Diploidy, Quagmire or Springboard? Rethinking Single-Genome Body-Brain Co-Evolution with Phenotypic Plasticity in Soft Robots

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- Evogym
- Soft-Robots
- Indirect-Encoding
- Phenotypic Plasticity
- Single Genome
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- Ploidy

Does diploidy and phenotypic plasticity coupled with an indirect-encoding and changing environments provide an advantage in the evolution of Voxel-Soft-Robots ?

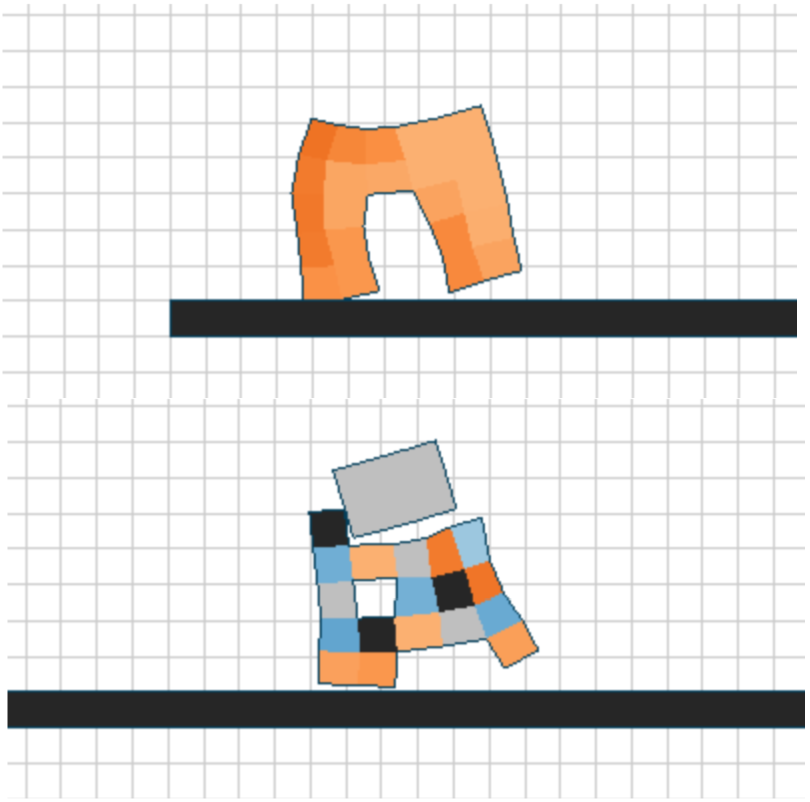


Fig 1. Voxel-Soft-Robots

Context – Voxel-Soft-Robots

- Multi-material soft systems formed by the aggregation of soft and simple building blocks called voxels.

- The EvoGym Library contains dozens of environments : Walking tasks, Object manipulation, Climbing, Locomotion tasks…

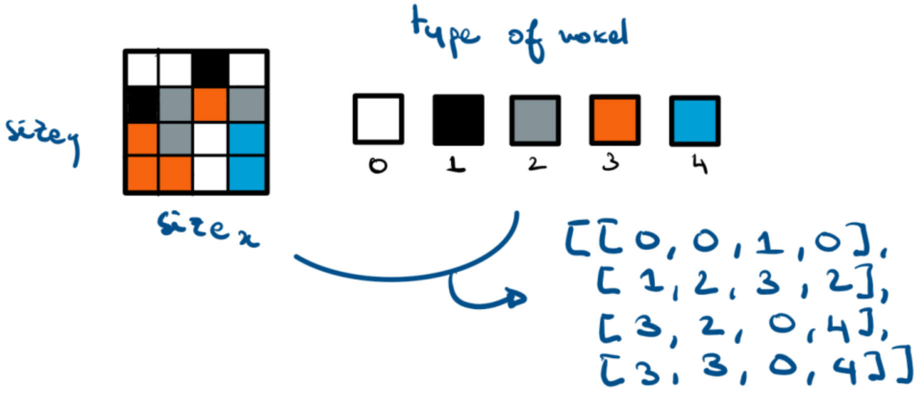


Fig 2. A Voxel-Soft-Robot in the Evogym Library

Context – Indirect-Encoding

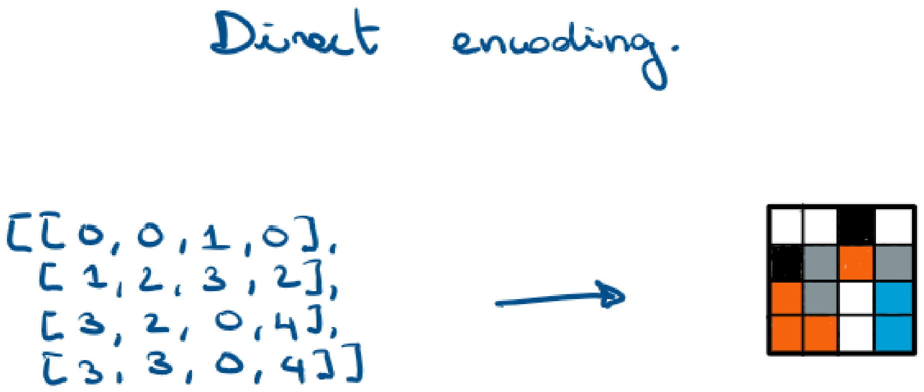


Fig 3. A direct encoding for the body of a Soft-Robot

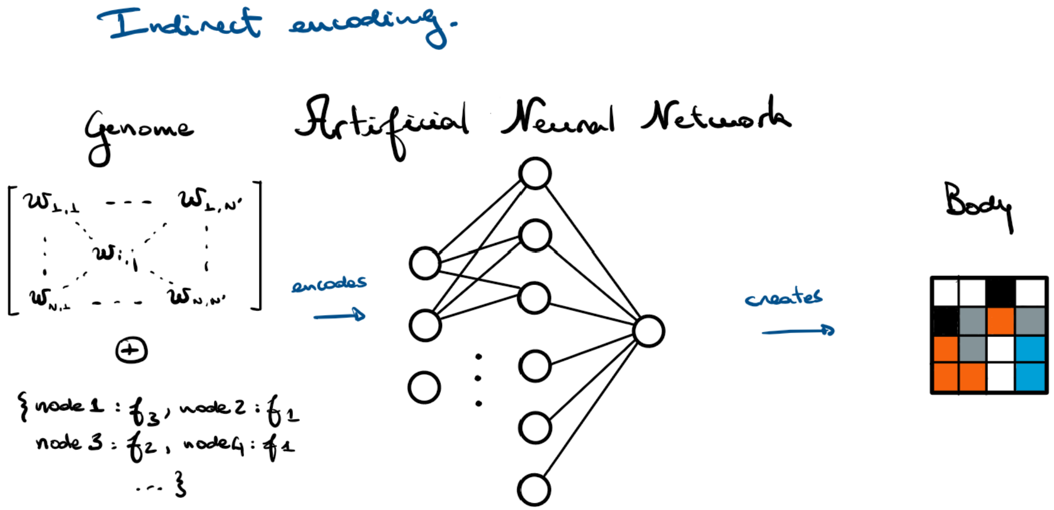


Fig 4. An indirect encoding for the body of a Soft-Robot

Context – Single-Genome Soft-Robots

- CPPN stands for Compositional Pattern Producing Network is a Neural Network whose nodes contains a unique activation function taken from a pool.
- CPPNs are applied to the entire space of possible inputs.
- The algorithm used was HyperNEAT.

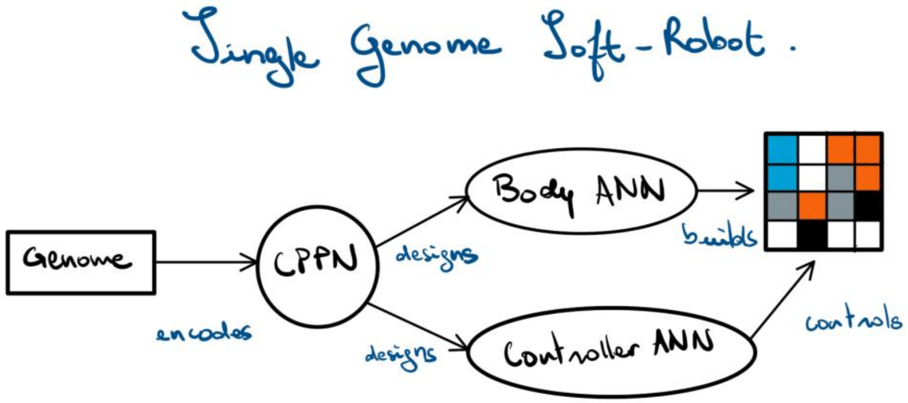


Fig 5. A Single-Genome Soft-Robot according to Tanaka and Aranha

Context – Single-Genome Soft-Robot (2)

