# Towards understanding the eco-evo-devo of artificial creatures in 3D physical simulation

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## Introduction

Niche construction refers to the phenomenon where organisms alter the selection pressures on themselves and others through their ecological activities (Odling-Smee et al., 2003). Evolutionary models examining the impact of niche construction on evolutionary processes have uncovered surprising outcomes that complex niche construction can significantly contribute to an open-ended evolutionary process in physically grounded environments, such as the long-term embodied evolution of robots (Chiba et al., 2016; Chiba et al., 2020). Despite this, the emergence of niche-constructing behaviors involving complex physical structures, such as those in a 3D multi-agent environment, remains poorly investigated.

We aim to explore the effects of the interactions between development and niche construction through the evolution of adaptive morphology and behavior of artificial creatures. We construct an evolutionary model in which a 3D artificial creature must cross two valleys to reach a goal, using developmental events and the construction of objects in a physically simulated environment. Preliminary results show that in cases where lifetime development and niche-constructing behavior were enabled to evolve, creatures tended to use a developmental event to cross the first valley, followed by niche construction to place objects in the valley, to cross the second valley, which resulted in a successful movement towards the target. This occurrence, prevalent in all trials of the case, captures our attention and suggests that such a universal phenomenon might be an interesting key finding for future work.

## Evolutionary Model

In this study, we used an evolutionary framework of artificial creatures in a 3D-multi-agent environment based on a Python module-based physics engine, PyBullet, to discuss eco-evo-devo in evolving artificial creatures (Fig. 1), which is described in detail in (Jaafar et al. 2023, 2024). The Hyper-NEAT is an evolutionary algorithm often used for evolving complex neural networks represented by the Compositional Pattern-Producing Network (CPPN) (Stanley, 2009). We adopt this to evolve the CPPNs used in the morphological development and behavioral generation as the genotype of each artificial creature (Fig. 1 (a), (b)). We assume that a single large CPPN determined by the genotype of a creature represents both CPPNs as its sub-networks. Each rigid-bodied creature consists of rectangular blocks connected with hinges. Their morphology develops by adding new blocks to the existing body blocks. A genotype of a creature generates two neural networks; one determines the morphological development (i.e., the addition of a new block or not, the length of the long sides of the new block, hinge direction, and to have fixed hinge or flexible joint) (Fig. 1(a)(i-iii).

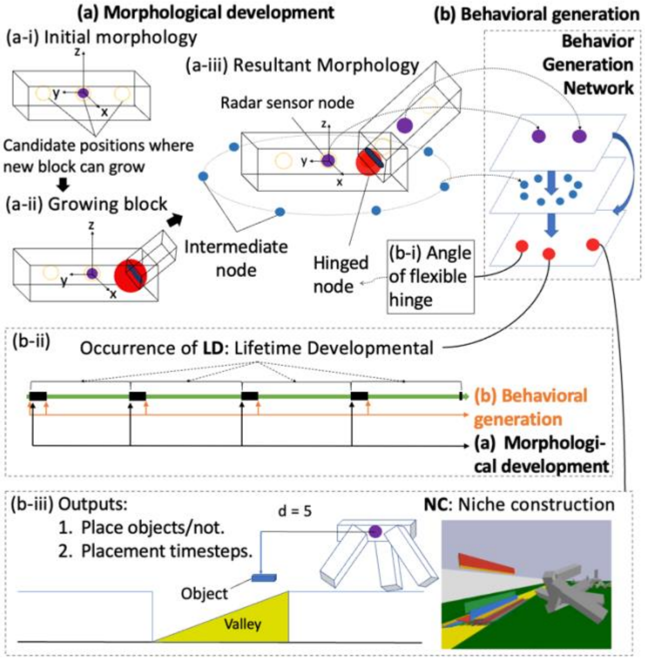

Fig. 1: Framework of artificial creature

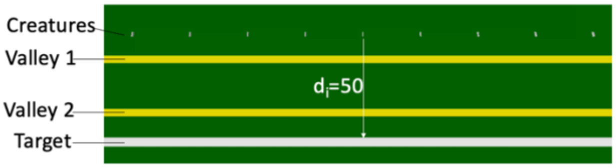

Fig. 2: Environment and task.

Following this, another neural network determines the behavioral generation process, such as hinge angles (Fig. 1(b)(iv)), the timing of lifetime development (LD) events (i.e., determining which timesteps developmental changes occur)

