Locomotion as a Result of Displacement of Resources

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Nature has invented several different mechanisms to implement locomotion. In some organisms, locomotion is a result of coordination of muscle movements in distinct parts of the body, e.g. walking behavior. It has been a source of inspiration for various artificial systems, e.g. Owaki and Ishiguro (2017). In other natural organisms, locomotion is an emergent effect of local interactions between many simple agents moving as aggregated swarms in their environment, e.g. amoeboid movement in eukaryotic cells, amoeba, and slime-molds. In such continuous locomotions, flows of substrates form pseudopodium towards favorable regions of the environment. The substrates that form the pseudopodium are taken from other parts of the organism located in less favorable regions. This displacement of substrates leads to a crawling-like movement of the organism. A comparatively similar mechanism is the locomotion of leaderless flocks of animals which have inspired several methods of self-organized locomotion for artificial swarms (Hornby and Pollack, 2001; Varughese et al., 2016). A related field is the formation of shapes in artificial swarms via repositioning of mobile agents, e.g. (Rubenstein et al., 2014). Here we report on a previous work (Zahadat and Schmickl, 2017) demonstrating a self-organized amoeboid-like locomotion controlled by a variation of a plant-inspired algorithm, called Vascular Morphogenesis Controller (VMC) (Zahadat et al., 2017). The VMC is initially introduced to guide the growth of artificial structures via a self-organized process, in the context of project *flora robotica*. The algorithm is inspired from competition of different branches in a plant enabling the plant to reach the areas with better conditions (e.g. more light). Here a variation of VMC is used to direct the locomotion of an organism by the means of growing branches towards favorable regions while the non-favorable branches are retracted leading to an amoeboid-like locomotion.

Vascular Morphogenesis Controller

The morphology of a plant changes over time as a result of interplays between the encoded genome and the environment (Scarpella et al., 2010). The branches of a plant seek local resources such as light from their immediate external environment and receive shares of limited common resources, i.e. water and minerals, from roots distributed by their internal vessel system. The common resource reaching a branch is used for the growth of the branch and production of new parts, i.e. new branches. The vascular system of a plant is dynamic and changes based on competitions for common resource between different branches (Leyser, 2011). A hormone called auxin is produced at the tip of each branch depending on its success in accessing local environmental resources (e.g. the amount of light). The branches in better locations produce larger amounts of the hormone. The hormone flows root-wards and regulates the quality of the vessels in its way. A branch with higher quality of vessels, receives larger shares of the common resource leading to further growth. This in turn may lead to a positive feedback by positioning the branch in an even better location, more production of the hormone and better vessels, and thus even further growth of the branch. A high share of the limited common resource for successful branches means lower shares of the resource for the others which maybe lead to decrease or stop of growth in the branches in less favorable regions of the environment.

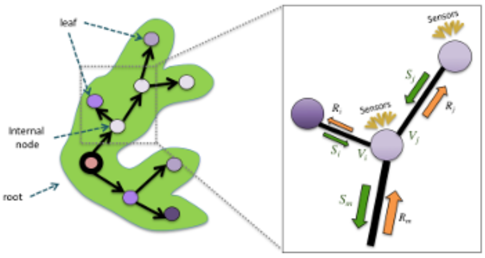

Figure 1: a schematic example VMC-guided organism.

The VMC abstracts the above concepts into a decentralized algorithm acting on growing acyclic directed graphs (see Fig. 1). The success of a leaf i in a graph depends on the local environment and parameters of the system, $S_i := \omega_{const} + \sum_{s \in Sensors} \omega_s \cdot I_s$, where I_s is the sensory input, and ω_{const}, ω_s are the constant and sensor-dependent production rates. The success value is transferred from each node to its parent where the total value of the success at the parent is $S_m = g(\rho_{const} + \sum_{s \in Sensors} \rho_s \cdot I_s) \cdot \sum_{b \in branches} S_b$, where ρ_{const}, ρ_s are the constant and sensor-dependent transfer rates and $g(x)$ is a sigmoid function mapping x to the range of (0, 1). The success passing from a node to the parent regulates its vessel, as $V_i = V_i + \alpha \cdot (S_i^{\beta} - V_i)$, where $alpha$ is the adaptation rate of the vessel, and β is a competition factor. The common resource at a parent node m is distributed between its children, $R_i = (R_m - c) \cdot \frac{V_i}{\sum_{b \in branches} V_b}$, where R_i is the resource reaching the child i, and c is the consumption rate of the resource at the parent node. If $R_i > Th_{add}$ at a leaf, the leaf grows into an internal node by addition of new children (branches) to it. If all the children of a node are leaves and their $R_i < Th_{del}$, the children are deleted altogether and the node becomes a leaf.

Implementation and Results

Unlike biological plants and the original versions of VMC, here we allow the root node of the graph to change over time. If the resource reaching the children of the root is higher than a threshold, the new root of the graph is the child with the higher resource and all the input edges of the node are reversed. In the current implementation, an organism grows from an initial root and every node can get two children. The environment contains a linear gradient of an environmental modality towards a target. Every leaf is capable of sensing the local value of the environmental modality (for simulation details see Zahadat and Schmickl (2017)). Fig. 2 shows the behavior of an organism moving towards a static target. The VMC parameters are evolved for such an environment). To test the reactivity of the evolved system in a dynamic environment, the same parameters are used for an organism in a setup where the position of the target circulates between four corners of a square. Fig. 3 represents the center of mass of the organism in the dynamic setup (for a video of this experiment, see https://youtu.be/2zOhRzRHRP0).

Conclusion

A variation of a plant-inspired algorithm for self-organized growth is successfully implemented here to conduct an amoeboid-like locomotion. Although the single agents are only capable of local sensing and perceive no directional information, the swarm-like organism as a whole is capable of motion towards preferable regions of the environment.

Acknowledgements

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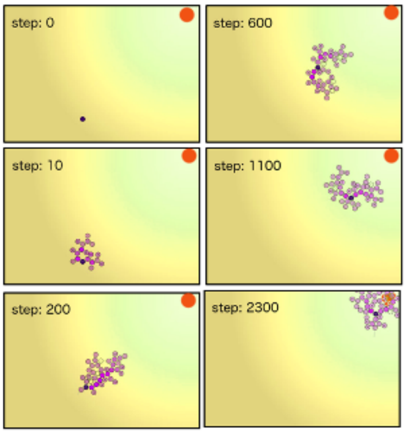

Figure 2: Morphology of the organism over time

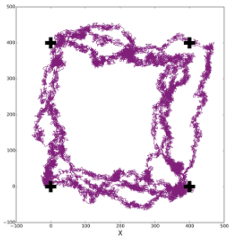

Figure 3: Trajectory of the center of the mass. The + signs show the position of the target at different times.

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