ETH zürich

On the origin of creatures
The evolution of virtual creatures in a rigid-body engine

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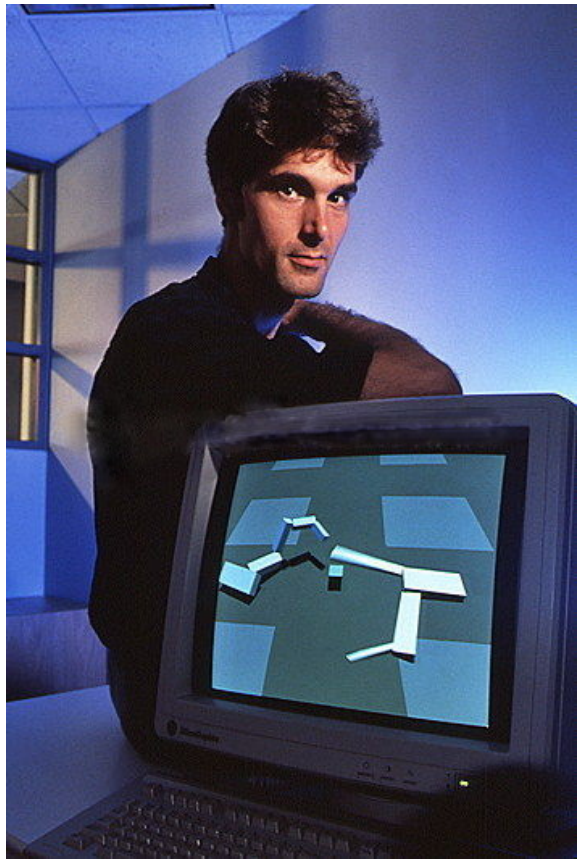
INI: Institute of Neuroinformatics

Contents

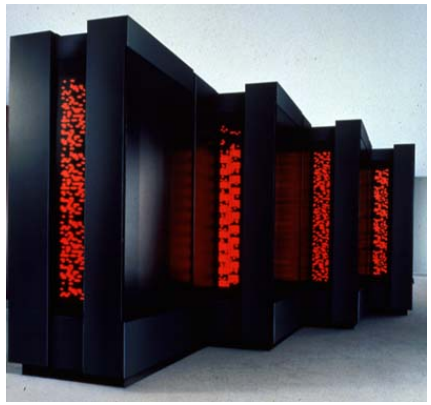
Karl Sims



- Computer artist and researcher from MIT Media Lab in the 1990s
- Wrote landmark papers on virtual creatures and artificial evolution

- Panspermia, 1990, Animation depicting a life cycle of an inter-galactic botanical life form.
- Evolved Virtual Creatures, 1994, Demonstration of research results show simulated block creatures performing various evolved behaviors.

Evolved Virtual Creatures



- Simulations were created on the IBM CM-5 (1024 cores, 32 GFlops/s)
- The creatures were evolved to display multiple modes of water and land based movements
- The creatures were also co-evolved in different species to compete for possession of a virtual cube, displaying the red queen effect.

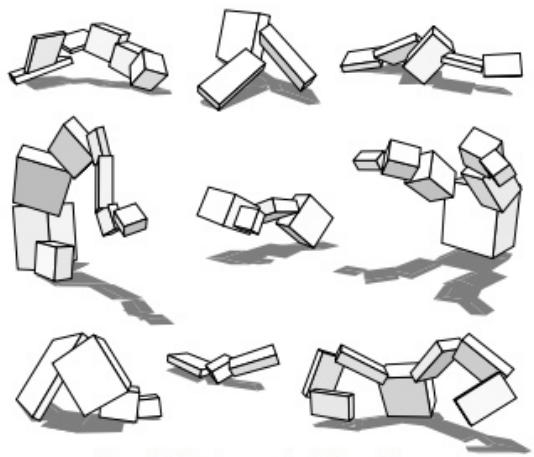


Figure 7: Creatures evolved for walking.

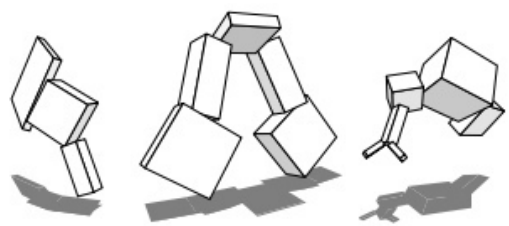
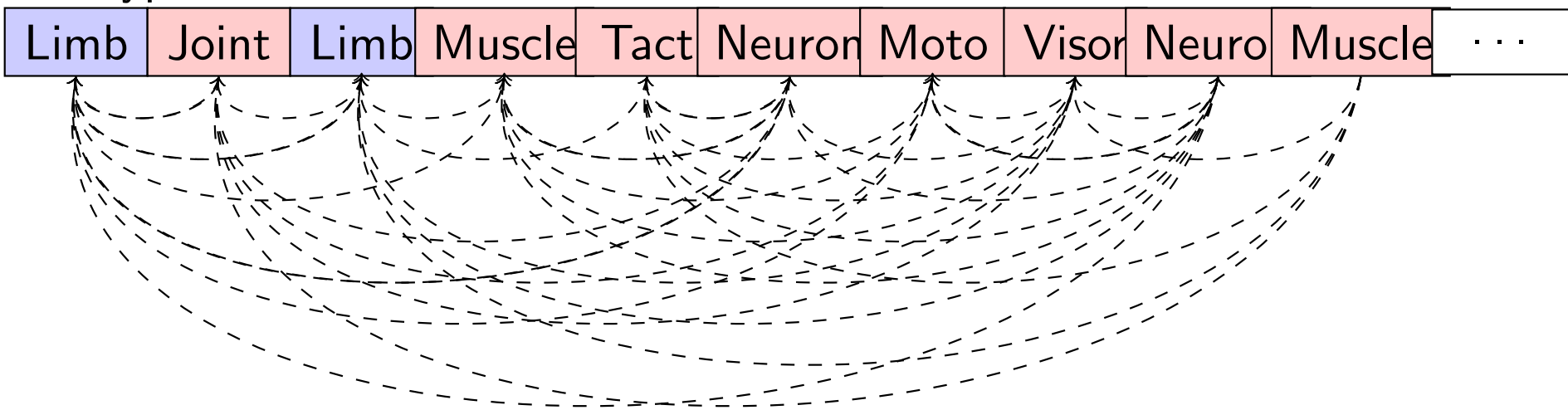


Figure 8: Creatures evolved for jumping.

Contents

Genetic language

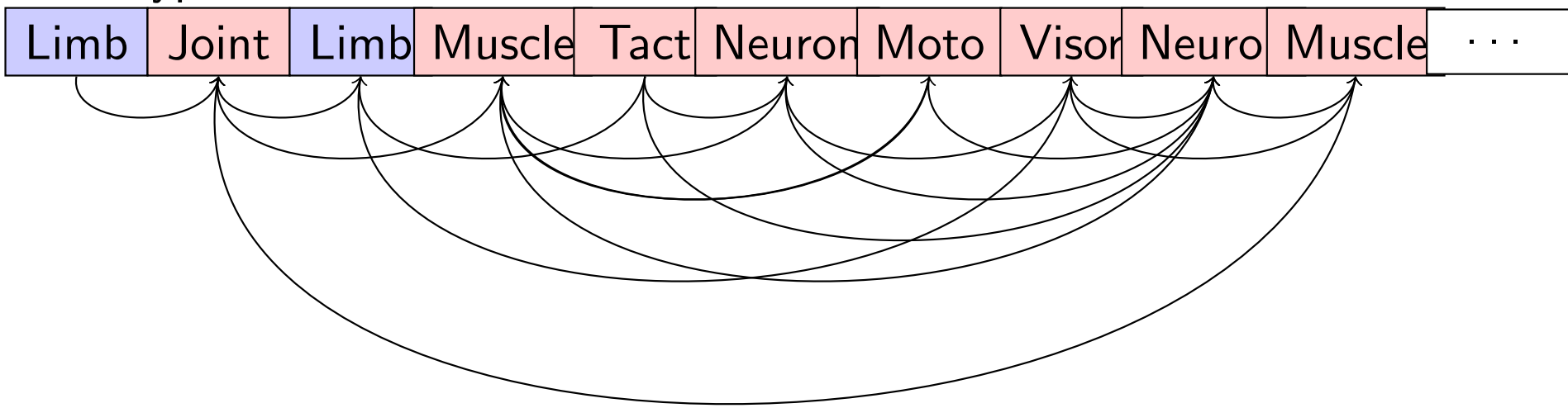
Genotype:



- **Limb** Part of creature body
- **Joint** Generic joint
- **Muscle** Muscle of Joint
- **Tact** Tactile Sensor
- **Moto** Motorceptor (Force)
- **Visor** Light sensor

Genetic language

Phenotype:



- **Limb** Part of creature body
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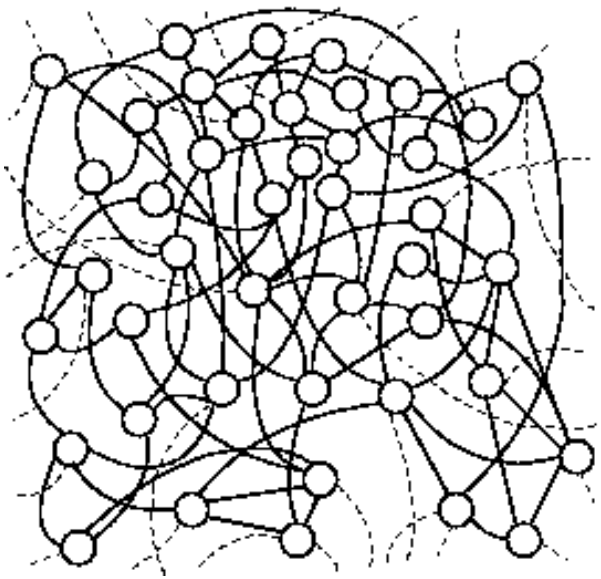
Neuronal network

Each neuron has a transfer function, which is one of:

- min
- max
- sum
- sum-theshold
- product
- abs
- sign-of
- greater-than
- exp
- log
- sin
- cos
- oscillate-wave
- oscillate-saw



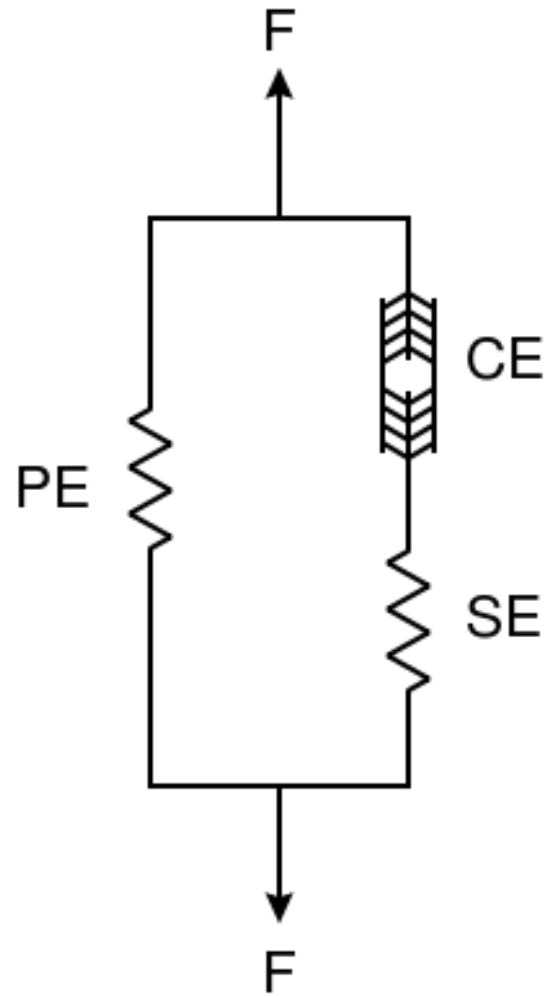
Oja's rule

- Finnish computer scientist Erkki Oja
- x is the input
- $y(x)$ is the output
- $w_i(n+1)$ is the new weight
- For $p = 2$, we have the root sum of squares (Cartesian normalization rule)
- Stabilized rule of Hebb's learning rule $\Delta w_i = \eta x_i y$

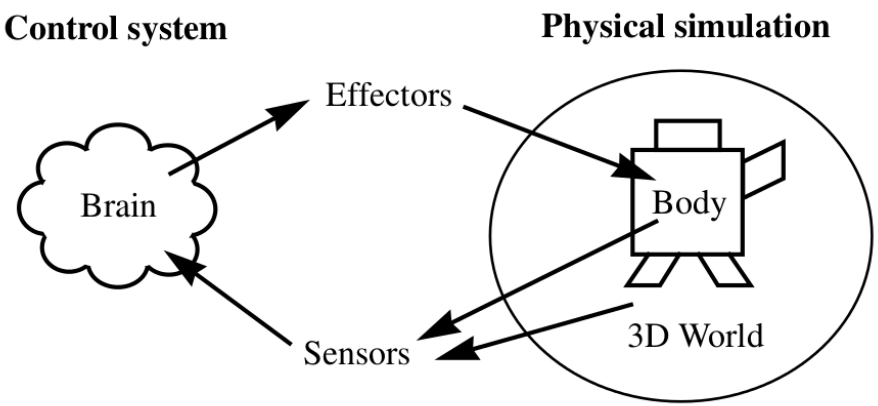
$$w_i(n+1) = \frac{w_i + \eta\, y(\mathbf{x}) x_i}{\left(\sum_{j=1}^{m} [w_j + \eta\, y(\mathbf{x}) x_j]^p\right)^{1/p}}$$

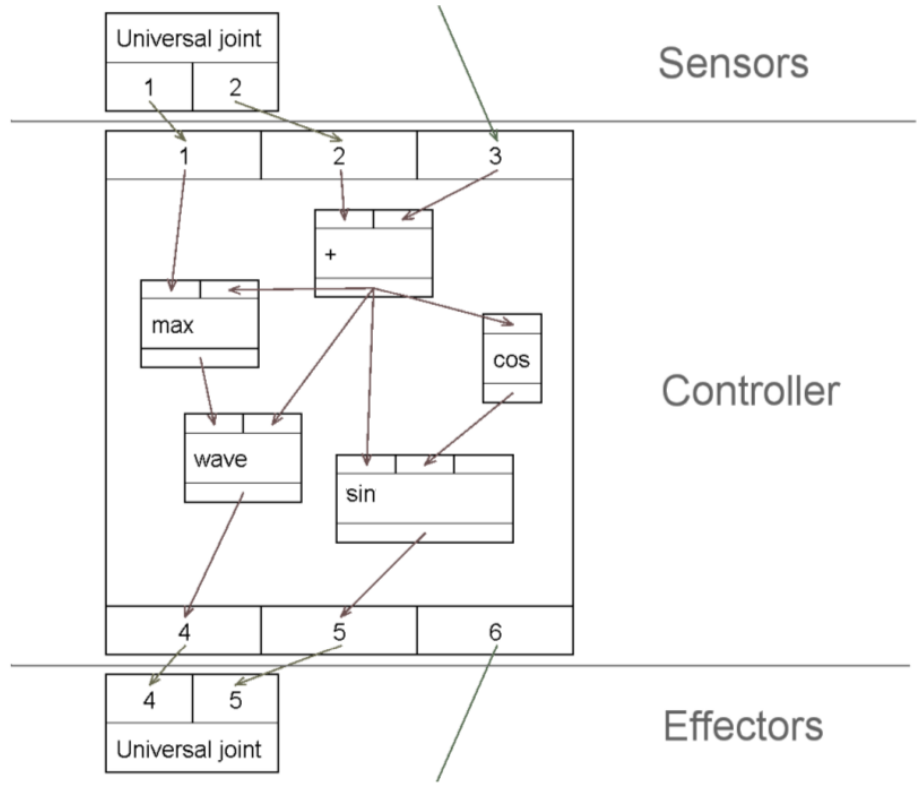
Hill's muscle model

- Physiologist Archibald Vivian Hill
- Equation of tetanized muscle contraction
- $(v + b)(F + a) = b(F_0 + a)$
  - F is the tension (or load) in the muscle
  - v is the velocity of contraction
  - F_0 is the maximum isometric tension (or load) generated in the muscle
  - a coefficient of shortening heat
  - $b = a \cdot v_0 / F_0$
  - v_0 is the maximum velocity, when $F = 0$