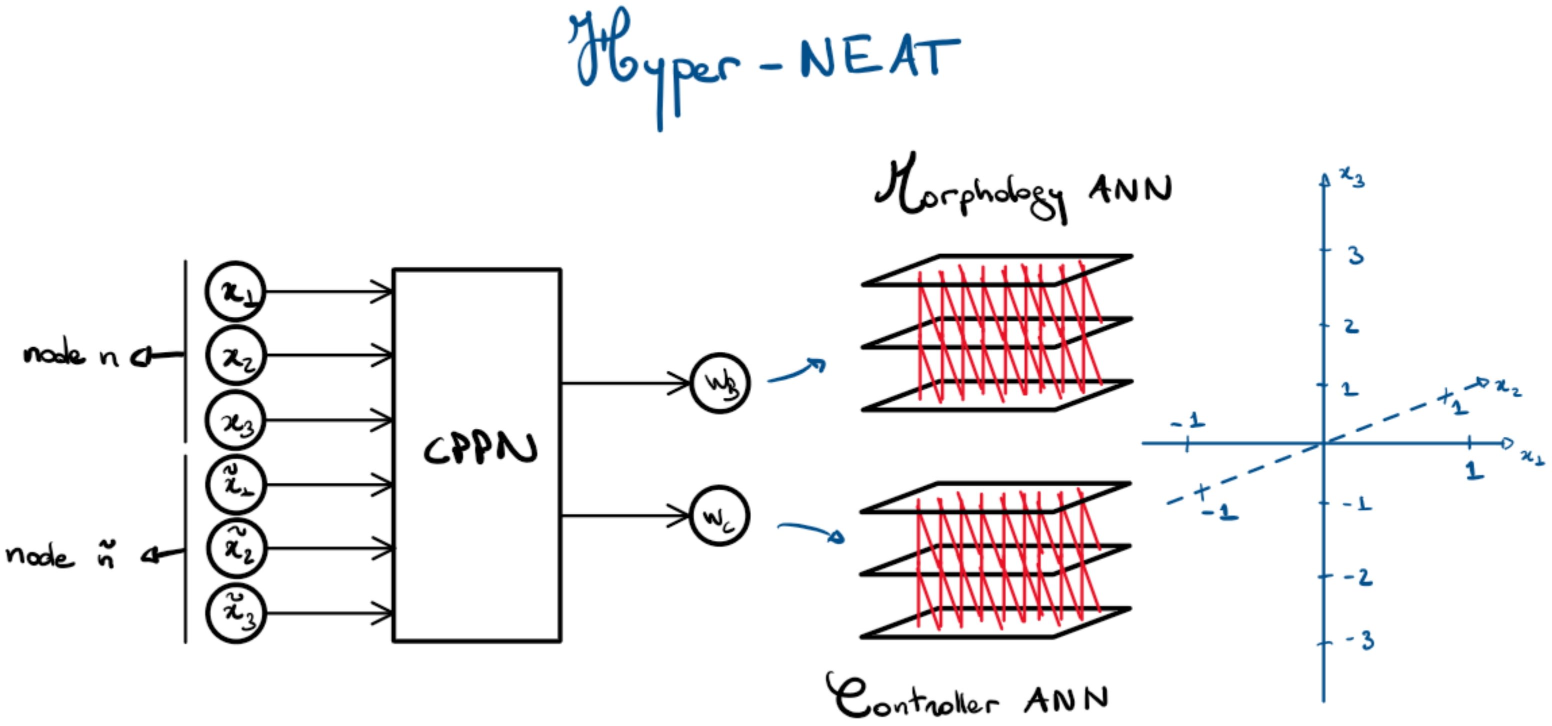


Fig 6. Hyper-NEAT used by Tanaka and Aranha

Context – Ploidy & Changing-Environment

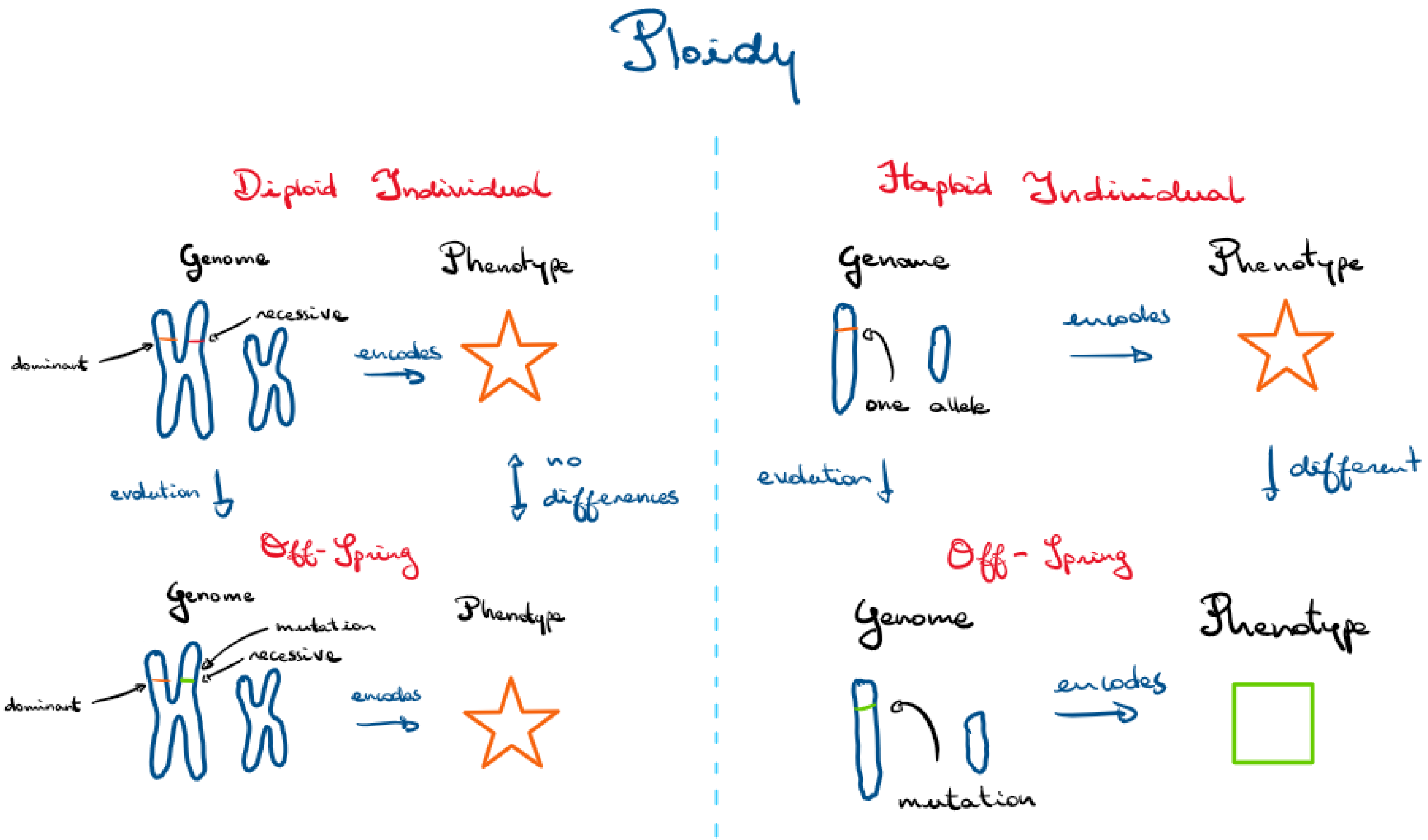


Fig 7. Differences between diploid and haploid individuals

Context – Phenotypic Plasticity

- Phenotypic plasticity is an organism's ability to show different traits from the same genotype depending on environmental conditions.

Method – Comparison between Plasticity

- Developmental Phenotypic Plasticity
- Chromosome Level Phenotypic Plasticity

Method – Developmental plasticity, Global process

- Same step for the creation of each robot.
- The CPPN is evolved using a simple Genetic Algorithm.

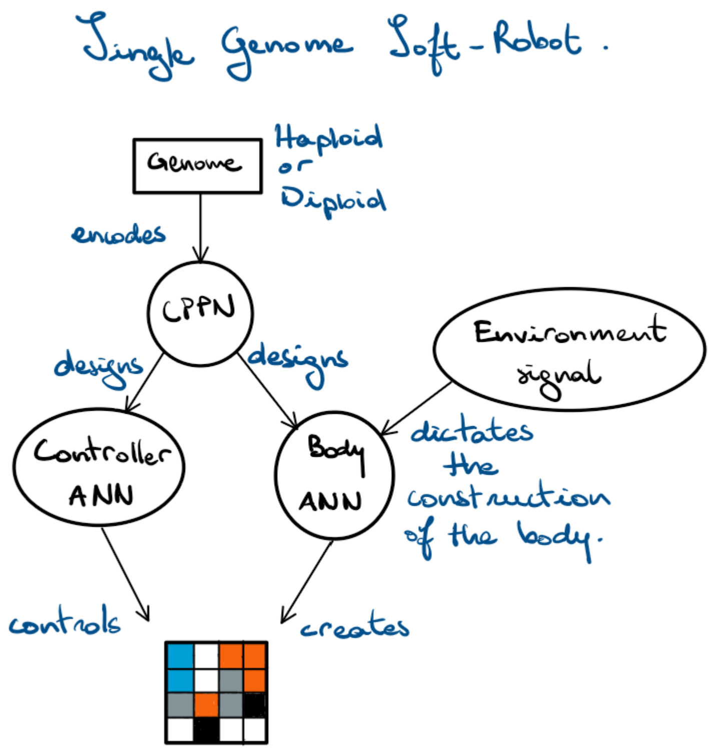


Fig 8. Description of the creation of the robot.