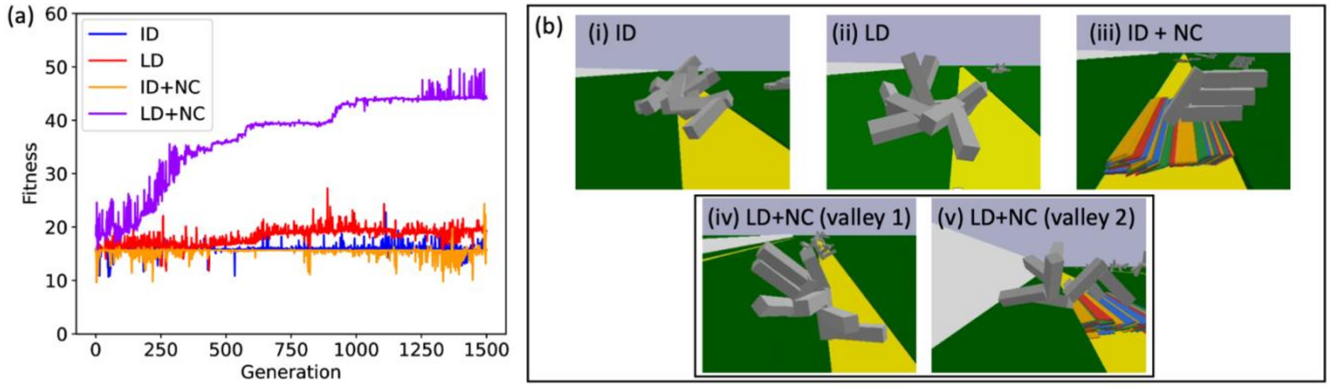

Fig. 3: (a) Average best fitness across 10 trials for four cases: Initial development (ID), lifetime development (LD), ID + niche construction (NC), and LD+NC. (b) Snapshots of the morphology and behavior of best creatures from each case. Video link: https://figshare.com/s/6307a5f5929b2ab16562.

(Fig. 1(b-ii)) and niche construction strategies (i.e., to place objects or not, and at which timesteps will objects be placed) (Fig. 1(b-iii)). Object placements can happen every 20 timesteps during a total of 20,000 timesteps. The decision to place objects is in response to the radar sensors used as the input of the behavioral generation network. Objects were positioned at a distance of 5 units from the creature's center node of the focal block (purple). The placement occurs only when position is within valley areas (Fig. 1(b-iii)). The objects are rectangular, and a single type of object has been chosen for simplicity. This network receives sensory inputs from a radar sensor (i.e., the distance between the coordinates of the creature and the target, the orientation of the creature towards the target, and the elapsed time from the beginning of fitness evaluation).

Fig. 2 illustrates a field for fitness evaluation, where artificial creatures are aligned in a straight line to simplify interactions, tasked with locomotion towards a target and crossing two valleys. Fitness is measured by the distance traveled from the starting point toward the target. We adapted the excessive elitism method, which modifies elitism in NEAT, by preserving the best (*M*=83) individuals as elite across generations to ensure diversity and reduce evaluation costs in this complex evolutionary process, which is described in (Jaafar et al., 2023, 2024). Non-elite individuals (*N*-*M*=12) from the population of (*N*=95), undergo selection and genetic operations for evaluation in each generation.

## Preliminary Experiments and Discussions

In our study, we explored the effects of the evolution of development and niche construction on creature evolution over 1500 generations, conducting 10 trials for each of the four cases: Initial development (ID) in which developmental event occurs 4 times at the initial step; lifetime development (LD) in which developmental event can occur according to the neural network output; ID + niche construction (NC); and LD+NC, with each generation running for 20,000 timesteps. Initially, we evolved a population to move towards a target on a flat surface without valleys, finding that a small body size (2.5 – 5 blocks) was most effective for mobility on flat surfaces and used as the initial population for the environment with valleys. We analyzed the average best fitness across 10 trials, as shown in (Fig. 3(a)) and revealed that in case ID, the fitness stagnated at around 15 due to creatures developing a large body size (about 12.5 blocks) early on, which limited their ability to cross the first valley, with some failing to progress further (Fig. 3(b)(i)). In the LD case, creatures initially adopted a small body size (2.5 – 5 blocks) for flat surface mobility. Upon encountering the first valley, they developed large body size at about 12.5 blocks, which then hindered their movement toward the second valley, resulting in a fitness plateau at around 20 (Fig. 3(a)(red)).

In the ID+NC case, which involved initial development and niche construction, the best-performing creatures maintained a small body size (2.5 – 5 blocks) to facilitate movement on flat surfaces. To cross the first valley, they relied on niche construction by placing objects to fill in the valley. Yet, their small size, while suitable for flat surfaces, made it challenging to navigate through the objects placed in the valley. Consequently, many creatures were unable to cross, becoming stuck midway (Fig. 3(b)(iii)). The greatest increase in fitness occurred in the case of LD+NC. In this case, creatures use small body sizes (2.5 – 5 blocks) to move from the initial position to the first valley. Then they adapted to a medium body size (7.5 – 10 blocks), utilizing LD to cross the first valley. With the growth of new body parts, the force was used to leap over the valley (Fig. 3(b)(iv)). After crossing, they successfully move across the flat surface with a medium body size, heading towards the second valley, where they utilize NC to fill the valley and facilitate crossing (Fig. 3(b)(v)). This adaptive strategy, combining LD and NC, was consistently observed in all 10 trials.

## Conclusion

We explored the influence of the evolution of development and niche construction on the evolution of artificial creatures in a complex 3D environment. Our observations revealed a consistent pattern of development and niche construction adaptation, indicating complementary role of both adaptation processes on the evolution of artificial creatures. This highlights the need for further research on this interesting finding.

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