Studying the neural processes that drive choice behaviour is essential to understand the extent and limits of cooperation [Declerck & Boone, 2018]. Tendencies of individual's decision making and therefore preferences to cooperate are innate and varying from person to person. Furthermore, intra-individual heterogeneity occurs at shorter time scales, as a consequence of variations in levels of various neurohormones [see, e.g. Gamble et al. 2014]. In this work, we investigate the effects of temporal changes at the individual and at the social level and their impact on cooperation in a higher-order network.

Previous research established a strong connection between neural connectivity, social interactions, including cooperation, as well as the topology of social networks in which these interactions unfold. For example, giving oxytocin to central individuals in a social network increases their trust and enforcement of cooperation norms through peer punishment thereby enabling cooperation [Li et al. 2022]. Neural synchrony – inter-person correlation based on brain activity - during decision making has also been shown to be related to cooperative interaction [Hu et al. 2018]. Furthermore, brain dynamics vary based on social network characteristics. More precisely, variability in reactivity to exclusion explains the density of friendship networks [Schmalzle et al. 2017]. Changes in network connectivity over time, in turn, are influenced by the human circadian clock that regulates neural activity [Alakorkko & Saramaki 2020]. Similarly, variations in the endocrine system (e.g. OXTR, OPRM1, DRD2) predict the social network structure [Han et al 2021]. More central individuals were also shown to have similar neural responses to their peers, whereas less central individuals exhibit more variable responses [Baek et al. 2022]. Although some recent work has considered cooperation in temporal networks [Li 2020], individual temporal variability in cooperation preferences and its impact on emergence of cooperation is far less understood. All in all, past research shows that there is a link between circadian clock, neuroendocrine system and therefore human behavior, and a social network as well as its dynamics.

To illustrate and to study the effects of temporal variability of cooperation preferences, we consider simulations of a stochastic mixed strategy prisoner’s dilemma played on a network, that potentially allows for multi-player games as in [Alvarez-Rodriguez,2022].

Prisoner’s dilemma is a game between two players where each player has to choose one of two possible strategies (to cooperate or to defect) and the payoff for each individual depends on the strategy taken by her, as well as by another player. The game can be iterated whereby it is known as the iterated prisoner's dilemma. In a pure strategy game, each agent chooses one fixed strategy. It can be changed over the course of the game (evolve) and the change in strategies is typically based on a comparison of recent payoffs. In a mixed strategy game, the strategy of an agent is a random variable with probability of cooperating p, therefore a pure strategy game is a special (deterministic) case of a mixed (stochastic) strategy game where p=0 or p=1 [Cimini & Sanchez 2015, Miyaji & Tanimoto 2021].

To incorporate temporal variability in cooperation, we employ a non-evolutionary prisoner's dilemma game, where probability, associated with a random variable of cooperation, is not a fixed value, but is time-varying - p(t). For example, temporal variability due to changes in neuromodulatory activity likely reminisces a periodic function such as sine, or a superposition of a set of periodic functions.

The initial results of such a setup suggest that cooperation patterns are affected by the temporal changes in agents’ preferences to cooperate in both pure-strategy and mixed-strategy prisoner’s dilemma game. Importantly, results depend on whether the functions p(t) interfere constructively in which case the two agents tend to cooperate more/less than their baselines synchronously.

In the paper, we plan to extend the initial work by incorporating evolution, memory and rationality to agents’ strategies. We will study effects of different p(t) patterns and emergence of global cooperation in a network-based model that supports more realistic higher-order games and temporality of network structure. We expect that in an evolutionary game, strategic synchronization may occur either at a macro- or meso- level as a direct consequence of the superposition of p(t). Lastly, we will frame the model and our simulation results in a language of neuromodulation. This work will contribute to understanding of the biological nature of social cooperation.