Putting it simply, the biological cell in our body can be compared to a large urban area. To be able to function effectively it must have an appropriate infrastructure: road network, public transport, water and energy supply, law and order services etc. For example, an analogue of the road network are the so called microtubules along which travel molecular motors. They are responsible for transport of substances within cells from one place to another. Its proper operation is of fundamental importance to normal cellular functioning and development. Some viruses, including HIV, use it to reach the center from the cell surface and there infect it. Transport of materials within the cell is also responsible for regulating neural connections in our body. Dysfunction of this activity leads to a number of neurodegenerative diseases associated with memory loss, including Alzheimer. Molecular motors fulfill also a number of other very important functions like allowing cells their division. The latter is critical in cancer medicine. Cancer cells reproduce themselves by division in a rushing way. Without the support of molecular motors this process could be completely inhibited. On the basis of these just few selected examples it is obvious why understanding of the mechanisms of intracellular transport is of paramount significance.

A typical size of the cell in our body is in the range of several micrometers that is roughly a hundred times less than the thickness of human hair. Therefore we cannot naively put our everyday intuition and understanding of the reality to the microworld of the cell. Instead of forces and gradients the friction and fluctuations, i.e. random perturbations play there a dominant role. Moreover, the latter factor cannot be eliminated which is in clear contrast with everyday experience where it has little effect. Broadly speaking, there are two mechanisms for the intracellular transport: diffusion and directed transport. The first one is based on the spontaneous spreading of the motor in random direction in such a way that its average position does not change in time. It is one of the consequences of inherently existing fluctuations, i.e. chaotic collisions of the motor with similar-sized molecules of the intracellular environment. When the rate of diffusion spreading measured by the mean square displacement of the motor is proportional to time we speak about a normal diffusion. When this process is developed slower (faster) then this case is termed as an anomalous diffusion, namely subdiffusion (superdiffusion). Directed transport of the motor requires energy consumption which is usually supplied to it as a result of a chemical reaction in the cell. Then the average position of the motor changes in time. By an anomalous directed transport we mean the phenomenon of negative mobility involving the motor movement in the direction opposite to the force applied to it.

For a deeper understanding of the molecular motor functioning in the planned project we want to study the mechanisms of emergence and control of their anomalous diffusion and transport processes as well as eventual coexistence of the last two. Molecular motors will be modeled in a simplified manner allowing to capture the essence of the observed transport phenomena, i.e. as a classical particle coupled to thermal bath of fixed temperature and moving under the influence of external forces in a one-dimensional periodic structure. In order to determine the mechanisms standing behind the anomalous intracellular transport and methods of their control we will analyze inter alia the following quantities of interest: the average velocity of the motor, its diffusion coefficient or transport efficiency. These features will be investigated not only after a long time evolution of the system (in a stationary state) but also during it. We will explore the full dynamics as well as the transient effects associated with it. We will formulate it in the framework of the Newton equation with a random force modeling the influence of fluctuations on the particle, i.e. with the help of Langevin equation. Our theoretical results may be experimentally corroborated in artificial physical setups like Josephson junctions and their systems (SQUID – Superconducting Quantum Interference Device) as well as cold atoms in optical lattices.

Research planned in the project will allow to face a number of fundamentals problems in thermodynamics of small systems and nonequilibrium statistical physics. Moreover, it will certainly contribute to a deeper understanding of the transport on the microscale, including intracellular, which play a paramount role in the existence of living organisms.