Execution of creatures





Fitness evaluation

- Fitness evaluation framework
- A creature is simulated for a certain evaluation time during which the fitness function measures the fitness of the creature
- Evaluates multiple fitness functions at the same time and combines them linearly

Evolution

- Selection
  - Only a certain percentage of creatures are selected for new generation
- Cross-over
  - Only certain percentage of creatures are allowed to breed
- Mutation
  - Other creatures are subject to mutation
  - Mutation of gene
  - Mutation of gene attributes
  - Mutation of gene links
- Successful creatures stay in the population and the population is refilled with new bred and mutated ones

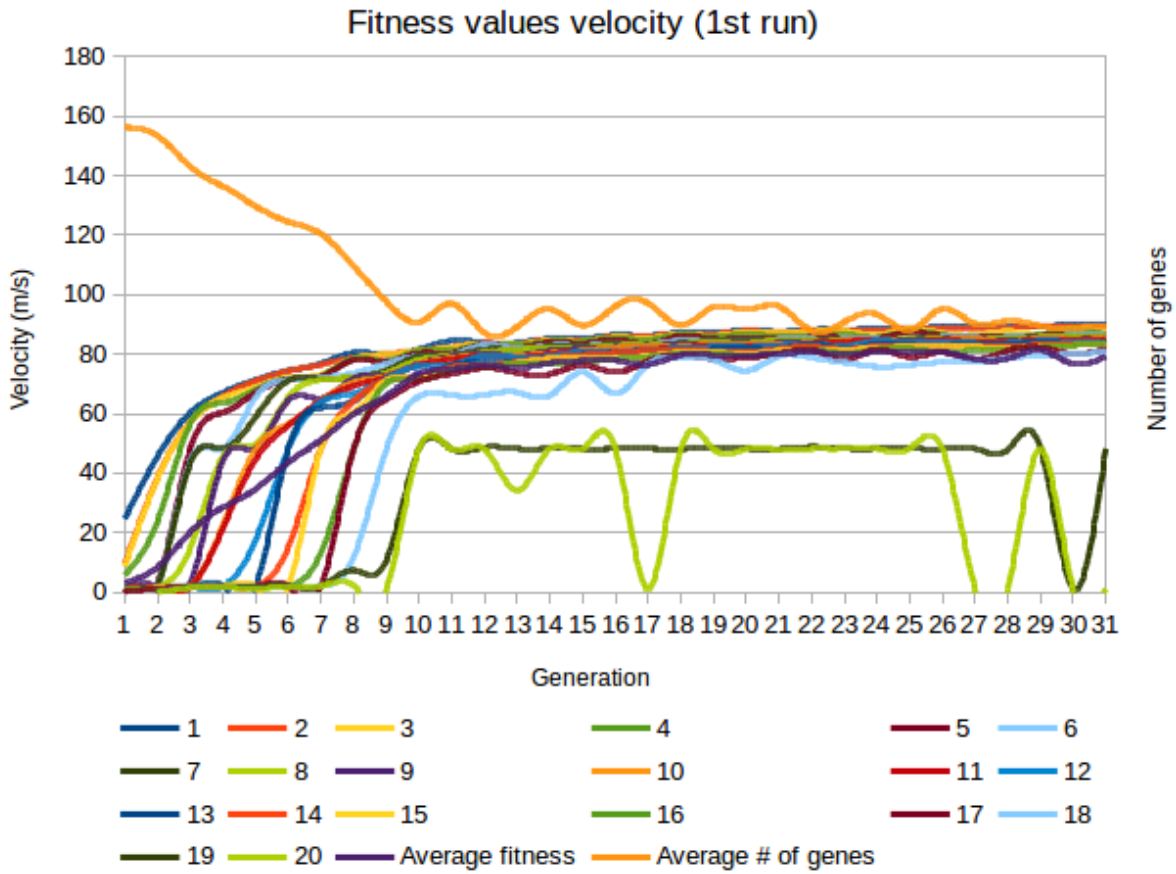
Contents

Velocity as the fitness function

- Sampling of position over time
- Moved distance in a certain time interval
- Continuous average
- Expectations: Some really moving creatures and some finding the exploit that only the main body has to move.
  (main body = first limb in phenotype)

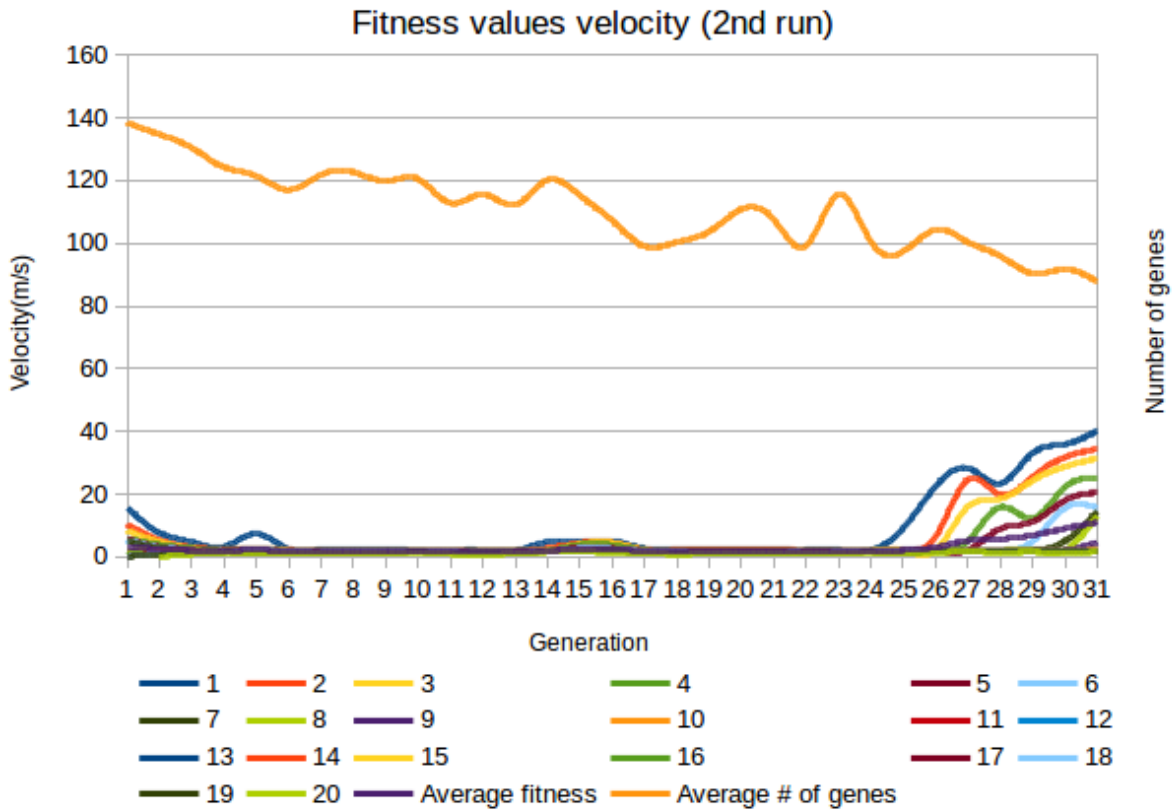
First run

- 20 Individuals
- 30 generations
- Check if they can exploit the fitness function
- Result: There was another exploit in the virtual world!

