The project is devoted to quantum information, the domain which incorporates both foundational approach as well as pragmatic approach. The most eminent example are Bell inequalities. For a long time they were solely of interest of philosophically oriented scientists, since their violation implied impossibility of classical description of Nature, in which unobserved features exist independently of measurement. In recent decades, it turned out that Bell's inequalities are heart of so called device independent quantum cryptography, hence they become of interest also for those, who were not interested in philosophical questions so far. Another important feature of quantum information is its unifying power – it brings together seemingly unrelated problems, for instance thermodynamics and uncertainty principle. Namely, recently thermodynamics has been reformulated in such a way, that it became so called resource theory – where the resource is the out of equilibrium state, and the gola is to transform one such state into another one. At the same time it was noticed, that uncertainty principle is also related to a resource – which is certainty. In both cases, a kay role is played by a notion of majorization (and its generalizations).

Since quantum information unifies various areas of research, and moreover, provides "pragmatic" methods to analyse foundational problems, it is possible to conduct an interdisciplinary approach, where one runs in parallel research in those various areas. As a result, many quantum information experts possess in their portfolio results concerning diverse spectrum of problmes.

In this project we wish to conduct such wide approach, and develop thermodynamics as a resource theory, Bell (and more generally contextual) inequalities, uncertainty principle as well as soe problem from theory of representations.

In the new approach to thermodynamics the basic question is :can a given microscopic system be transformed form one state to another one, by energy preserving operations, if heat bath is accessible? In the present project, we plan to provide new results characterizing allowed transitions, including catalytic ones (i.e. where a presence of a catalyst is necessary). We want also to investigate to what extent one has to control heat bath, in order to run such a transition.

Uncertainty principle is a strictly quantum phenomenon, namely there are such settings of two measuring devices, that their joint outputs will never be deterministic, if the systems measured by them are identically prepared. Recently, the research on uncertainty principle has been boosted thanks to quantum information approach. In particular, an uncertainty principle with quantum memory was proposed, as well as traditional inequality was replace with generalized inequality connected with so called majorization. Also form of uncertainty principle was developed, which can be applied to other than quantum theories, serving to distinguish quantum theory from other hypothetical theories. In the project we wish, in particular, to combine the majorizaton approach with the uncertainty with quantum memory, as well as design a new form of uncertainty principle, with full symmetry between system and memory.

Bell inequalities are some constraints for correlations of measurement outcomes, which are satisfied in classical description of Nature, but are violated in quantum description (and in experiment). We plan to analyse violation of Bell inequalities (or more generally contextual inequalities) in several aspects. First, from fundamental result in Banach space theory, one knows, that quantum violation cannot be too strong, if there are two measuring devices, and binary outputs (the ratio between quantum and classical values is bounded by so called Grothendieck constant). In the project we will analyse a family of Bell/contextual inequalities which exhibit growing number of outcomes. It appears in a natural way in interferometric schemes. We wish to analyse the connection beween the number of outcome, and strength of quantum violation. We want also to relate quantum value with notions for graph theory (our family is connected with family of graphs). It is known, that violation of Bel inequalities is due to quantum entanglement . Important states are those bound entangled, discovered in Gdansk, where entanglement is for some reason fundamentally hidden. Recently there has been a break-through: it was shown that such states can violate Bell inequalities. We wish to check whether such states can provide unbounded violation of Bell inequalities.

Finally, we want to find matrix elements of irreducible representations of partially transposed permutation operators. This is the most technical part of the project. We will then apply the constructed irreps to build bound entangled multipartite states, that can be further tested by Bell inequalities. We predict many other applications, including optimal asymmetric cloning with more than one input copy.

Our project concerns important problems for quantum information. Especially, the quantum information approach to thermodynamics is a hot subject, which boomed after article in 2013 by the PI of the present project.