detection Advisory

- Conflict Detection is one of the primary tasks of any ATCO.
- After each scenario, an advisory appeared on subjects' screen.
- Participants had to indicate whether they accepted or rejected the advisory using the binary remote controller inside fMRI.



Data Preparation

fMRI pre-processing performed using SPM 12 and the default pipeline settings in Connectivity Toolbox (CONN), which was recommended by Cognitive Neuroimaging Centre, Nanyang Technological University.

Data passed through band pass filter of [0.008 to 0.09Hz] to normalise it, and remove random artefacts associated with spiking and motion.

Data Analysis

- Functional Connectivity: Some brain regions are more correlated with specific cognitive functions than others.
- Seed-based Correlation Analysis (SCA) used to identify functional connectivity in the brain during both the scenario and the conflict detection prompt advisory.
- SCA performed using the CONN toolbox utilising the standard weighted General Linear Model (GLM).
- The GLM follows the equation $Y = X\beta + \varepsilon$, where,
  - Y: Represents the measured fMRI signal from a single voxel as a function of time.
  - X: One or more experimental design variables, each multiplied by a weighting factor β.
  - ε: Random error.

Data Analysis

- Brain regions with statistically significant activation across all 4 subjects were reported in the results.
- Bonferroni method is usually used to minimise likelihood of Type 1 errors but it is too conservative, considering the sample size.
- False Discovery Rate (p-FDR) was used instead to determine statistical significance, with α = 0.05.

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First SCA: Anterior Cingulate Cortex

TABLE I. AREAS WITH SIGNIFICANT EFFECTS

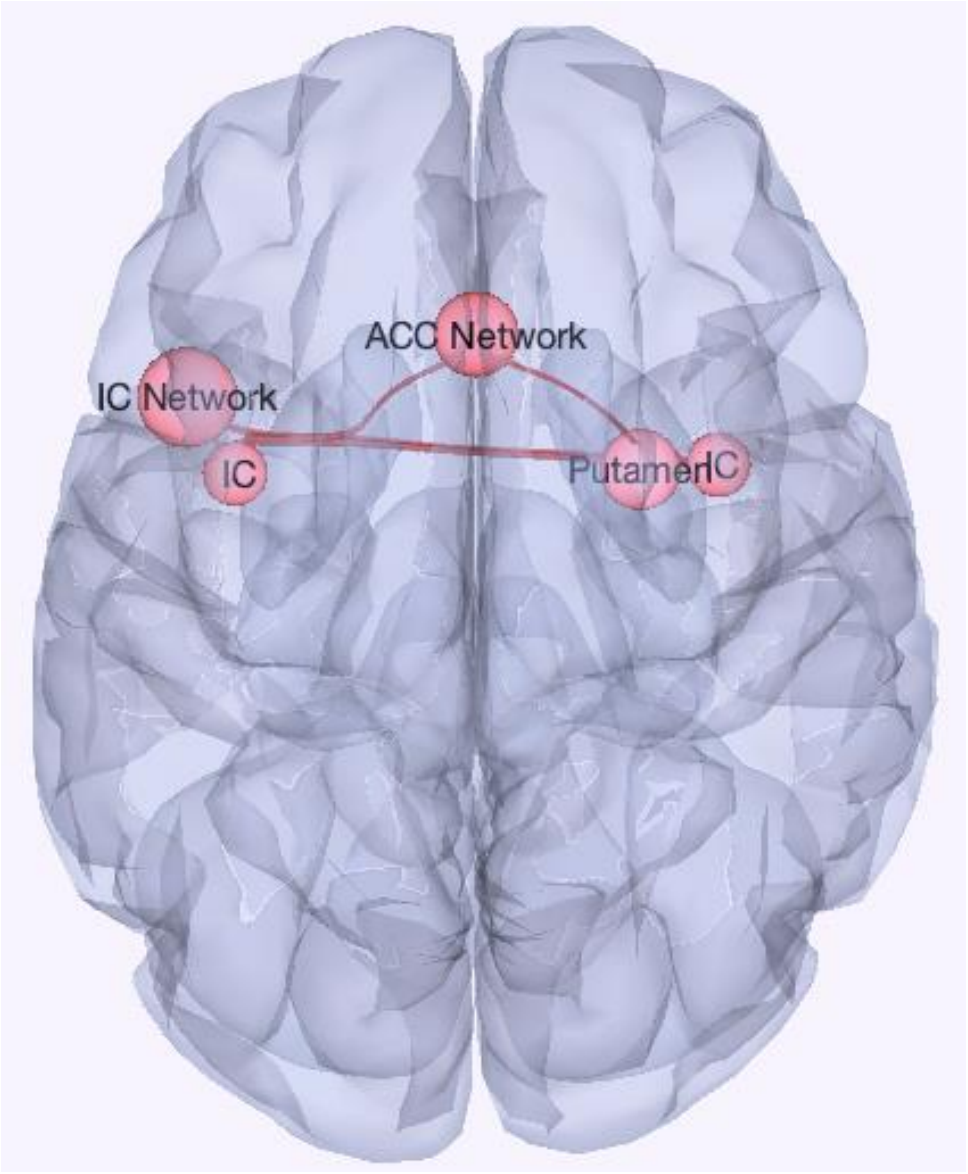
Seed: Anterior Cingulate Cortex Network			
Scenario Number	***Areas where p-FDR < 0.05***	***Prompt Number***	***Areas where p-FDR < 0.05***
Scenario 1	Insular Cortex Network	Prompt 1	Insular Cortex Network
Scenario 2	-	Prompt 2	Insular Cortex Network, Amygdala, Putamen
Scenario 3	Insular Cortex Network	Prompt 3	-
Scenario 4	Insular Cortex Network	Prompt 4	-
Scenario 5	Insular Cortex Network, Putamen	Prompt 5	Insular Cortex Network, Nucleus Accumbens

Second SCA: Insular Cortex

TABLE II. AREAS WITH SIGNIFICANT EFFECTS

Seed: Insular Cortex (Atlas)			
Scenario Number	***Areas where p-FDR < 0.05***	***Prompt Number***	***Areas where p-FDR < 0.05***
Scenario 1	Anterior Cingulate Cortex Network, Insular Cortex Network	Prompt 1	-
Scenario 2	-	Prompt 2	Insular Cortex Network
Scenario 3	Anterior Cingulate Cortex, Insular Cortex Network, Putamen	Prompt 3	-
Scenario 4	-	Prompt 4	-
Scenario 5	Insular Cortex Network, Nucleus Accumbens	Prompt 5	Posterior Cingulate Cortex Network

Visualisation of Superimposed Quantum Effect



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Conclusions

- Quantum-Inspired model proposed where,

$$|\psi\rangle = \alpha|00\rangle + \beta|11\rangle + \gamma|01\rangle - \gamma|10\rangle$$

- Weights of each component will determine ATCO trusting behaviour, which has not been demonstrated empirically. However, model has potential to reflect the full spectrum of ATCO trusting behaviour.

- Quantum effects were not observed throughout the experiment, but segments of the data displayed quantum characteristics, which suggests that model is valid and more robust than traditional models.

Future Work

- Uncertainty principle has not been demonstrated yet. It is unclear at this point if it is applicable in quantum cognition.
- Studies need to be conducted with a larger sample size to achieve results with greater statistical significance.
- Brain regions associated with different types of trust was inferred from human-human trust literature. This needs to be validated for human-machine trust.

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