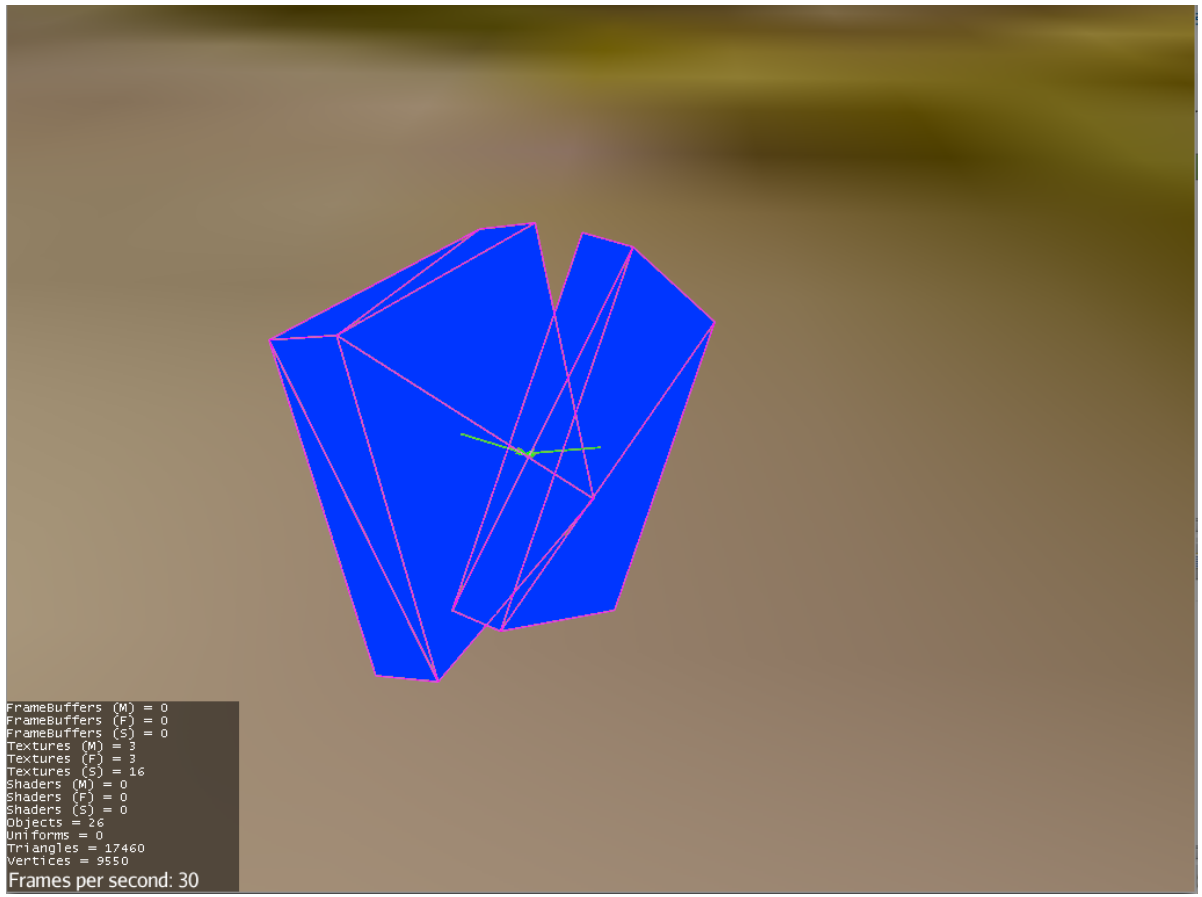


Second run

- 20 Individuals
- 30 generations
- The problem of the previous run is fixed
- Check if they can exploit the fitness function
- Result: They found several exploitation strategies!



