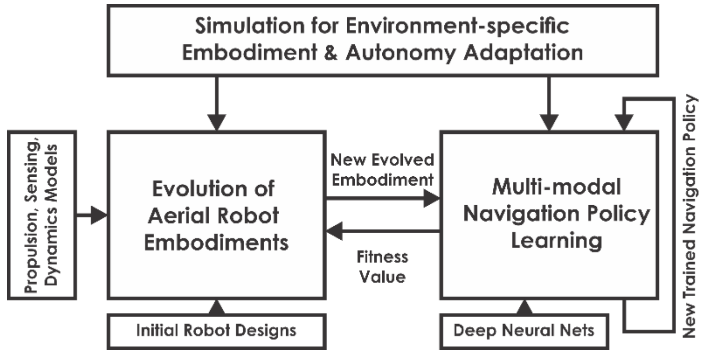
Learning and Evolution for Embodied Autonomy

(Available for 1 student or 2 students)

Abstract: In September 2021, the finals of the DARPA Subterranean Challenge took place and Team CERBERUS – led by the PI – won the competition. Both for CERBERUS and for the other top-scoring teams, flying robots presented scouting capabilities but otherwise the bulk of the mission was carried by ground robots owing to their extended endurance and effective range. This contradicts our intuition regarding the benefits of flying robots in demanding subterranean environments with first being the fact that they do not depend on the challenges of the otherwise perilous terrain. A host of species, such as bats or insects, demonstrate the analogy of benefits of flying systems in natural underground environments but flying robots still need fundamental improvements to reach similar performance. This master thesis is motivated by the observation that despite the vastly different missions that flying robots undertake, and the different environments in which they operate, certain types of vehicles – primarily multirotors and fixed-wing systems – dominate across use cases. We claim that this is not only counterintuitive, as a higher variety of embodiments and autonomy solutions would follow the natural paradigm, but also we claim that this likely represents the key reason for the limitations observed on autonomous flying robots. Specifically, we claim that an environment-specific co-synthesis and co-optimization of the robot's "body" (airframe, sensing, propulsion) and "brain" (autonomy functionality especially relying on data-driven learning methods for navigation) is necessary. Reflecting upon this analysis, in this master project you are tasked with employing the combined benefits of evolutionary algorithms and learning to facilitate the automated environment-specific adaptation of flying robot embodiments. As a case study, the class of highly cluttered underground cave and mine corridors are considered and the hypothesis is that environment-specific body/brain co-synthesis will lead to significantly different robots with significantly improved navigation performance for the particular environment type. To make this tangible, we self-constraint on the class of flying robots employing propellers with DC brushless motors, while the airframe may involve both rigid and soft components. We search the correct selection of genotypes and phenotypic expressions for evolutionary embodiment adaptation, combined with efficient deep learning-based navigation policies with the performance of the latter being used as the signal to guide evolutionary adaptation.



Tasks:

- Study of literature in evolutionary robotics and identify most applicable genotypes for the variation of aerial robot embodiments.
- Study of literate in policy learning and employ a reinforcement learning method for deriving navigation controllers.
- Design the combined embodiment body-brain co-synthesis process guided by the performance of the learned navigation policy within a specific class of environments.
- Perform "evolutionary/learning iterations" towards environment-specific novel flying embodiments with likewise environment-specific navigation autonomy.

Literature (indicative):

[1] Tranzatto, M., Miki, T., Dharmadhikari, M., Bernreiter, L., Kulkarni, M., Mascarich, F., Andersson, O., Khattak, S., Hutter, M., Siegwart, R. and Alexis, K., 2022. CERBERUS in the DARPA Subterranean Challenge. Science Robotics, 7(66), p.eabp9742.

[2] Gupta, A., Savarese, S., Ganguli, S. and Fei-Fei, L., 2021. Embodied intelligence via learning and evolution. Nature communications, 12(1), p.5721.

[3] Doncieux, S., Bredeche, N., Mouret, J.B. and Eiben, A.E., 2015. Evolutionary robotics: what, why, and where to. Frontiers in Robotics and AI, 2, p.4.

[4] Luck, K.S., Amor, H.B. and Calandra, R., 2020, May. Data-efficient co-adaptation of morphology and behaviour with deep reinforcement learning. In Conference on Robot Learning (pp. 854-869). PMLR.

[5] Howard, D., Eiben, A.E., Kennedy, D.F., Mouret, J.B., Valencia, P. and Winkler, D., 2019. Evolving embodied intelligence from materials to machines. Nature Machine Intelligence, 1(1), pp.12-19.

[6] Cheney, N., MacCurdy, R., Clune, J. and Lipson, H., 2014. Unshackling evolution: evolving soft robots with multiple materials and a powerful generative encoding. ACM SIGEVOlution, 7(1), pp.11-23.

Linked to upcoming new project. Main supervisor: Kostas Alexis, Professor, NTNU