Résumé du projet de recherche (Langue 1)

Each model of quantum computation comes from a different physical intuition. TQC is based on the braiding of anyons (particles which induce a phase when exchanged). AQC is based on the adiabatic passage from a simple initial starting Hamiltonian to a final Hamiltonian where the answer to the computation is encoded. In MBQC a large entangled state is prepared, and the computation driven by making a series of local measurements and corrections. In recent years many tools have been developed in particular for the analysis of MBQC, which have been incredibly powerful in understanding it as a model, indeed acting as the stepping stone to the proof of depth complexity gap. These tools will be our gateway to understanding the relationships with AQC and TQC. Tools : - The concept of phase transitions is immediately present for AQC and TQC. Indeed AQC can be considered as a phase transition from an initial 'phase' to a complete 'phase' at the end of the computation. TQC relies on topological order, and has already been linked to phase transitions [11]. Décembre 2012 AAP Digiteo- DigiCosme 2013 5/7

Interestingly these are not described by the classical symmetry-breaking Landau theory of phase transition, they do not have any local order parameter that describes the phase transition but they are rather described by a new set of quantum numbers such as the ground state quantum degeneracy or the topological entanglement entropy [12]. Recently a framework was developed within MBQC whereby the computation itself can be considered as a phase transition with the information about the solution acting as a phase parameter [13]. Developing this further as a means to compare the models gives new perspectives in translating results and intuition from one model to another, for example in the role of entanglement, and the translation of naturally addressable problems such as Blind QC. Workplan - The first task of the student will be to formalise the translation of flow to TQC and AQC. We will begin by defining this structure over the surface code. Such a structure is already in place for the Topological error correcting code defined by Goyal et.al. [14]. We aim to extend this notion of determinism to a wider class of codes and to any TQC model. We will then use the Bacon Flammia translation of MBQC to AQC to translate the structure of flow to this model. - The structural link between flow and entanglement has lead recently to the study of classical simulatability of MBQC [6]. Although TQC and AQC stem from radically different concepts, there are already strong paths to connect them to MBQC. In the case of TQC, the underlying computation is carried out on the same formalism of local measurements on stabiliser states. At the same time Bacon and Flammia recently developed a direct translation from AQC to MBQC [10]. These provide an explicit way of translating the concept of flow to both the AQC and TQC models. - The concept of phase transitions is immediately present for AQC and TQC. Indeed AQC can be considered as a phase transition from an initial ‘phase’ to a complete ‘phase’ at the end of the computation. TQC relies on topological order, and has already been linked to phase transitions [11]. Décembre 2012 AAP Digiteo- DigiCosme 2013 5/7

Phase transitions are an encompassing concept in physics. We will ask what else can be learned by considering computation as a phase transition. For example can universality of computation be considered something of a postulate, or even law for computation in the same way the second law of thermodynamics. Can this then be used to give a framework that should be satisfied by all ‘good’ computational models, which will allow better more complete comparison of future models.

Résumé du projet de recherche (Langue 2)
Each model of quantum computation comes from a different physical intuition. TQC is based on the braiding of anyons (particles which induce a phase when exchanged), AQc is based on the adiabatic passage from a simple initial starting Hamiltonian to a final Hamiltonian where the answer to the computation is encoded. In MBQC a large entangled state is prepared, and the computation driven by making a series of local measurements and corrections. In recent years many tools have been developed in particular for the analysis of MBQC, which have been incredibly powerful in understanding it as a model, indeed acting as the stepping stone to the proof of depth complexity gap. These tools will be our gateway to understanding the relationships with AQc and TQC. Tools - The concept of flow defined for MBQC is built from the stabiliser operator of the underlying entangled graph state of a given MBQC [9]. Flow was the underlying structural tool which led to the proof of a depth complexity gap, and has also been recently used to connect entanglement and other bases for showing classical simulatability of MBQC [6]. Although TQC and AQc stem from radically different concepts, there are already strong paths to connect them to MBQC. In the case of TQC, the underlying computation is carried out on the same formalism of local measurements on stabiliser states. At the same time Bacon and Flammia recently developed a direct translation from AQc to MBQC [10]. These provide an explicit way of translating the concept of flow to both the AQc and TQC models. - The concept of phase transitions is immediately present for AQc and TQC. Indeed AQc can be considered as a phase transition from an initial 'phase' to a complete 'phase' at the end of the computation. TQC relies on topological order, and has already been linked to phase transitions [11]. Décembre 2012 AAP Digiteo- DigiCosme 2013 5/7 Interestingly these are not described by the classical symmetry-breaking Landau theory of phase transition, they do not have any local order parameter that describes the phase transition but they are rather described by a new set of quantum numbers such as the ground state quantum degeneracy or the topological entanglement entropy [12]. Recently a framework was developed within MBQC whereby the computation itself can be considered as a phase transition with the information about the solution acting as a phase parameter [13]. Developing this further as a means to compare the models gives new perspectives in translating results and intuition from one model to another, for example in the role of entanglement, and the translation of naturally addressable problems such as Blind QC. Workplan - The first task of the student will be to formalise the translation of flow to TQC and AQc. We will begin by defining this structure over the surface code. Such a structure is already in place for the Topological error correcting code defined by Goyal et.al. [14]. We aim to extend this notion of determinism to a wider class of codes and to any TQC model. We will then use the Bacon Flammia translation of MBQC to AQc to translate the structure of flow to this model. • The structural link between flow and entanglement has lead recently to the study of classical simulatability of MBQC. Having established the flow for AQc and TQC in the previous step of the project we aim to bound entanglement of any given TQC model based on its flow. We will explicitly calculate expressions for the entanglement between geometrical patterns in the surface code so that these results could be compared with the bound obtained via flow. • We will next try to use the information-based new tools defined in the first part of the project to the study of phase transition. The aim will be to try to draw a connection between the topological entropy quantum number and flow and to link it with universality. • The next part of this project will be on applying the formal translations developed to the questions of depth complexity and possibilities of Blind QC in AQc and TQC. We will study the implications in terms of implementation within the different models. We will then investigate how the depth complexity translates through the structure of flow as well using this to translate Blind QC. • The final part of this project will be the most ambitions and more speculative, which will depend on the previous progress made. Completing the previous parts of the project will already be an excellent body of work for a PhD, however we have an even more ambitious vision for work. We will use flow and the structural approach in line with the developed correspondence of the phase transition pictures, to explore a more general approach to the viewing of computation as a phase transition, beyond the models considered so far. Phase transitions are an encompassing concept in physics. We will ask what else can be learned by considering computation as a phase transition. For example can universality of computation be considered something of a postulate, or even law for computation in the same way the second law of thermodynamics. Can this then be used to give a framework that should be satisfied by all ‘good’ computational models, which will allow better more complete comparison of future models.

Informations complémentaires (Langue 1)

There will be considerable collaboration with colleagues in University of Edinburgh, University College London, Oxford University and National University of Singapore.