Creatures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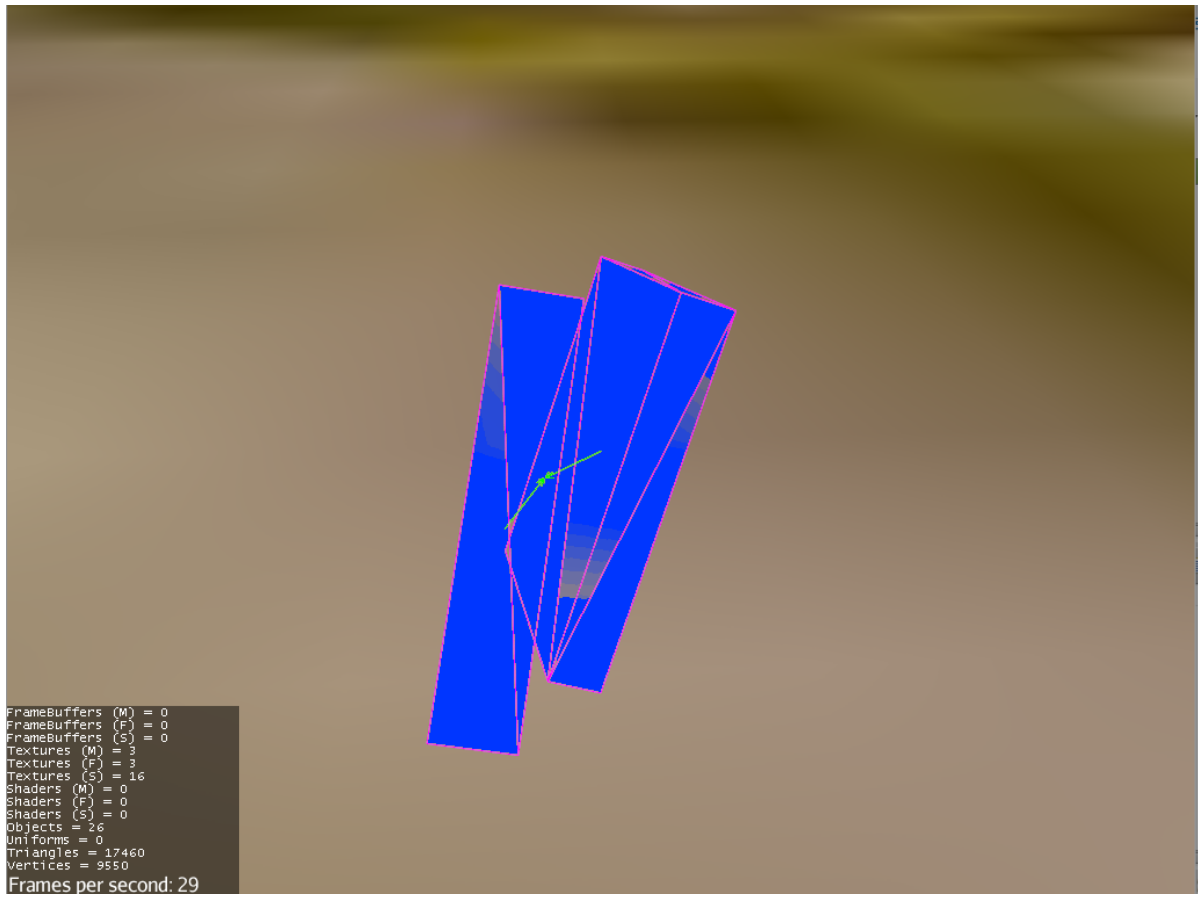
Creatures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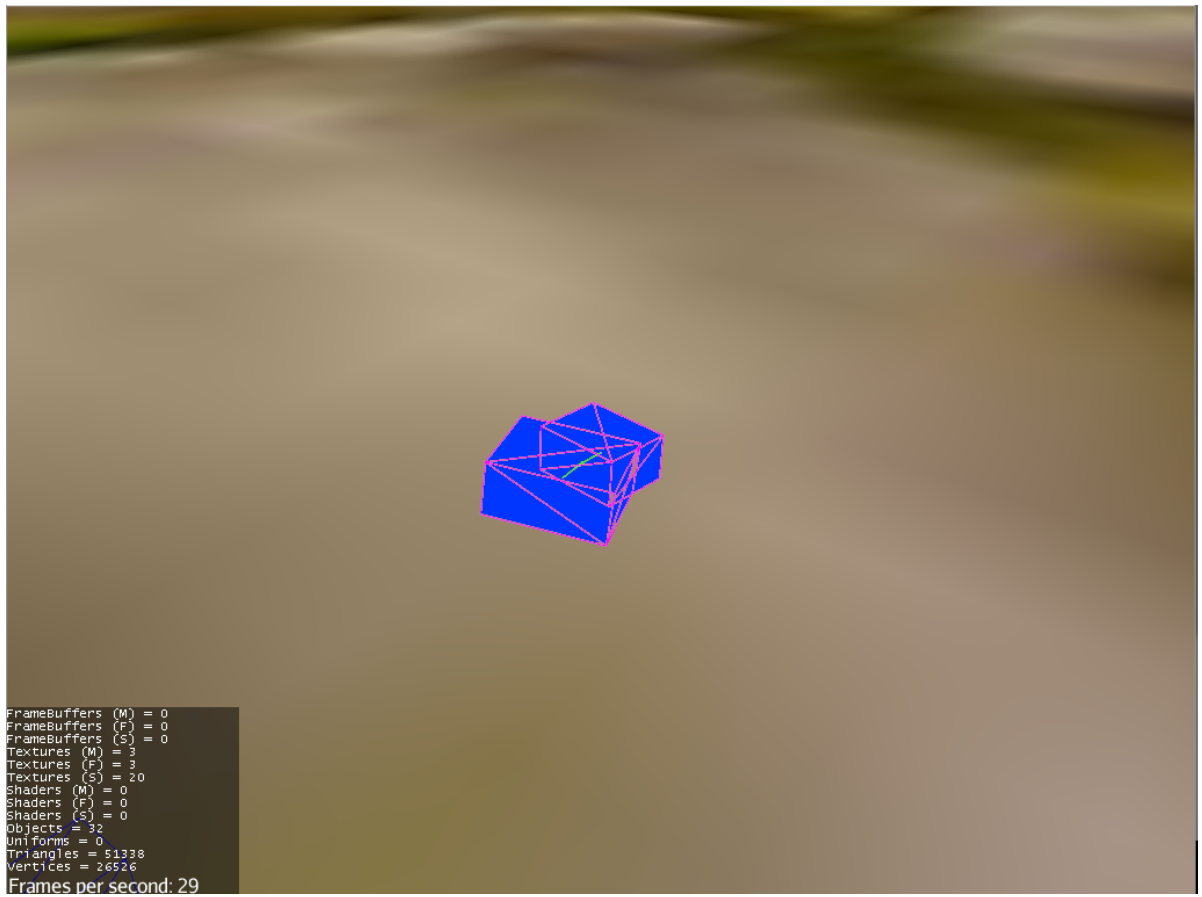
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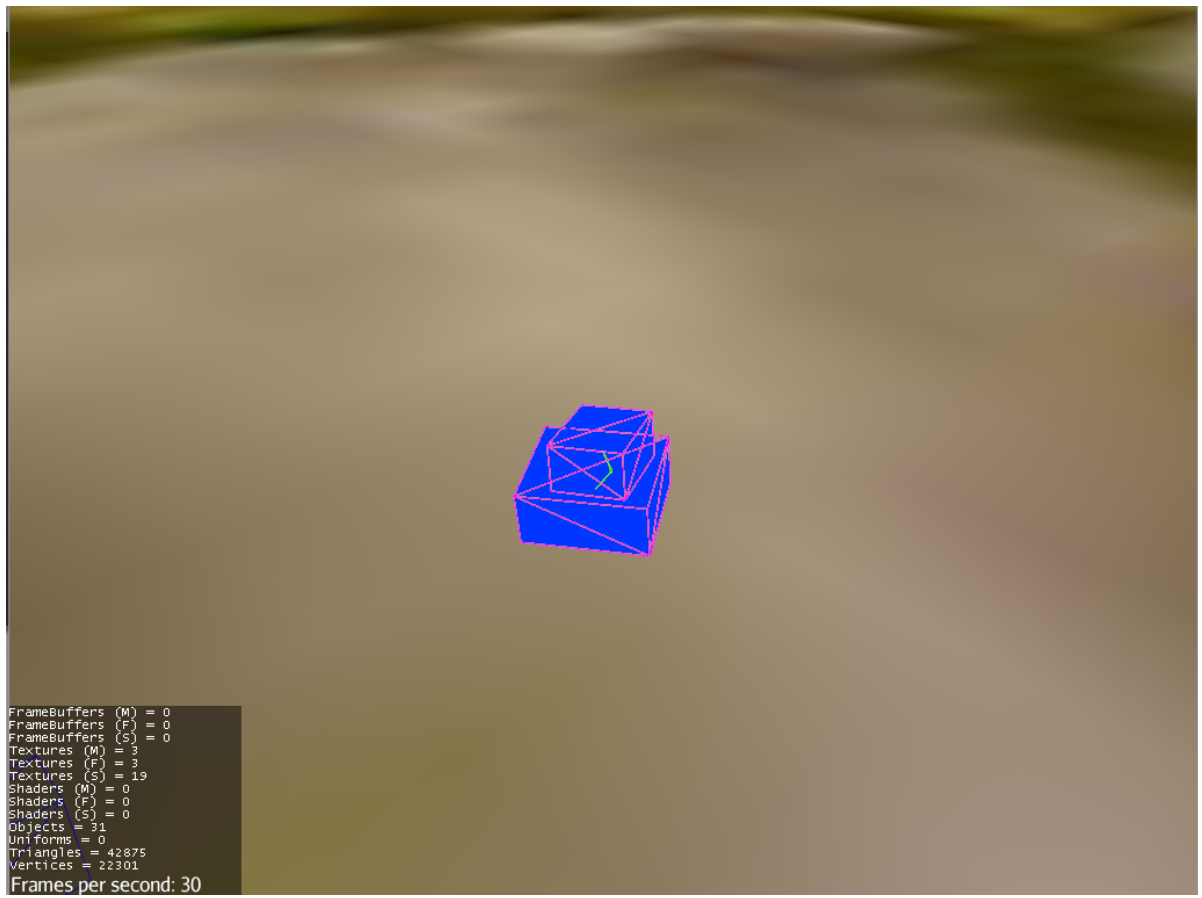
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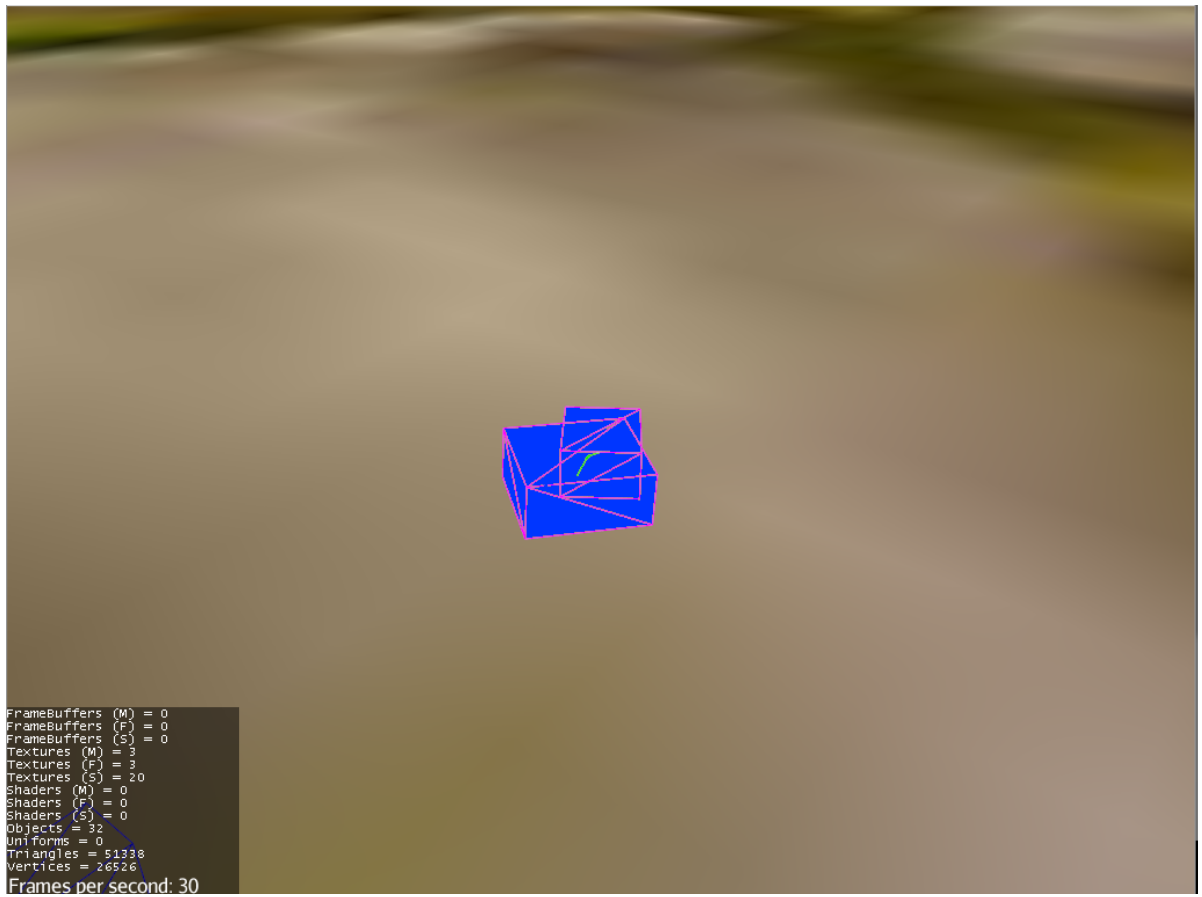