Method – Developmental plasticity, CPPN

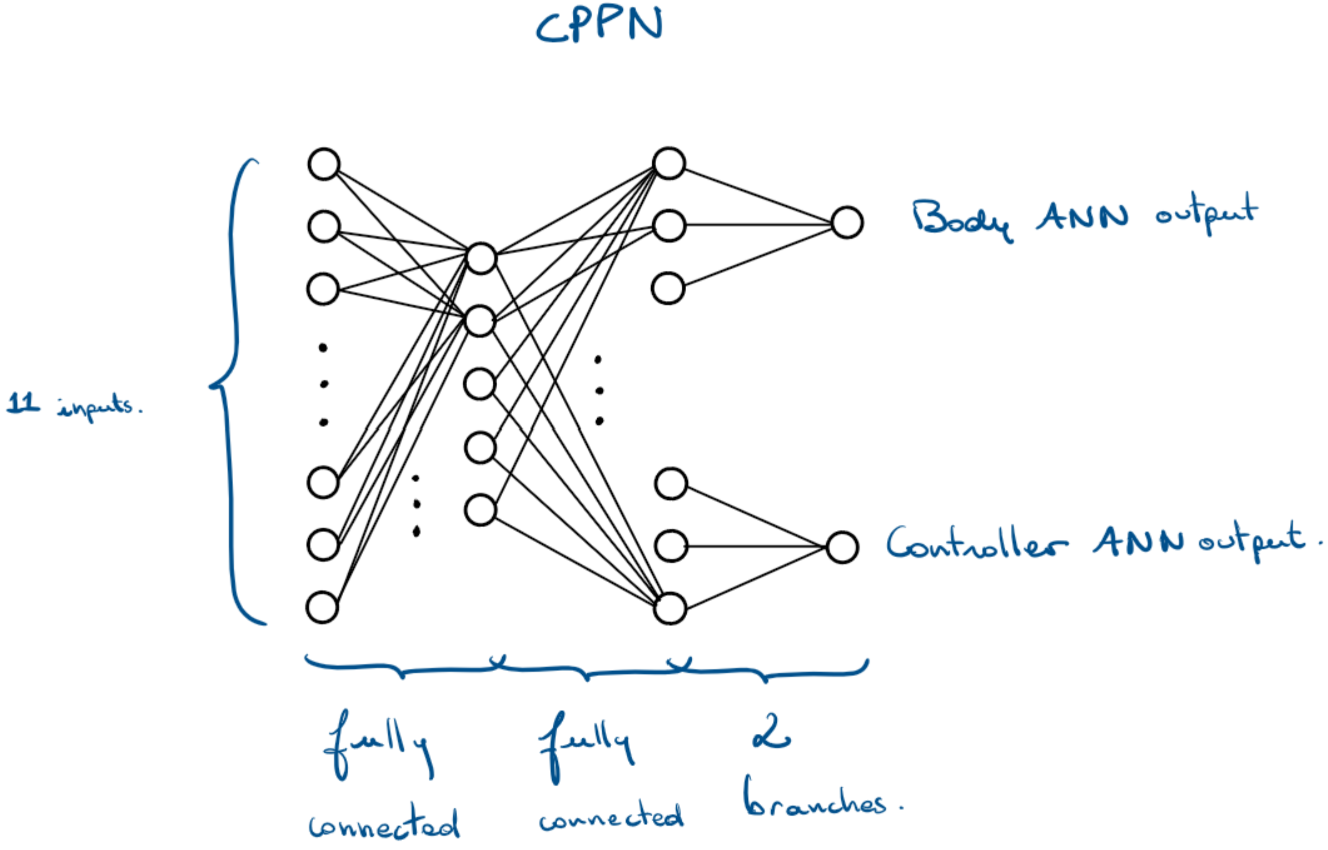


Fig 9. Shape of every CPPN in the experiment

Method – Developmental plasticity, Haploid vs Diploid

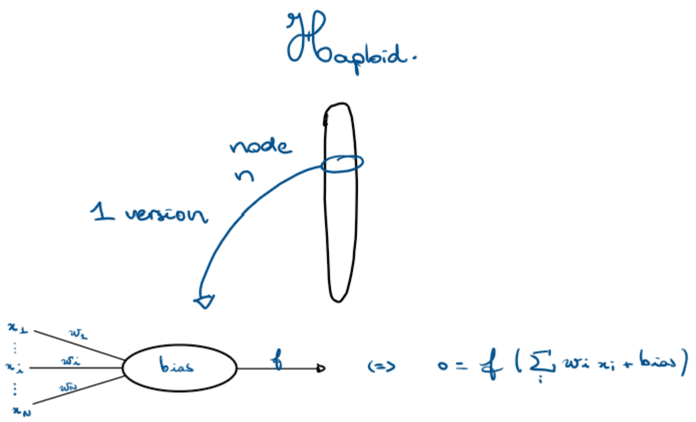


Fig 10. Haploid representation of the genome

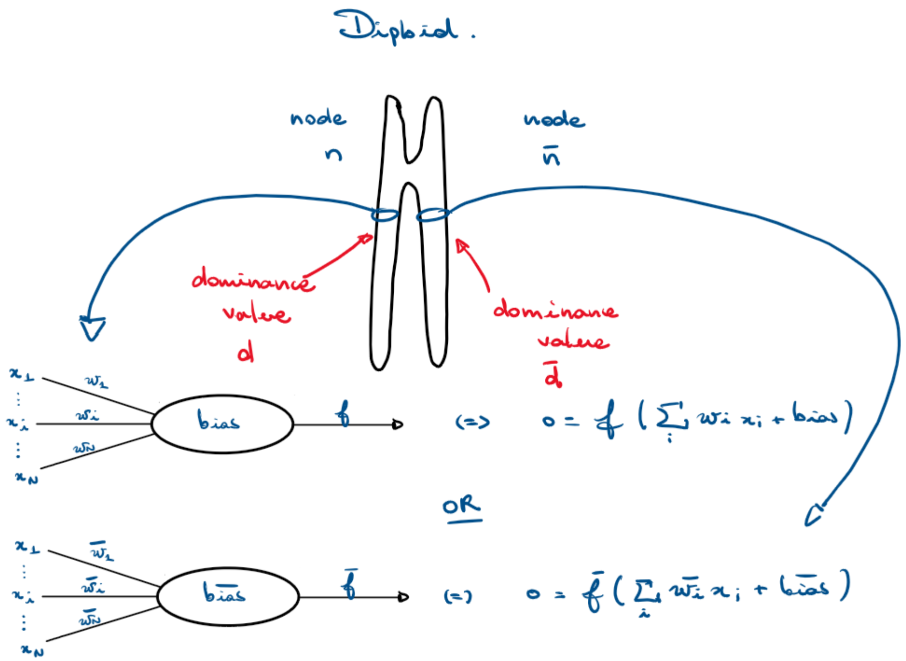


Fig 11. Diploid representation of the genome

Method – Developmental plasticity, 5D Substrate

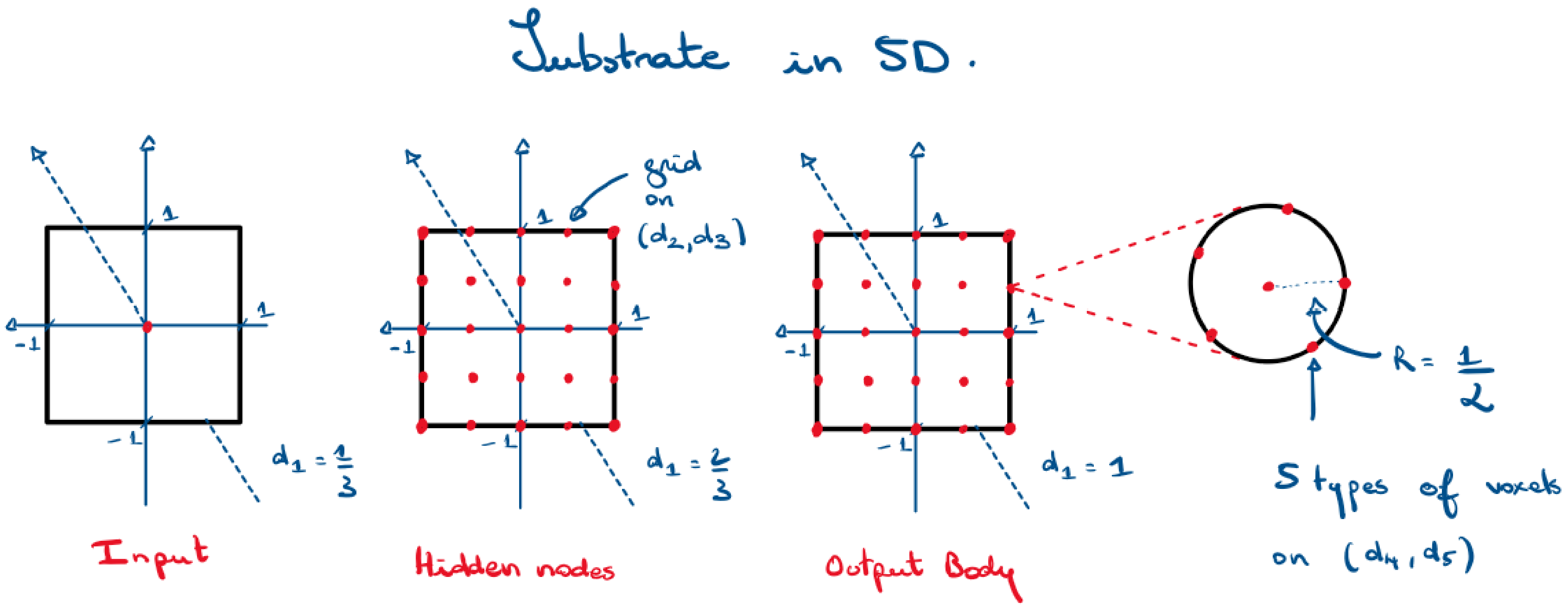


Fig 12. Representation of the substrate in 5D; only the Body ANN is depicted here

Method – Developmental plasticity, Environment Signal & Body

- Phenotypic plasticity is an organism's ability to show different traits from the same genotype depending on environmental conditions.

- Our method exploit the phenotypic plasticity to produce several phenotype from a single genome.

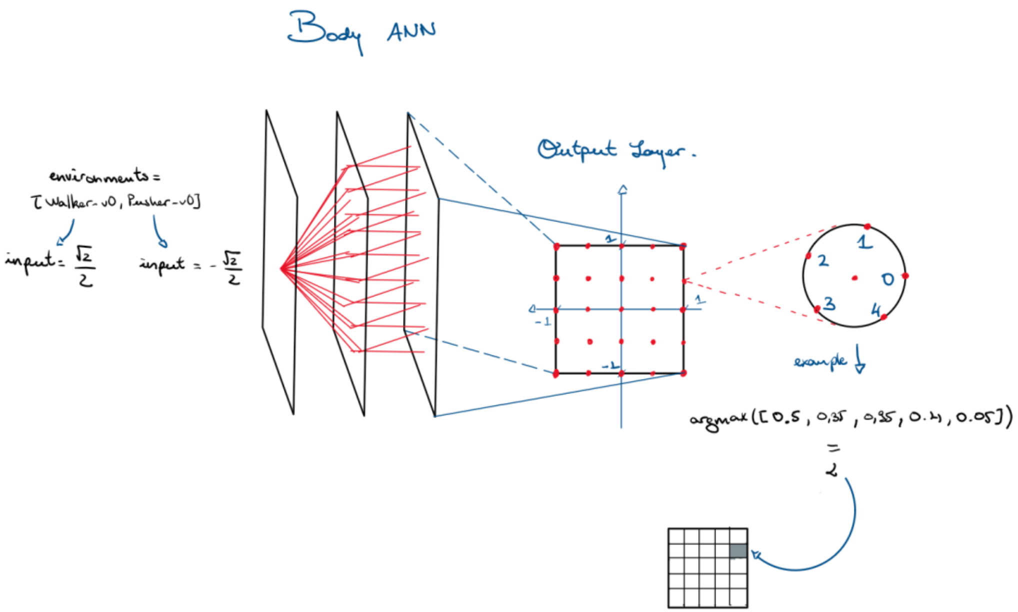


Fig 13. Construction of the body depending on the environment

Method – Developmental plasticity, Controller

- The input size of the controller depends on the different voxel composing the body.
- The controller is built once the body is already created.
- The substrate of the Controller only uses 3 dimensions but is laid in 5.

Method – Developmental plasticity, Genetic Algorithm

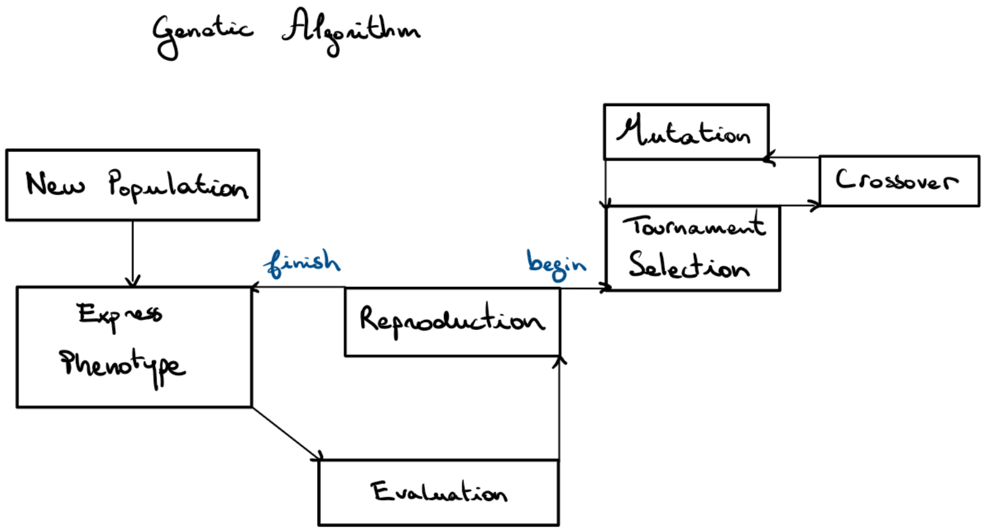


Fig 14. Genetic Algotithm for the haploid individuals

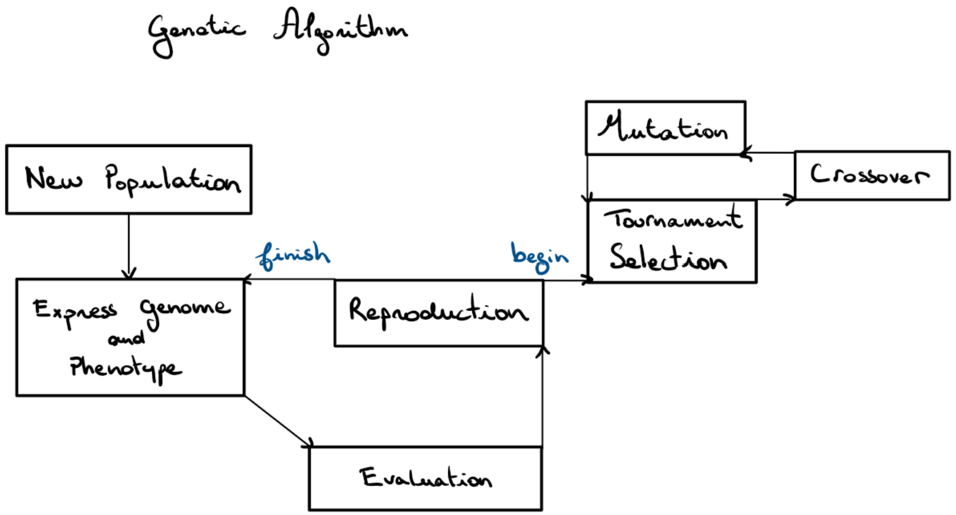


Fig 15. Genetic Algotithm for the diploid individuals

Method – Developmental plasticity, Crossover

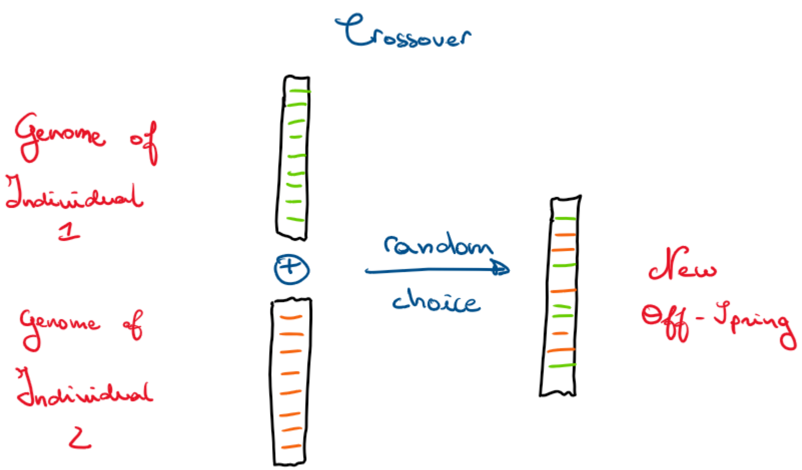


Fig 16. Crossover for the haploid individuals

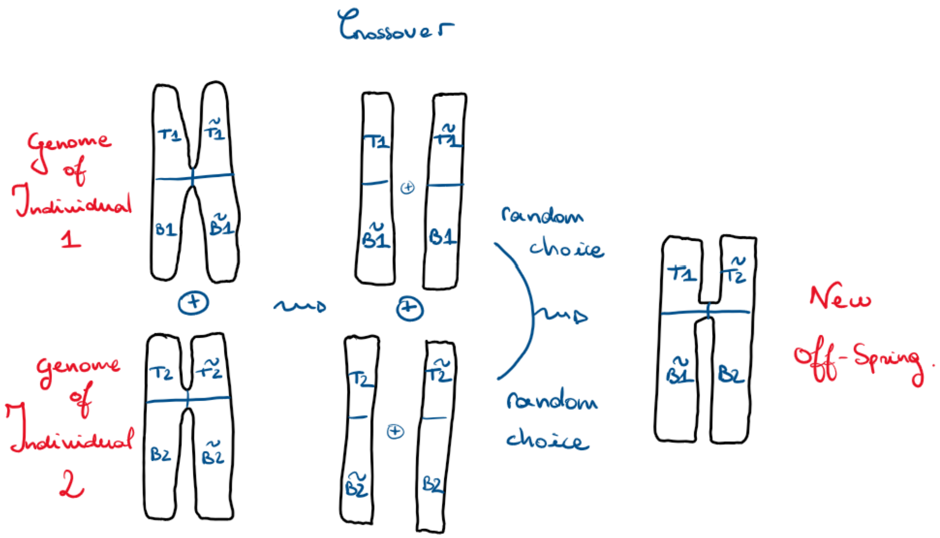


Fig 17. Crossover for the diploid individuals

Method – Developmental plasticity, Mutation

- Mutation = Gaussian noise (mean 0, std sigma) added to a gene's value
- Each type of genetic information has its own sigma : weights, biases, dominance
- sigma is the same whether the gene is on the dominant or the recessive node
- A gene mutates only if a random draw (uniform in [0,1]) falls below its own threshold
- Each type of gene also has its own threshold
- Weights and biases : noise added directly to the current value
- Dominance : same process, but values kept in [0,1] : any excess is reflected back inside (0.96 + 0.1 ⍰ 0.94)
- Activation function: replaced by a new one drawn from {tanh, gauss, sin}

