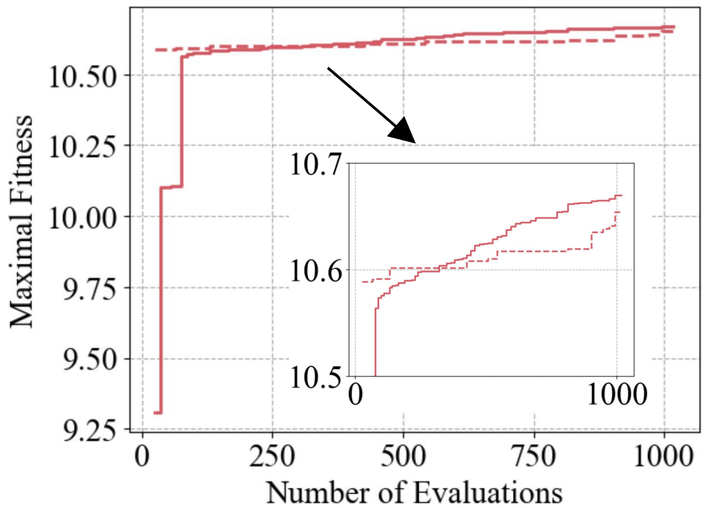
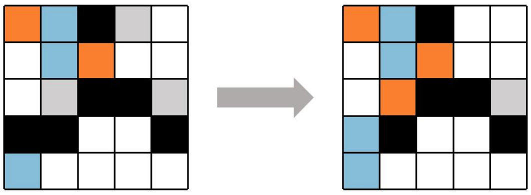
Supplementary material 3: Comparison with random editing

To further showcase the effectiveness of our diversity reflection mechanism (DiRect), we re-implemented our experiments with DiRect replaced by random voxel mutations. We conducted a paired two-tailed Student's t-test, and found that the fitnesses of randomly mutated robot designs are significantly lower their pre-editing counterparts (p<**0.001**). In contrast, the fitnesses of robot designs before and after DiRect modification show no significant difference (p=**0.19**). The evolution with random editing also suffers from reduced optimization efficiency (**Supplementary figure 3-1**), as the stochastic exploratory behavior often disrupts essential functional structures. LLM-aided diversity reflection, on the other hand, holds a distinct ***"informed"*** nature. Specifically, it builds on successful designs discovered along the evolutionary trajectory, and promotes exploration without compromising functionality.

For illustrative purposes, here we present two examples of diversity reflection, including both the pre- and post-editing morphologies, along with explanations provided by the LLM for its modifications. It can be seen from **Supplementary figure 3-2** that the LLM is indeed able to identify critical substructures within robot designs, and modifies only the voxel placements that do not affect functionality, yet promote diversity. These results provide sound evidence that DiRect is reliably functioning as an ***intelligent*** mutation operator.



Supplementary figure 3-1. Comparison between diversity reflection and random editing. It is worth noting that LASeR w/ DiRect was able to swiftly catch up with and surpass LASeR w/ random editing, despite the inferior initialization.



1. Change the soft voxel at position (0,3) to an empty voxel.

Reasons: This position does not disrupt the structural integrity of the robot as it is on the edge of the robot design. Removing this soft voxel introduces an empty voxel, which can help create a more diverse structure while still allowing the remaining voxels to maintain connectivity.

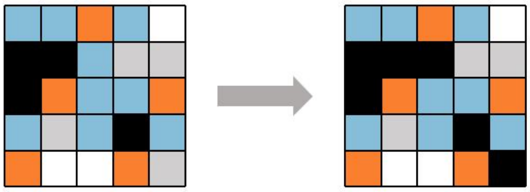
2. Change the rigid voxel at position (3,0) to a vertical actuator.

Reason: This alteration allows for additional movement capabilities in that region. The vertical actuator can facilitate upward motion, enhancing locomotion without violating any constraints.

3. Change the soft voxel at position (2,1) to a horizontal actuator.

Reason: By replacing a soft voxel with a horizontal actuator, we introduce functionality that can aid in lateral movement. This change enhances the overall flexibility and capability of the design while keeping the structure intact.

(a) An example of DiRect modifications on Walker-v0



1. Change the voxel at (1,2) from a vertical actuator to a rigid voxel.

Reason: The vertical actuator in this position does not significantly contribute to the pushing mechanism since it is already surrounded by other actuators and soft voxels. Replacing it with a rigid voxel will maintain structural integrity while potentially enhancing the overall rigidity of the robot.

2. Change the voxel at (4,4) from a soft voxel to a rigid voxel.

Reason: This position is already supported by surrounding voxels, and converting it to a rigid voxel increases stability at the base of the robot. It also ensures that the bottom row maintains contact with the ground, which is crucial for effective pushing.

(b) An example of DiRect modifications on Pusher-v0

Supplementary figure 3-2. Illustrative examples of DiRect modifications. Each example includes the pre- (left) and post- (right) editing designs, together with the modifications and justifications provided by an LLM to enhance morphological diversity.