Creatures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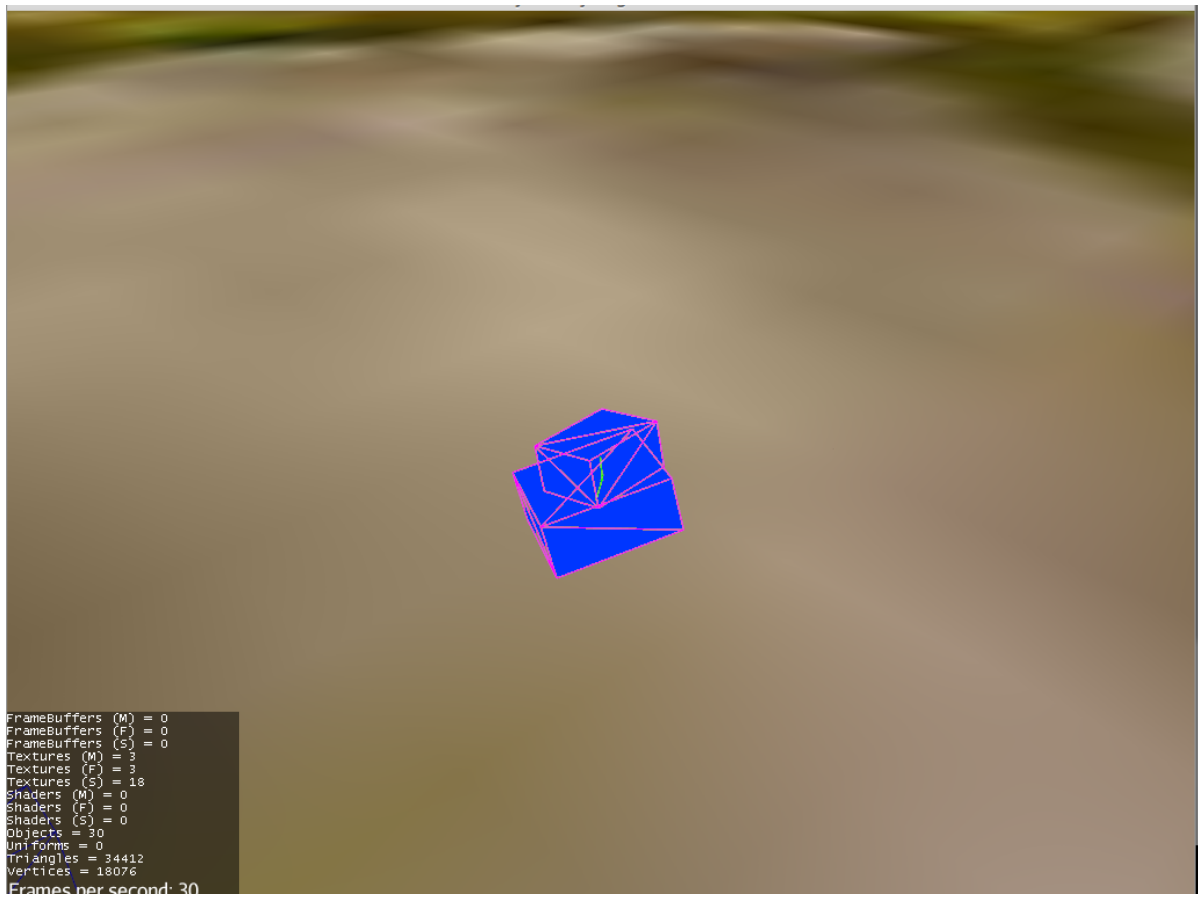
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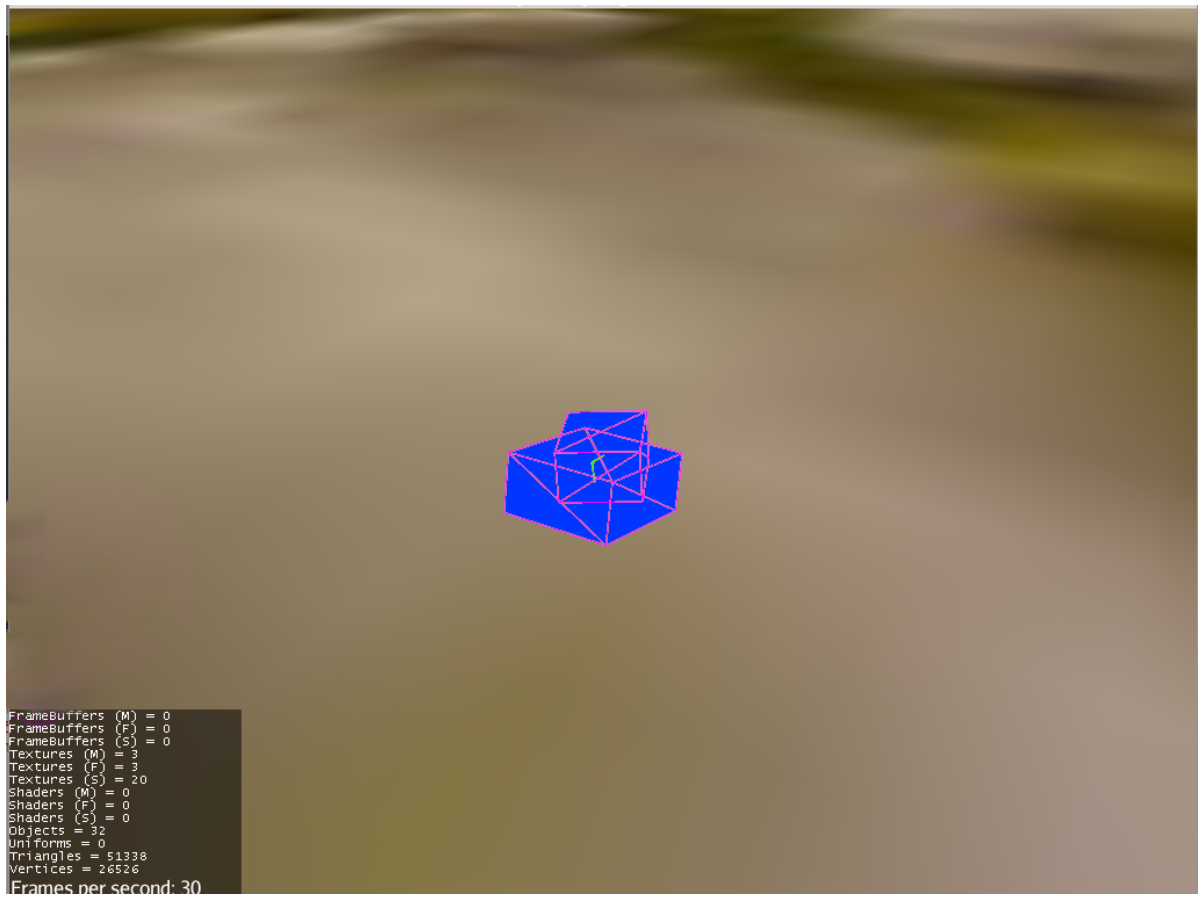
Creatures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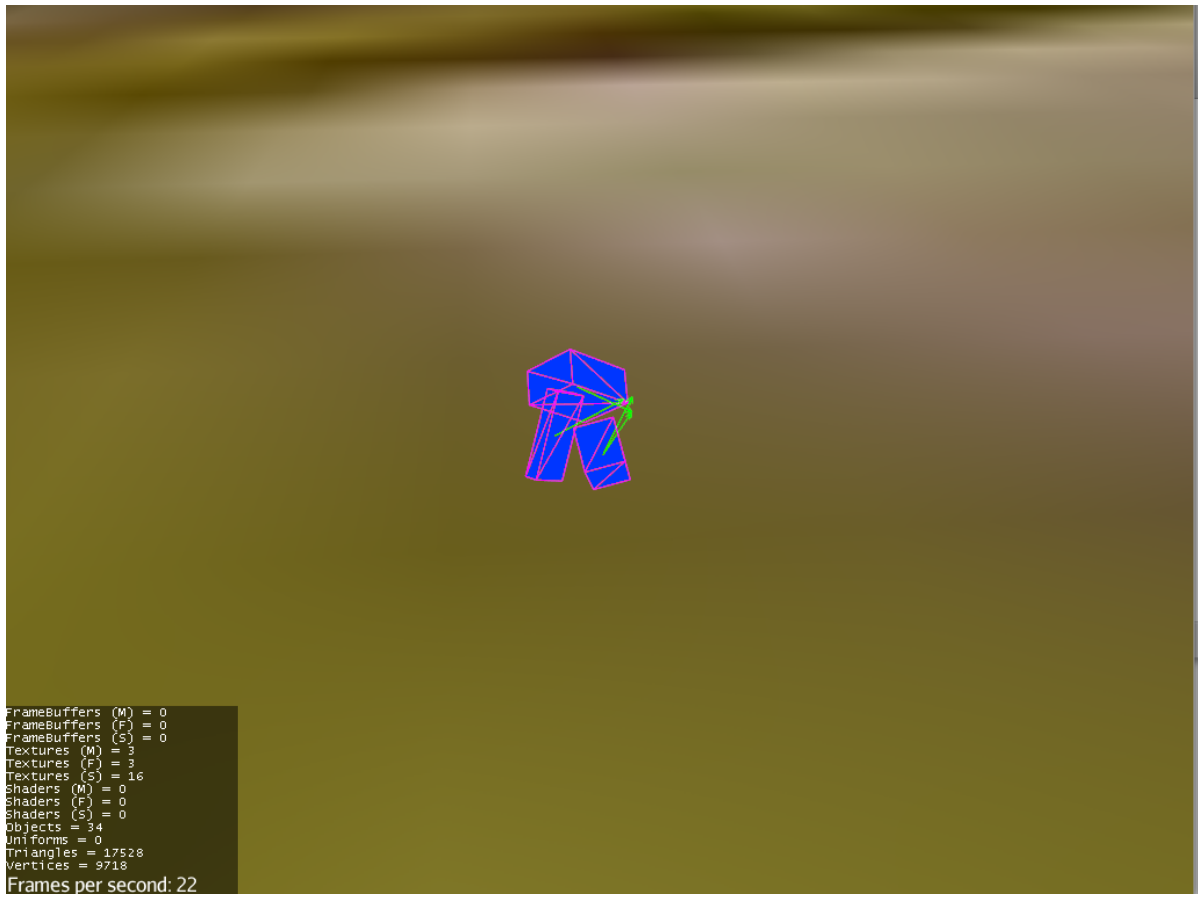
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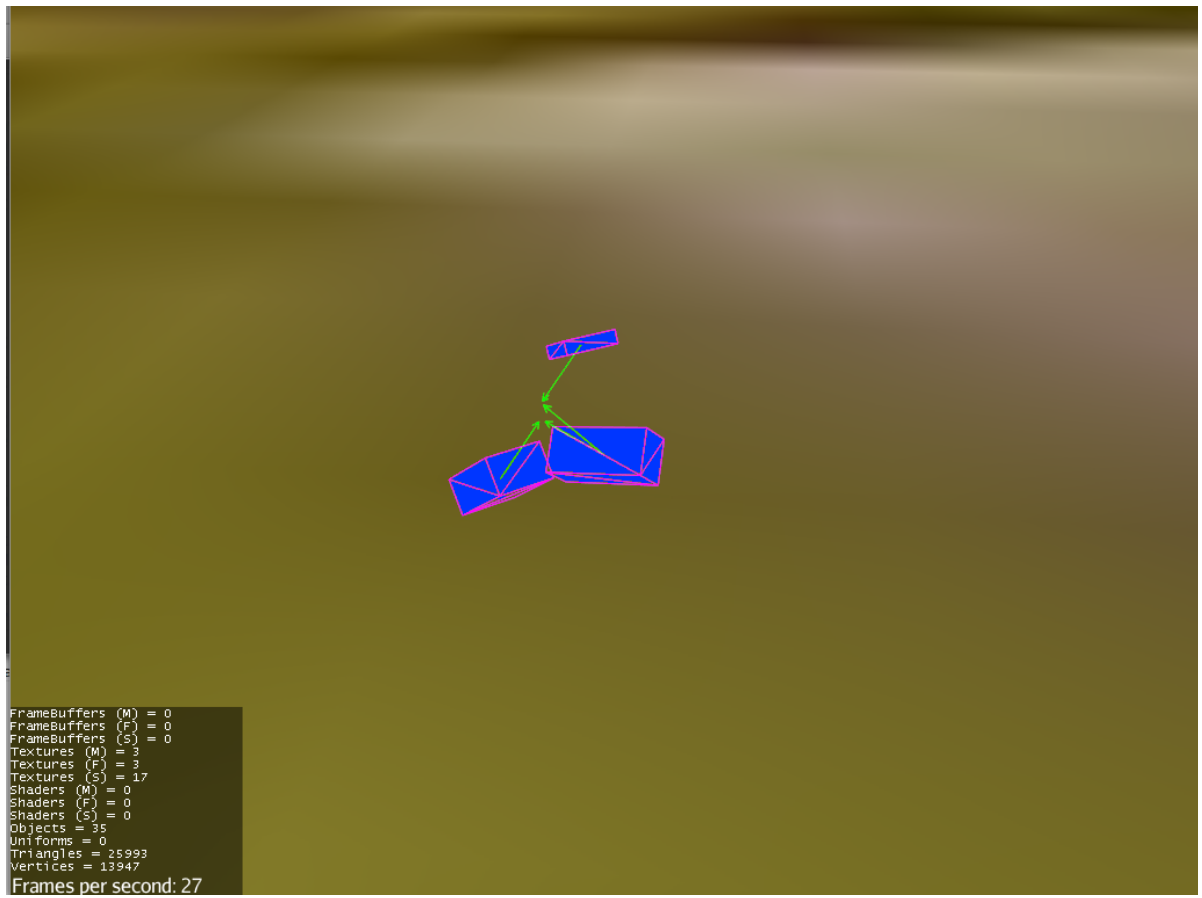
Frames per second: 22