Method – Chromosome-Level Plasticity, Environment Signal

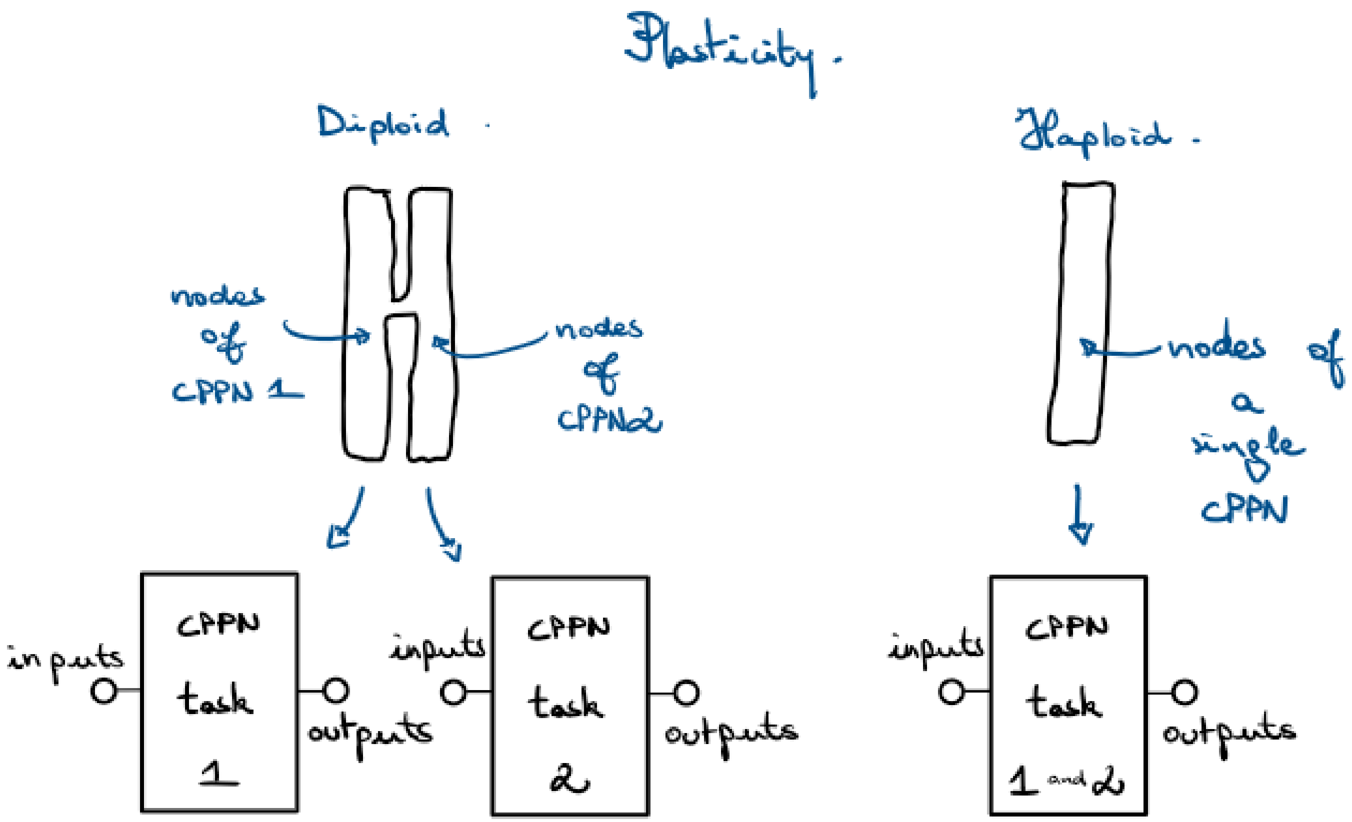


Fig 18. Chromosome-Level Plasticity

Method – Chromosome-Level Plasticity, Crossover

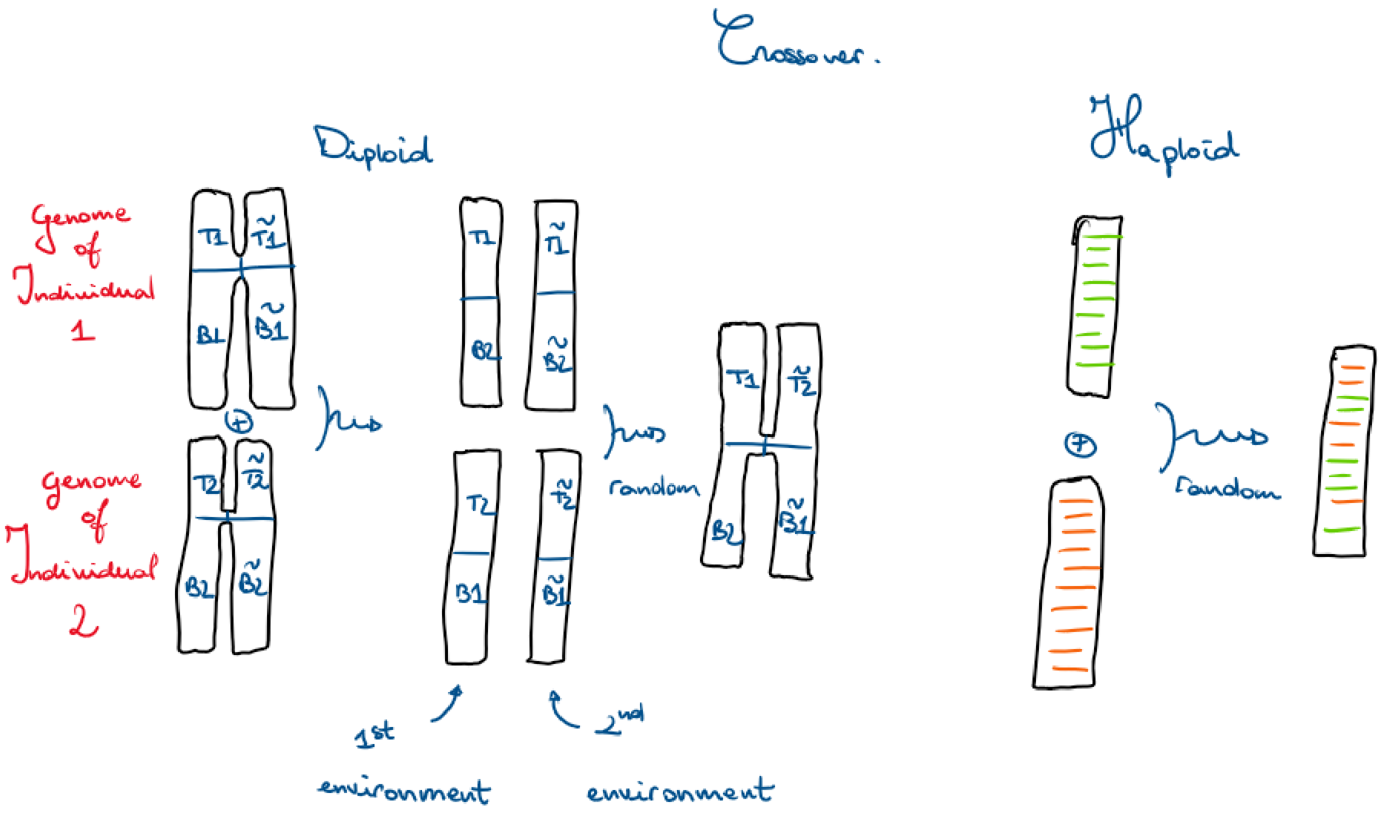


Fig 19. Crossover used for the Chromosome-Level Plasticity

Parameters

Parameter	**Value**
Evolution	
Population size	128
Number of generations	600
Environment switch	every 20 generations
Independent runs	5
Tournament size	2
Winners per tournament	1
Elites kept per generation	1
Reported individuals	40
Genome	
Activation function pool	gaussian, sin, tanh
Initialisation range, weights	$[-1, 1]$
Initialisation range, biases	$[-1, 1]$
Bound on the weights	$[-20, 20]$
Bound on the biases	$[-20, 20]$
Mutation	
Threshold, weights	0.03
Threshold, biases	0.01
Threshold, activation functions	0.01
Threshold, dominance	0.07
σ, weights	0.1
σ, biases	0.1
σ, dominance	0.1
Evaluation	
Episode length, Thrower-v0	300 time steps
Episode length, Pusher-v0	1000 time steps
Episode length, Walker-v0	500 time steps

