The electronics has been significantly developed over the last few decades. The rapid progress in semiconductor manufacturing technologies has allowed the miniaturization of the basic electronic components, and as a result: the miniaturization of the electronic devices. Further miniaturization encounters the limitations - both technological and related to the fact, that the classical physics is no longer sufficient to describe the phenomena as observed at the nanoscopic scale. The theory which describes and predicts those phenomena is the quantum mechanics. Therefore, the modern electronics must be supported by the quantum theory.

Thus the further development in technology and miniaturization of the electronic devices requires a change of the previous approach. One of the conceptions of solving that problem is the theoretical idea of a quantum computer. The idea, that was first mentioned by a genius physicist - Richard Feynman - in 1986, is that the quantum theory would be used in storing and processing the information. A basic unit of information - bit (which is always in one of two definite states: "0" or "1", as the classical transistor) - would be replaced by a quantum bit: so-called qubit. The qubit can store the information as a superpositions of two states. The studies on the physical realization of qubits have been made for years both experimentally and theoretically. Among the proposed realizations of the nanodevices storing the quantum information are the semiconductor nanostructures, i.a. the quantum dots. Quantum dot is a small structure of nanometer-size, which confines some definite number of electrons inside owing to the suitable potentials. One can imagine a quantum dot as a little box with some electrons inside. Under specific conditions - e.g. introduced by the potential shifts - the single-electron current flows through the dot. Those conditions mean that the energy of the electrons confined in our "box" is sufficient for electrons to let one of them escape from the "box" (to the electrode - so-called drain). When the escape happens the number of the electrons inside the "box" is reduced by 1. However, there is an empty space inside the quantum dot left by the electron which escaped - then a new electron falls from the outside (from the other electrode, so-called source) into the "box" and the number of electrons is the same as at the beginning. Then the new, additional electron moves to the drain, and so on. The electric current is defined as the motion of the free charges - e.g. the electrons - so we have just described the current flowing through the quantum dot. It can be experimentally blocked by changing the potentials (so-called Coulomb blockade: under these conditions the current does not flow and there is a constant number of electrons inside the dot).
Similar discussion could be presented for a number of "boxes" laying next to each other - in such way we would describe so-called tunnel-coupled, multiple quantum dots. Under specific conditions the current also flows through the multiple quantum dots or is blocked. The system of two tunnel-coupled quantum dots is a popular example of hypothetical, physical realization of qubits.

Our discussion went from the classical transistors to the idea of processing the information based on the single particles. The phenomena that occur at the nanoscale are so complex that probably it will take a long time to build the quantum computer. So far, the basic research in the nanostructure properties is necessary; both experimental and theoretical. This is the purpose of the proposed project: within this project we will study the properties and the conditions of current flow in single and double quantum dots, describing theoretically experiments on those nanostructures scanned by the tip of a special microscope that is able to collect the data on such small structures (it is the scanning gate microscopy technique: SGM). The tip of the microscope manipulates the conditions of the system and therefore the SGM technique can be used in the experiments related to the lifting of the Coulomb blockade (so-called Coulomb blockade microscopy). Such experiments hardly require theoretical explanation. On the other hand: the theoretical discussions can lead to results interesting enough to be performed by the experimenters.

The phenomena that occur in the nanostructures are described by very complex equations, so it is impossible to solve them analytically (i.e. there is no possibility of obtaining the math function as the solution). Therefore, the only way to achieve the results is the numerical modeling, which means calculations based on the approximate methods that allow for simulation the phenomena described by the equations. Thus, the project will provide a simulation software for modeling the effects related to the scanning gate measurements of the current flow in the quantum dots. Considered quantum dots are fabricated on so-called two dimensional electron gas (2DEG), which is formed at the interface of two materials. The methodology of the project will allow for simulations of the experimental conditions in a precise way: in our calculations the perturbation induced by the scanning tip and the influence of the electrons which form the electron gas will be taken into account. The potential derived from 2DEG can change the form of the tip-induced potential effectively - the change depends on the tip position. Within this project the form of the effective tip-induced potential will be studied, because it is crucial in the SGM experiments.

Under the influence of the tip the Coulomb blockade can be lifted - even if there is no current flow in the absence of the tip, so the electron current depends on the position of the tip. We will calculate the current maps as functions of the tip position. The aim of our project is to reconstruct the quantum dots properties using the maps: the charge distribution inside the quantum dots in particular.

The time-varying potential can be applied to the tip of the scanning microscope, which will be also studied by us. We will perform the simulations of the spin rotations in the single and double quantum dots. The electron spin is some internal property of the electron, which can be in one of two states (directions): up or down. The electron state can be changed by manipulating the electron spin using the AC potential of the tip.

To summarize, the aim of the project is to describe theoretically and explain the phenomena that are related to the SGM experiments on the quantum dots. The proposed project will develop the numerical models.