Creatures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Frames per second: 27

Creatures


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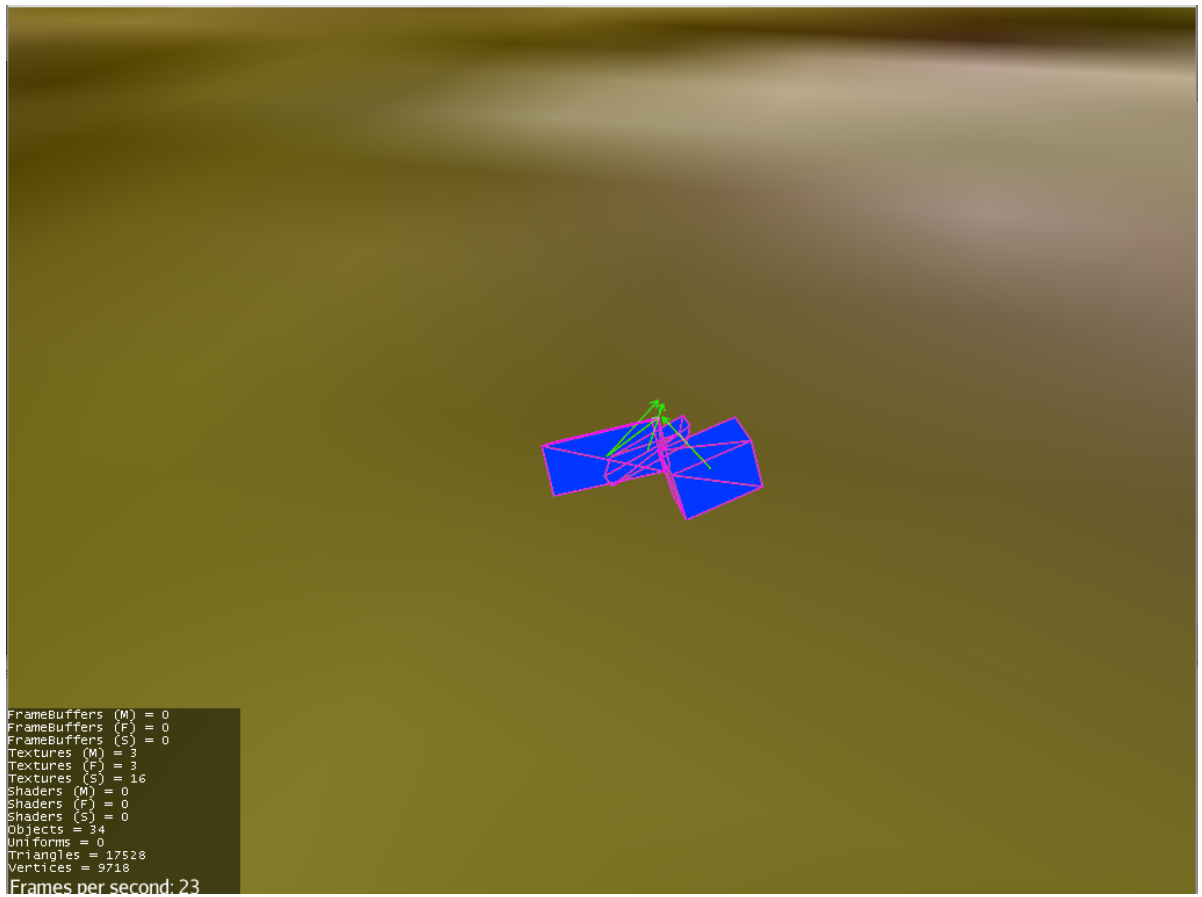
Frames per second: 27