Results – Organization

- Developmental Phenotypic Plasticity
- Chromosome Level Phenotypic Plasticity

Results – Developmental plasticity, Pusher and Walker

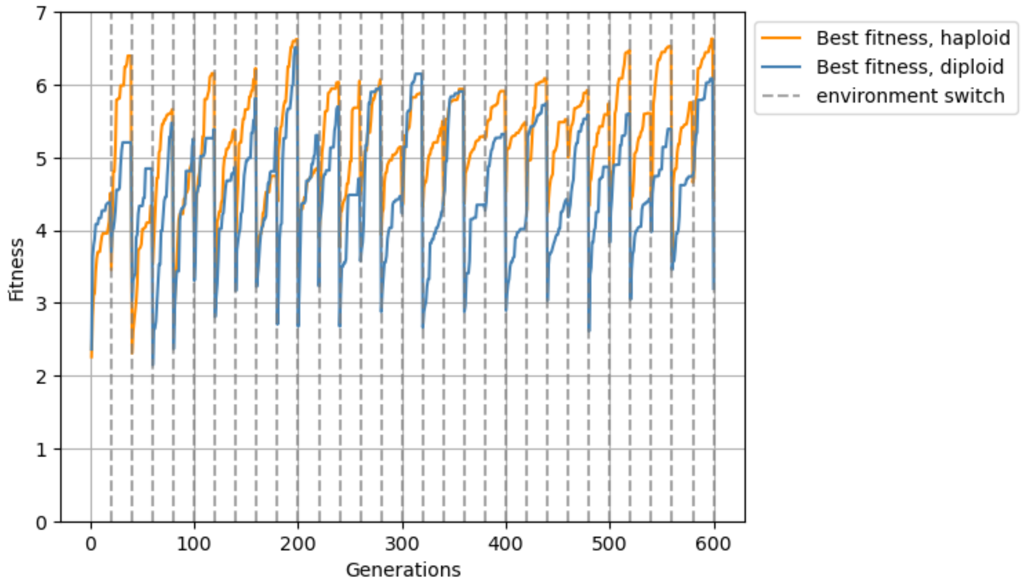


Fig 20. Average best fitness on 5 runs

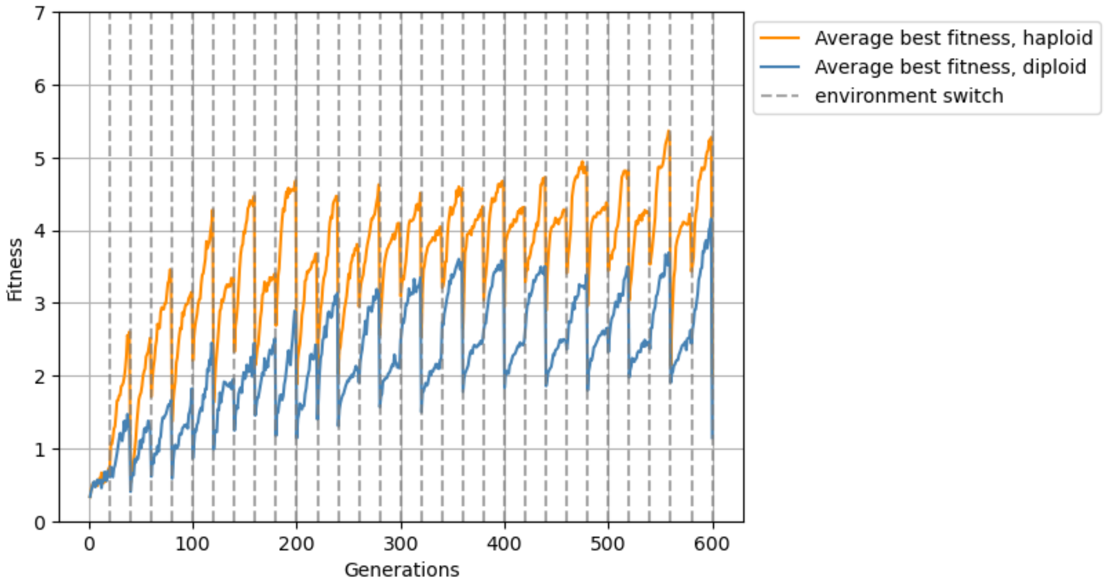


Fig 21. Average of the average of the 40 best fitness on 5 runs

Results – Developmental plasticity, Pusher and Walker

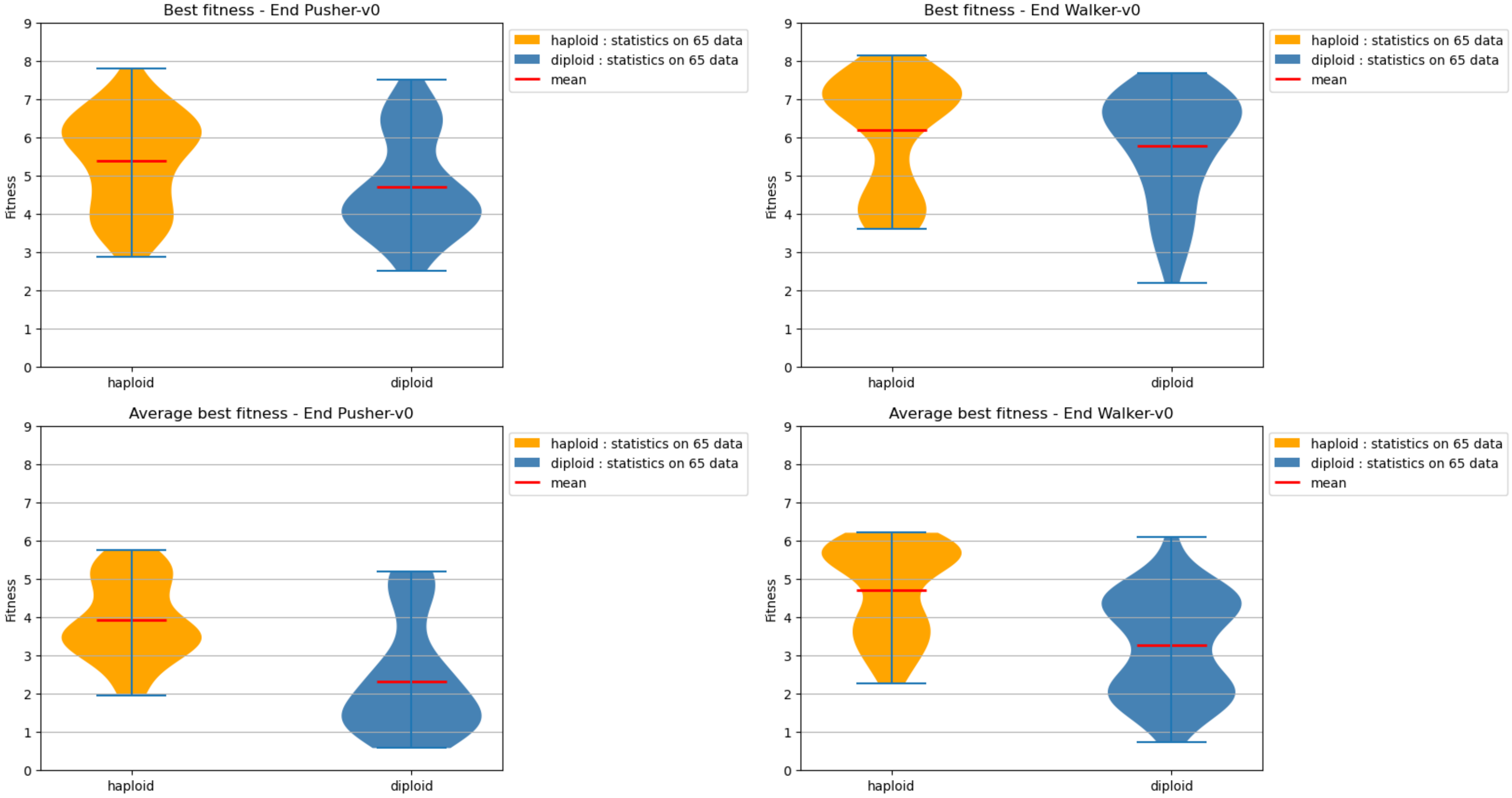


Fig 22. Violin plot of the fitness at the end of each environment

Results – Developmental plasticity, Pusher and Walker

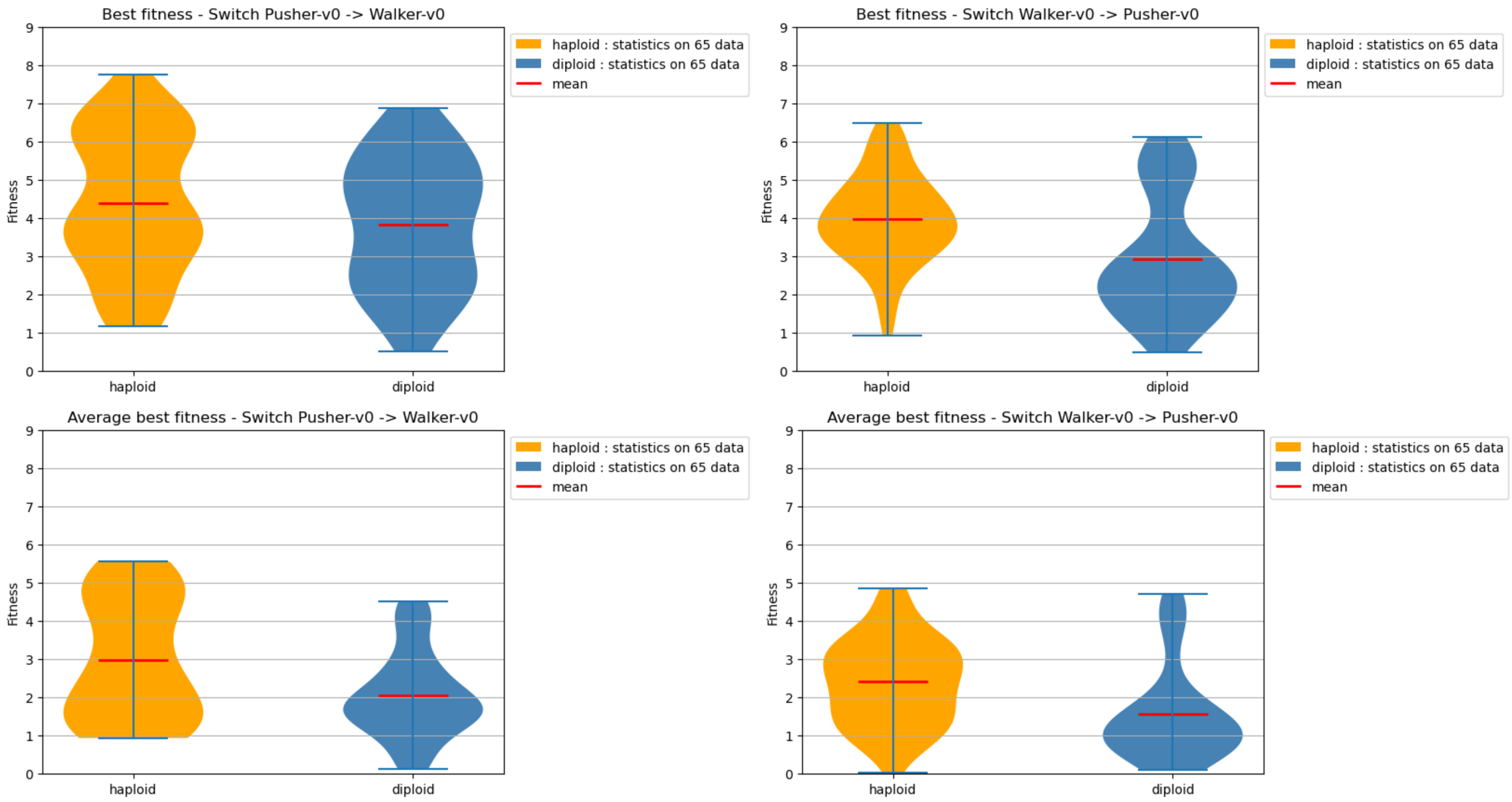


Fig 23. Violin plot of the fitness at the begining of each environment

Results – Developmental plasticity, Pusher and Walker

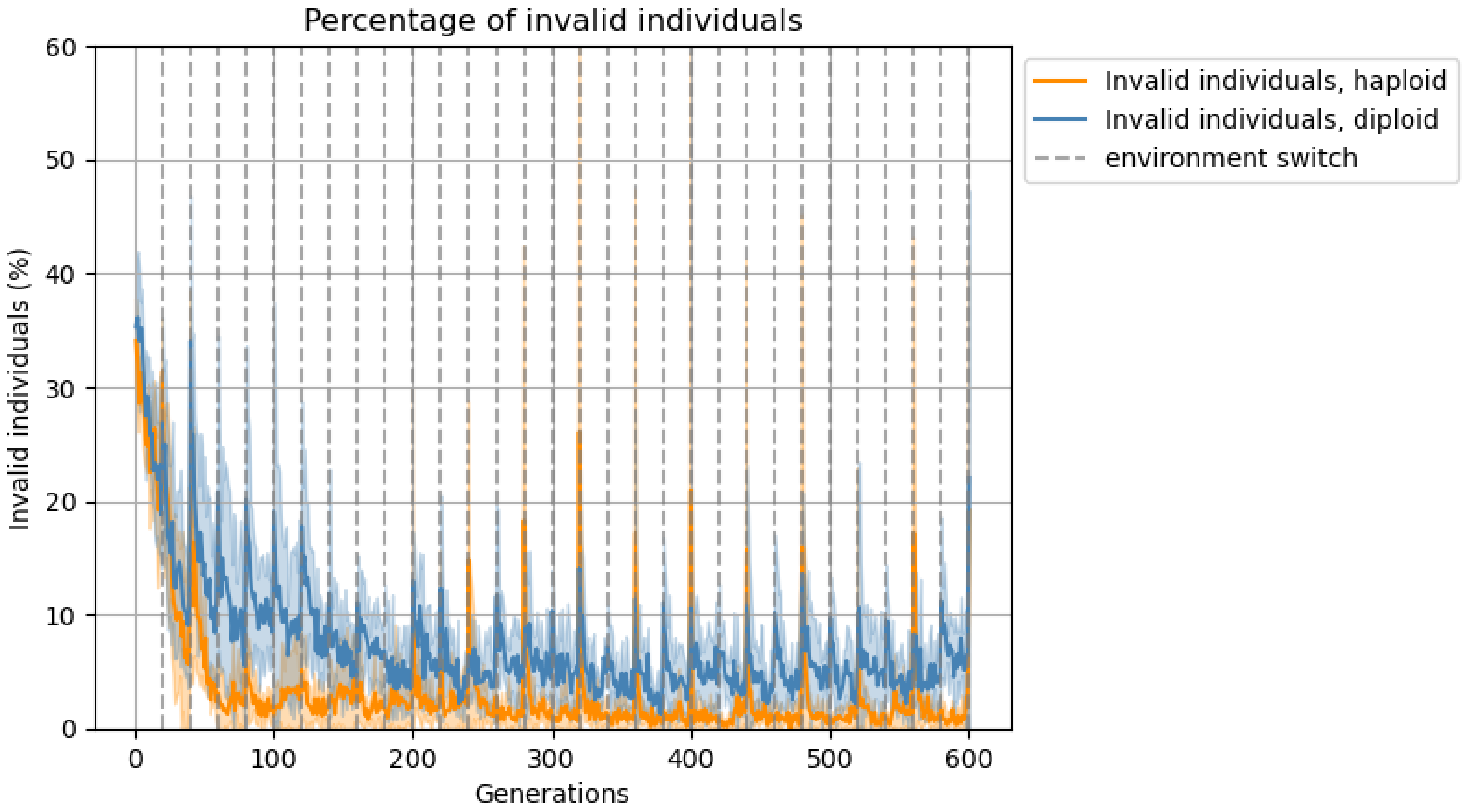


Fig 24. Evolution of the percentage of invalid individuals accross generations

Results – Developmental plasticity, Pusher and Walker

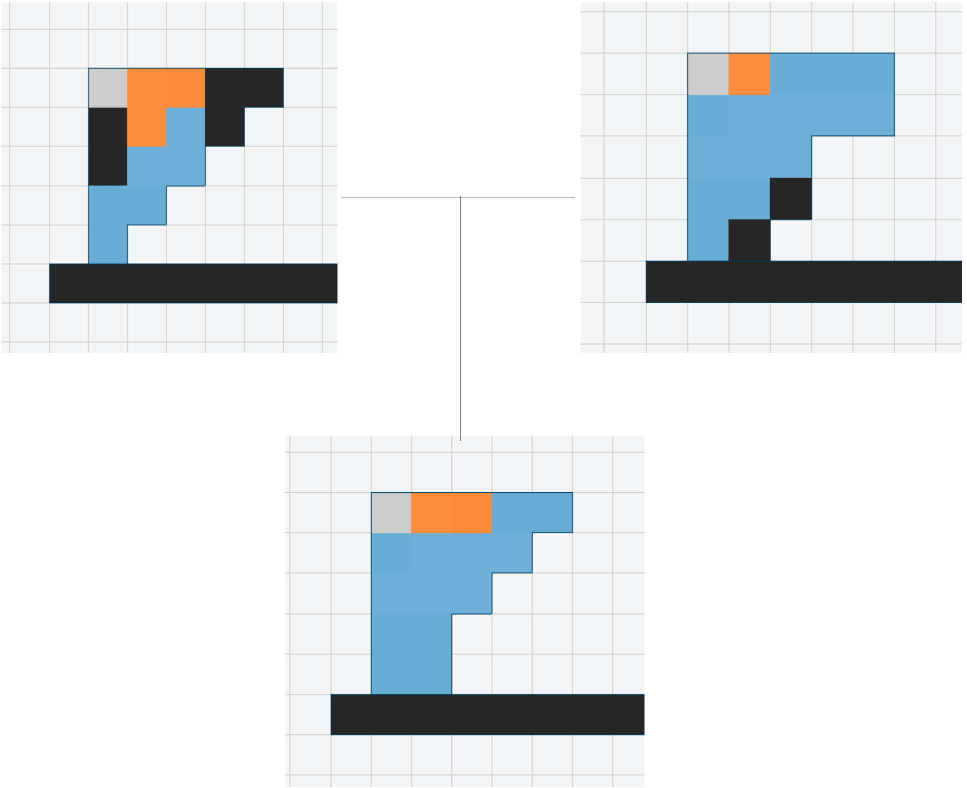


Fig 25. Example of a haploid family on the pusher environment

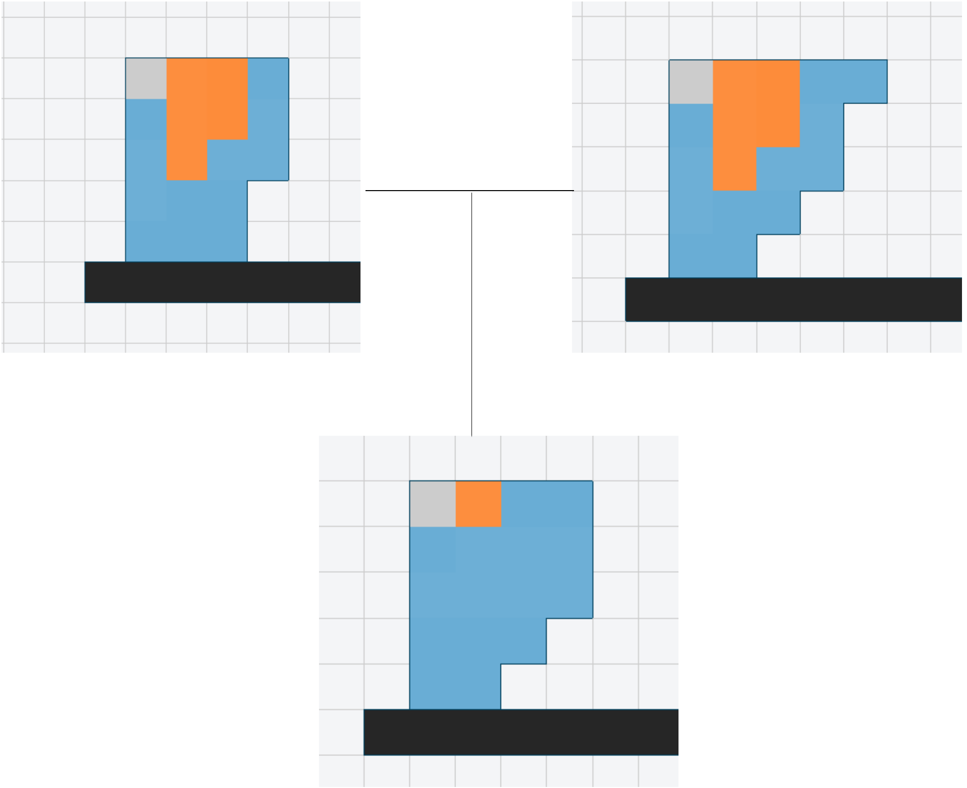
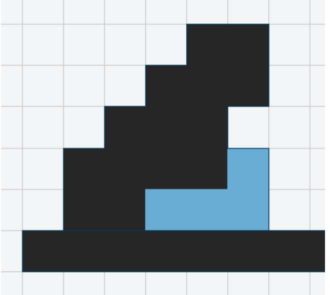
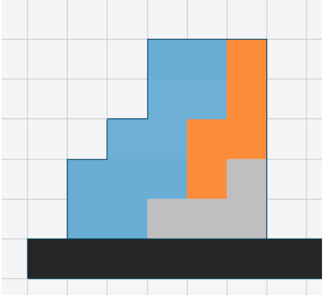


Fig 26. Example of a diploid family on the walker environment

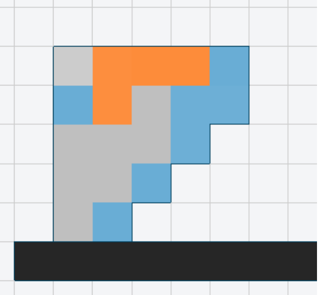
Results – Developmental plasticity, Pusher and Walker



(Haploid) Body created by the Body ANN with a positive bias on Pusher-v0 right after the switch



(Haploid) Body created with the same Body ANN with a negative bias on Walker-v0



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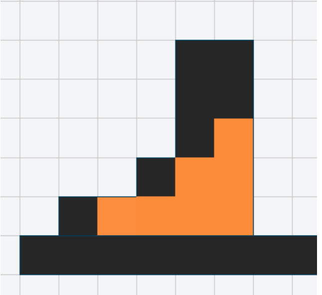

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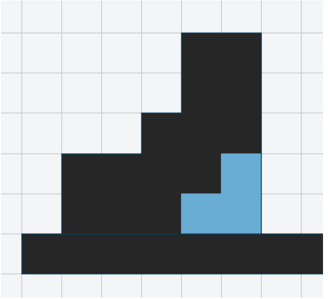
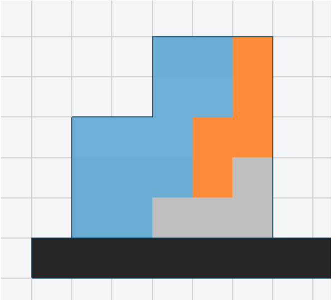
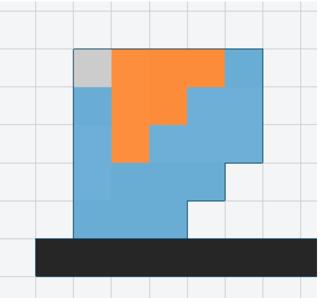


(Haploid) Typical body of Pusher-v0 before the episode of Walker-v0



(Haploid) Typical body on Walker-v0 before the switch



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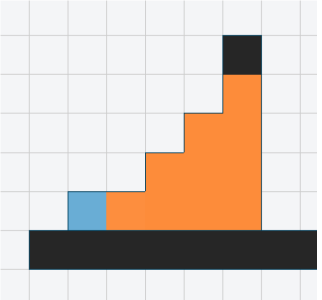


(Diploid) Typical body on Pusher-v0 before the switch

Fig 27. deep study of the effect of the encoding

Results – Developmental plasticity, Pusher and Walker

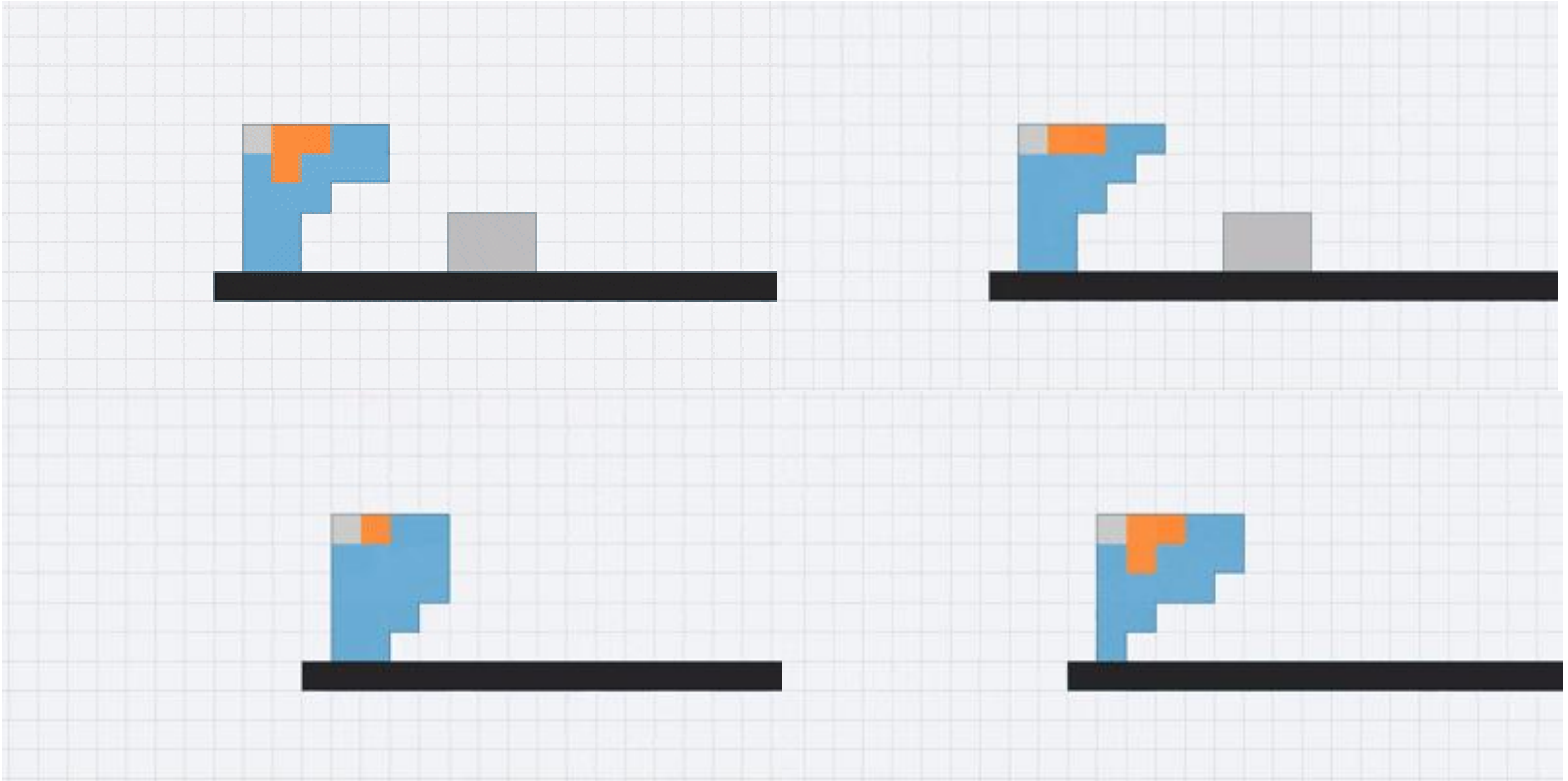


Fig 28. Diploid (right) and Haploid (left) robots evolved

Results – Chromosome-Level Plasticity, Pusher and Walker

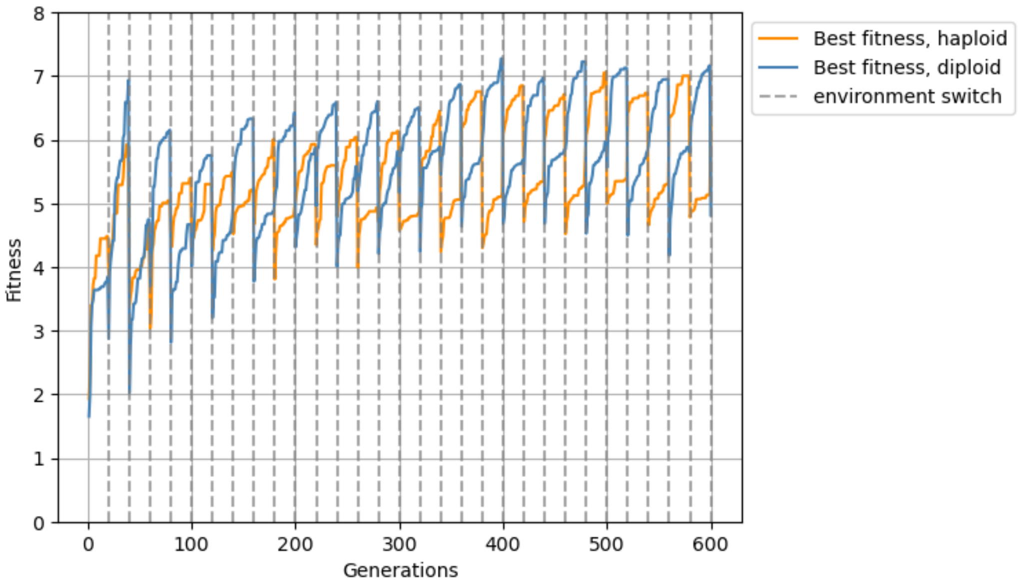


Fig 29. Average best fitness on 5 runs

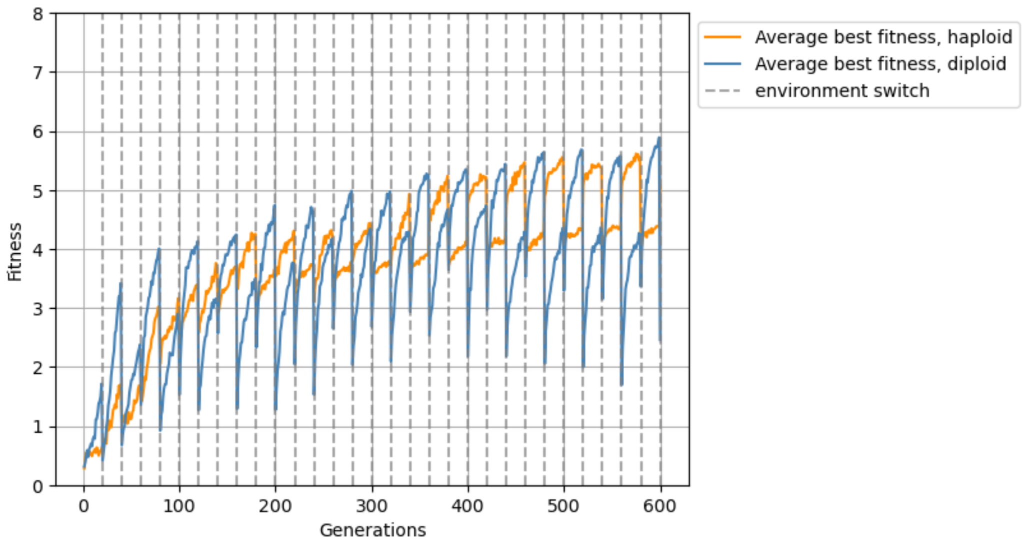


Fig 30. Average of the average of the 40 best fitness on 5 runs

Results – Chromosome-Level Plasticity, Pusher and Walker

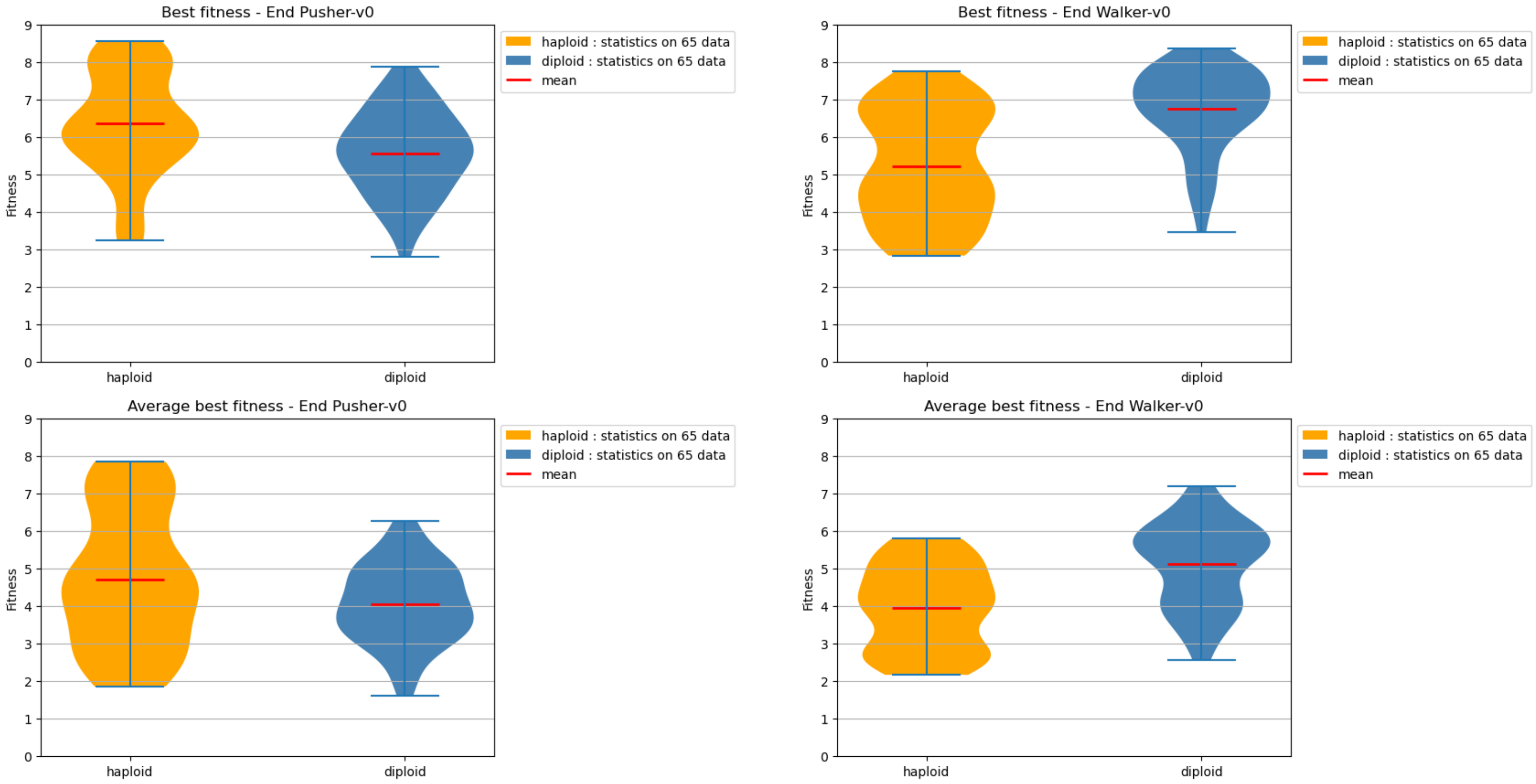


Fig 31. Violin plot of the fitness at the end of each environment

Results – Chromosome-Level Plasticity, Pusher and Walker

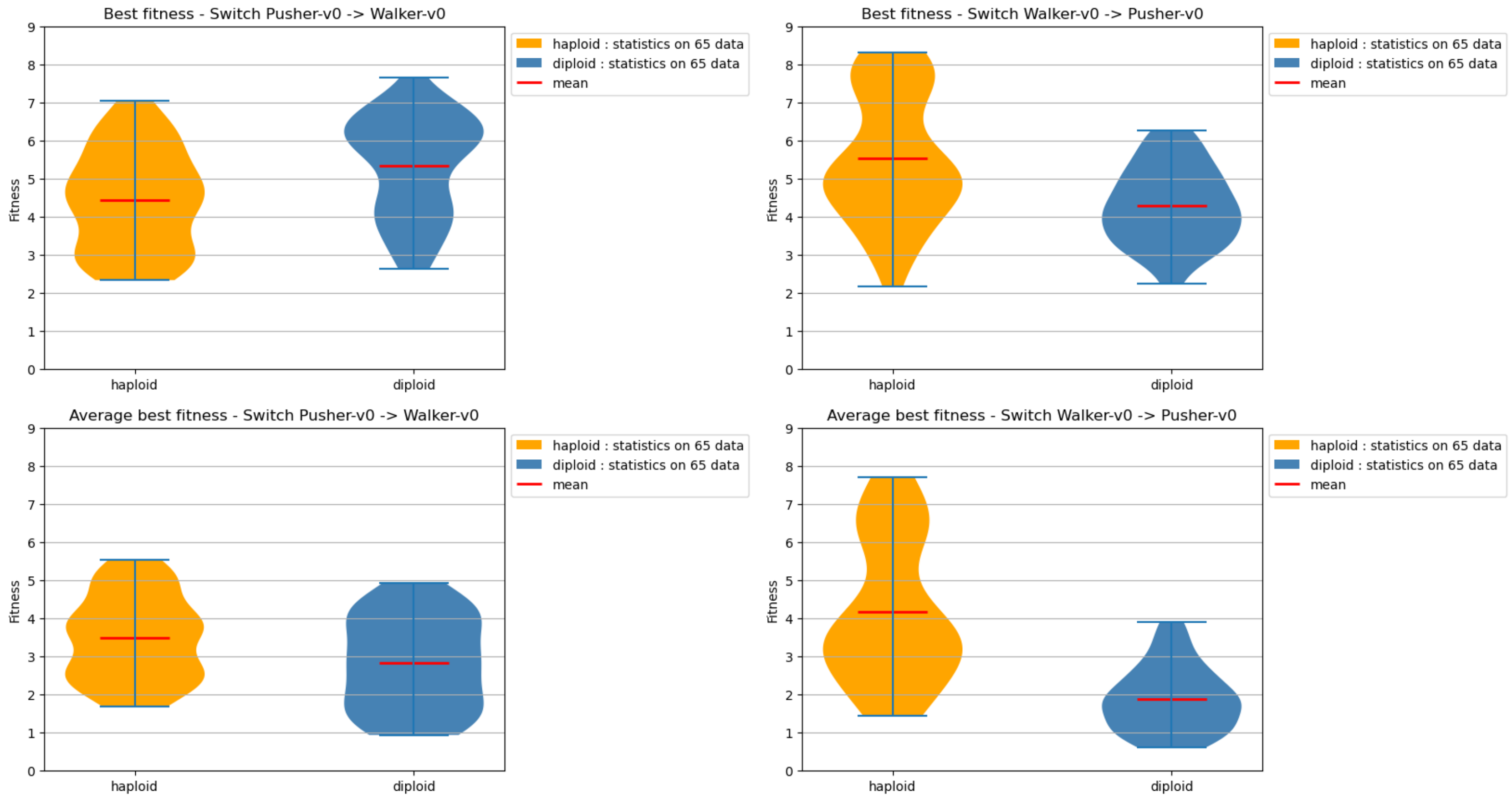
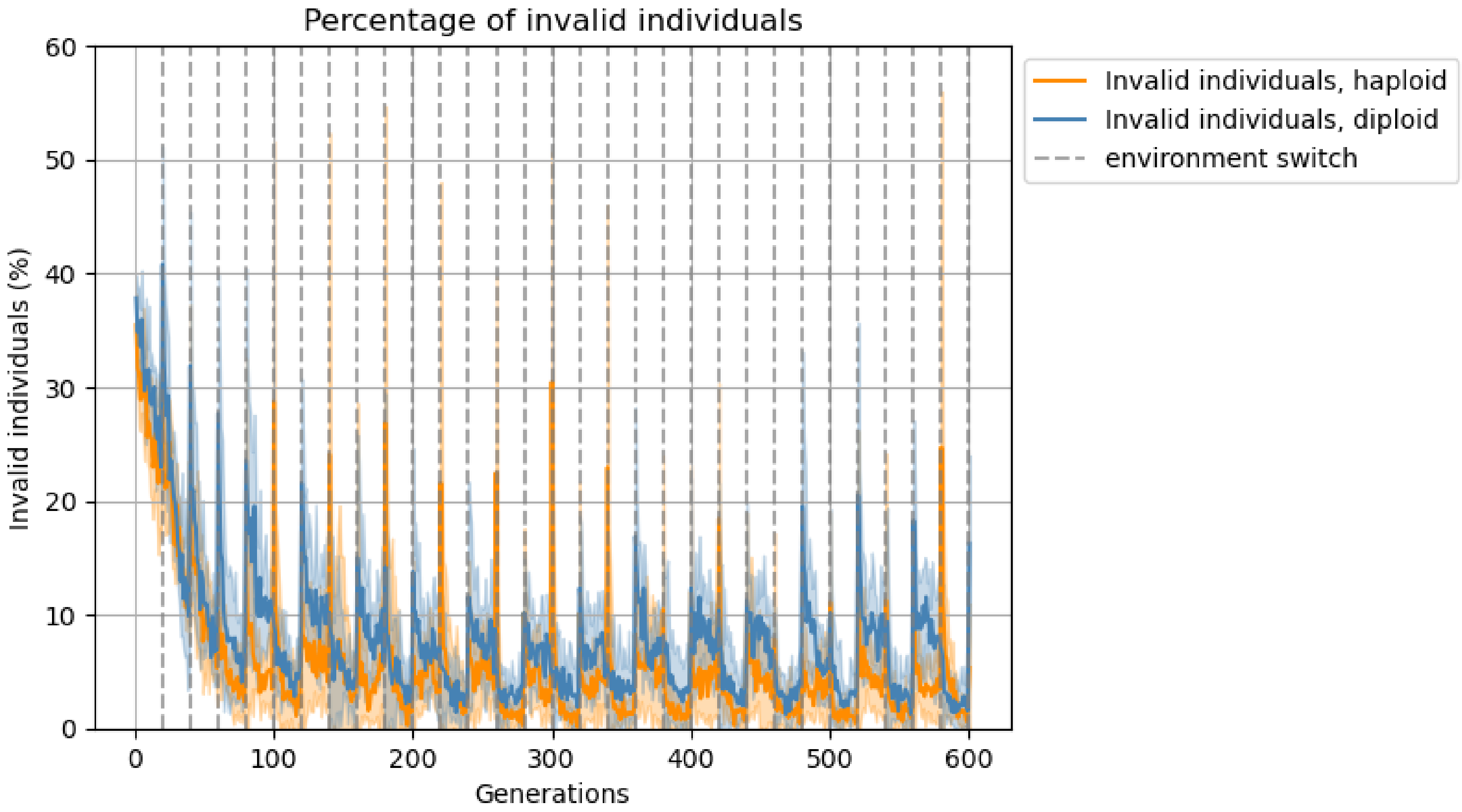


Fig 32. Violin plot of the fitness at the begining of each environment

Results – Chromosome-Level Plasticity, Pusher and Walker



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Results – Chromosome-Level Plasticity, Pusher and Walker

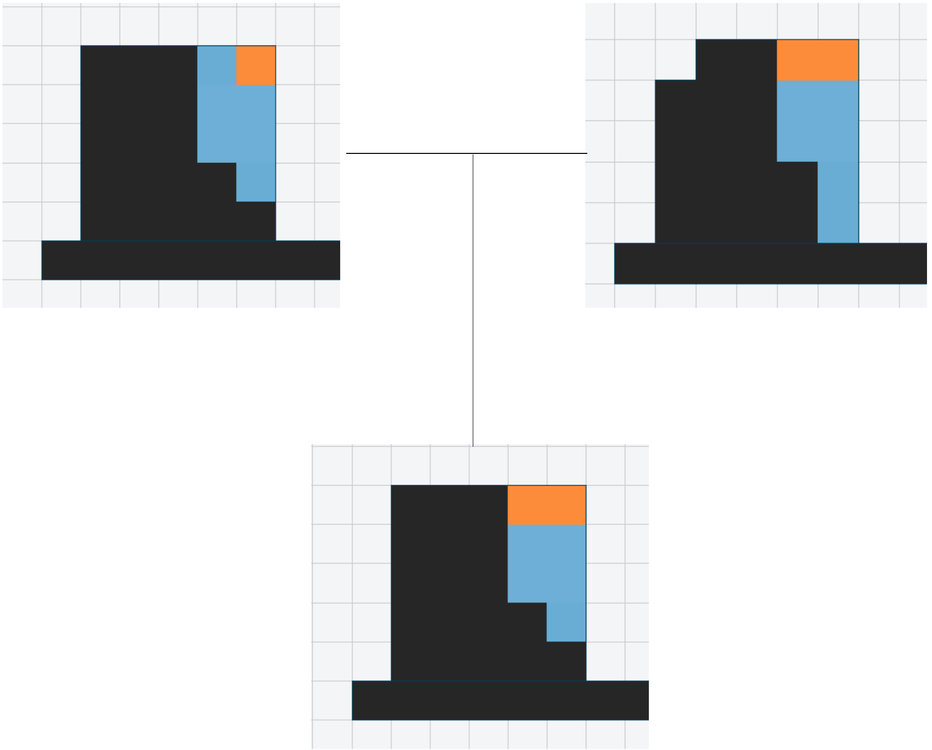


Fig 34. Example of a haploid family on the pusher environment

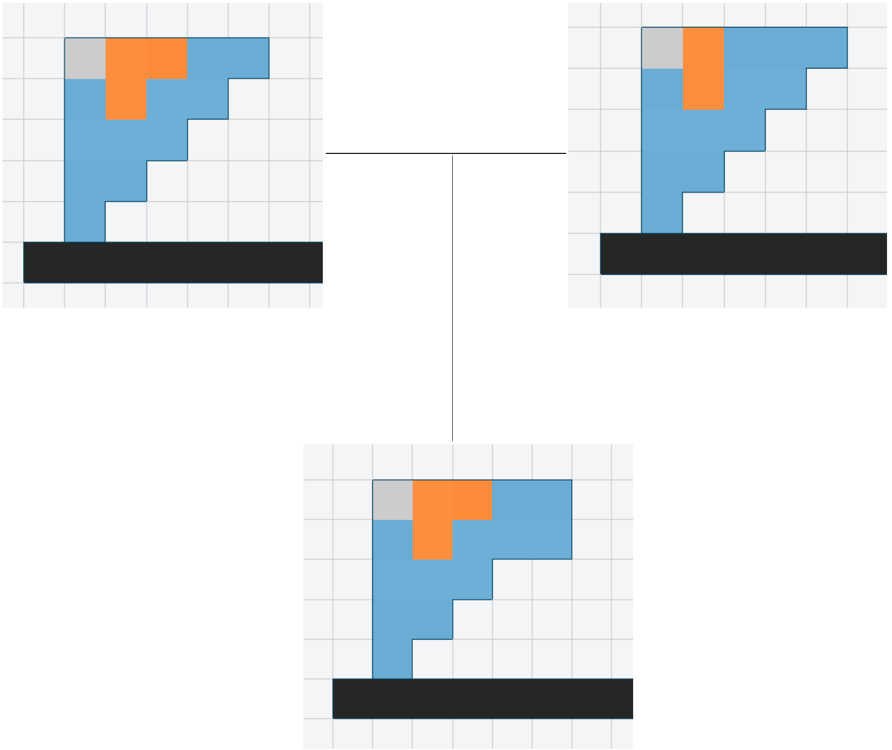
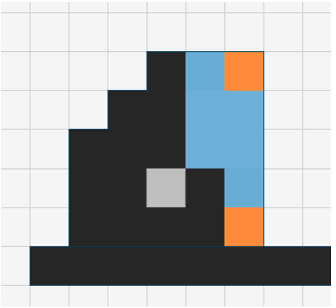


Fig 35. Example of a diploid family on the walker environment

Results – Chromosome-Level Plasticity, Pusher and Walker



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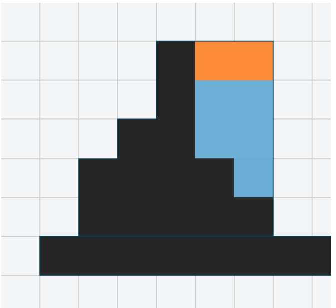
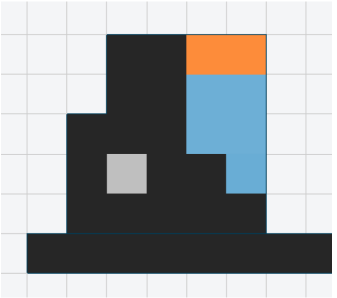
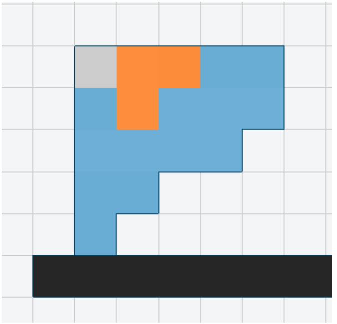


(Haploid) Typical body of Pusher-v0 before the episode of Walker-v0



(Haploid) Typical body on Walker-v0 before the switch



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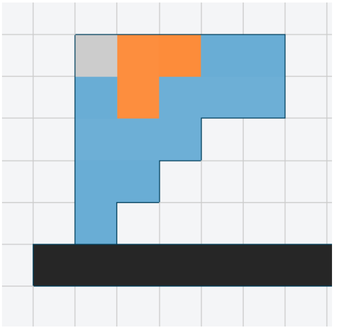

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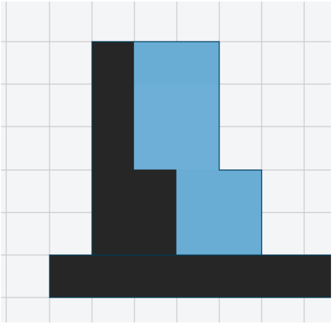

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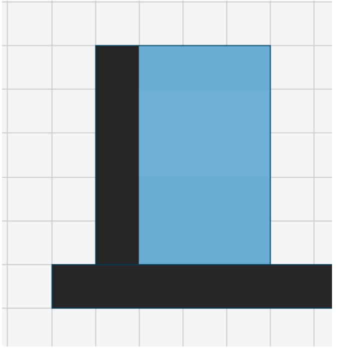

(Diploid) Typical body on Pusher-v0 before the switch

Fig 36. deep study of the effect of the encoding

Results – Chromosome-Level Plasticity, Pusher and Walker

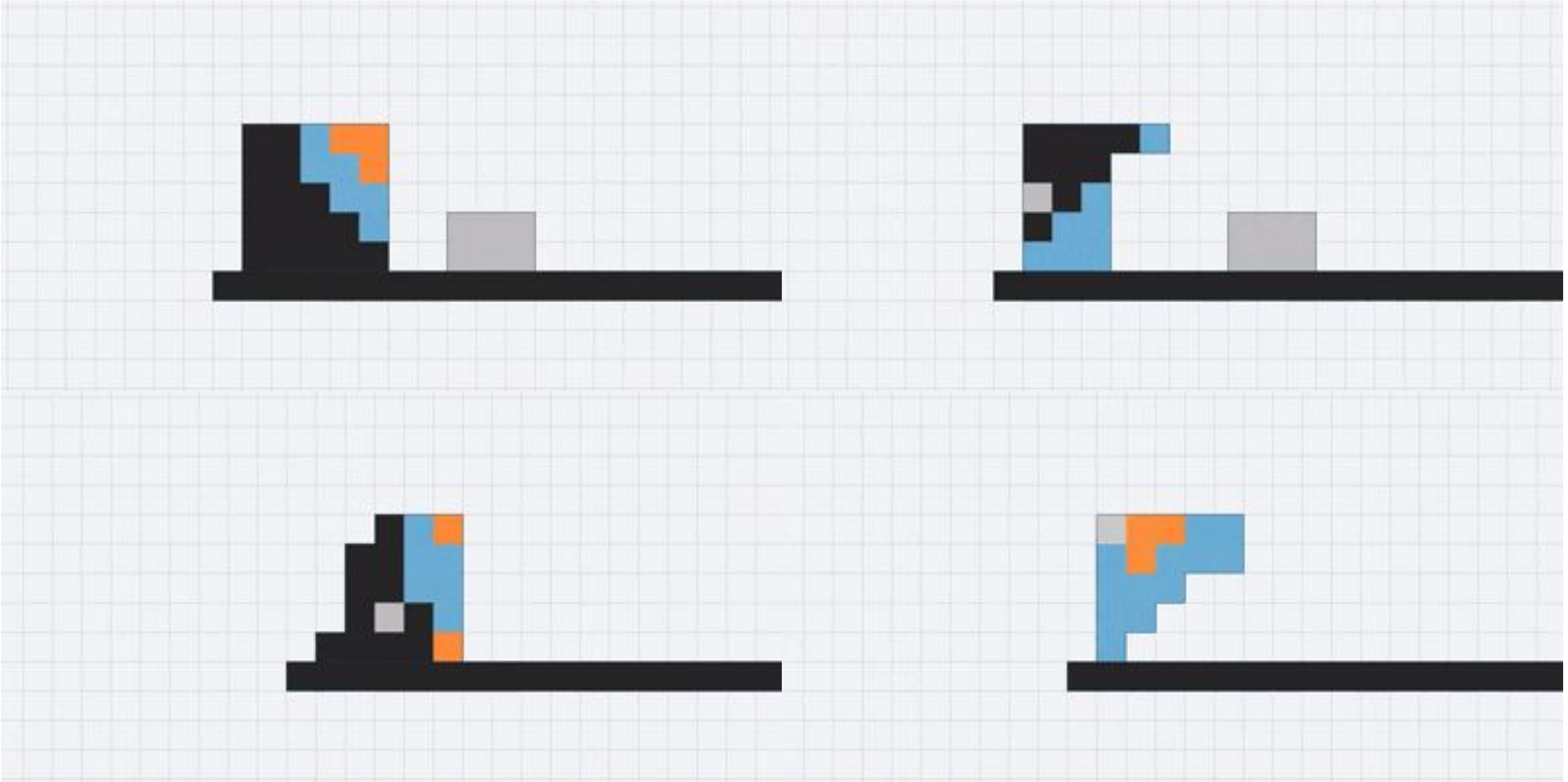

Fig 37. Diploid (right) and Haploid (left) robots evolved

Conclusion

- Haploid Developmental Plasticity and Diploid Chromosome-Level Plasticity yields similar results

- Thanks to the developmental plasticity the genome can be even more compressed without sacrificing the results on multiple environments

- Diploidy creates noise, this noise is disturbing the efficiency of the indirect-encoding with Developmental Phenotypic Plasticity but is highly beneficial for the Chromosome-Level Plasticity