Creatures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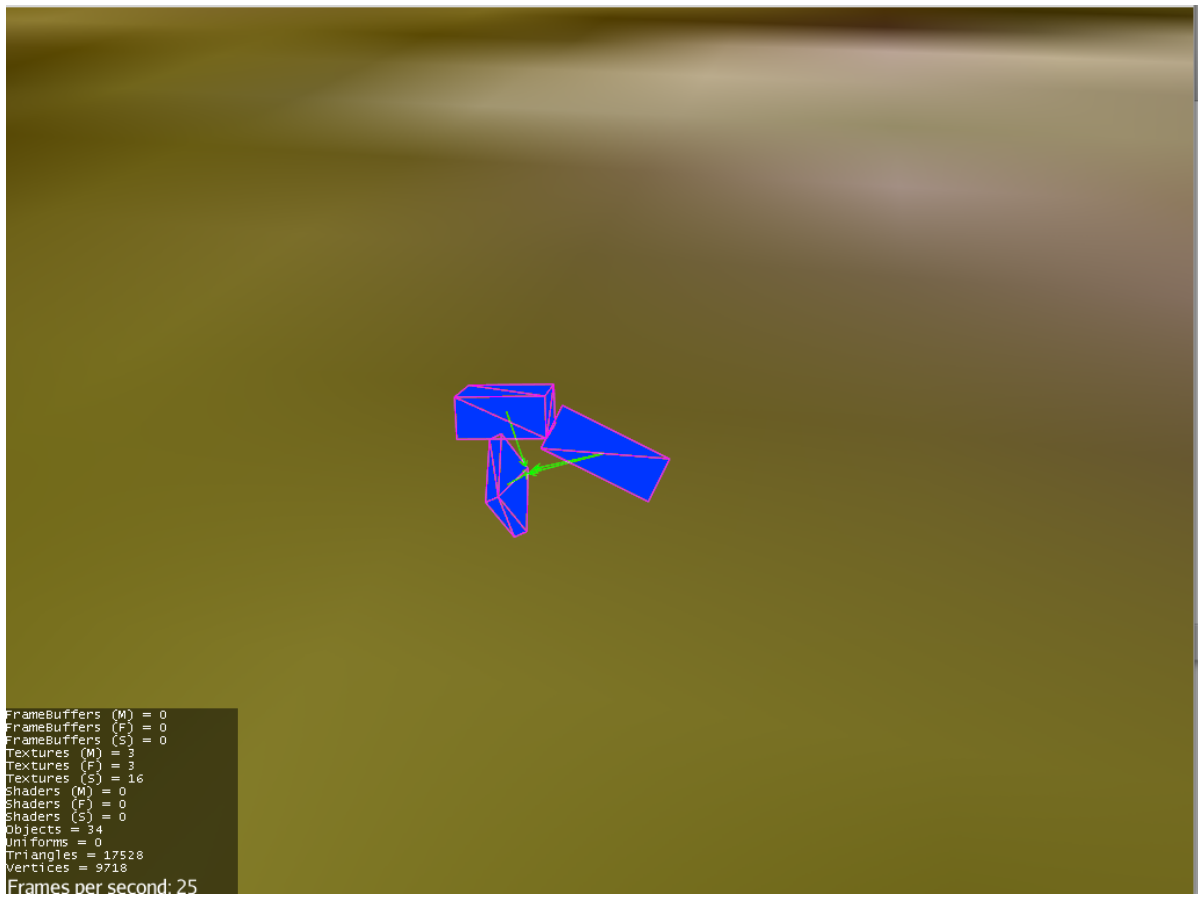
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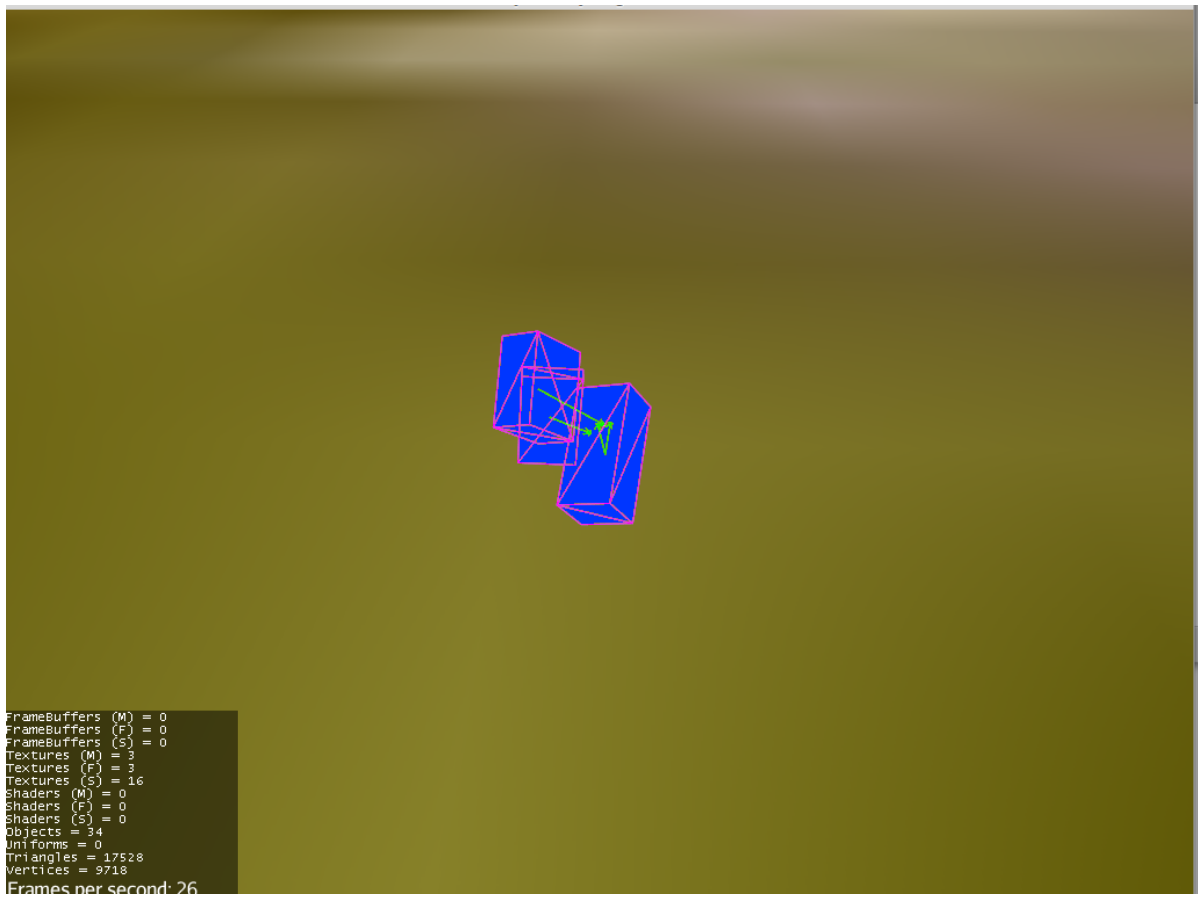
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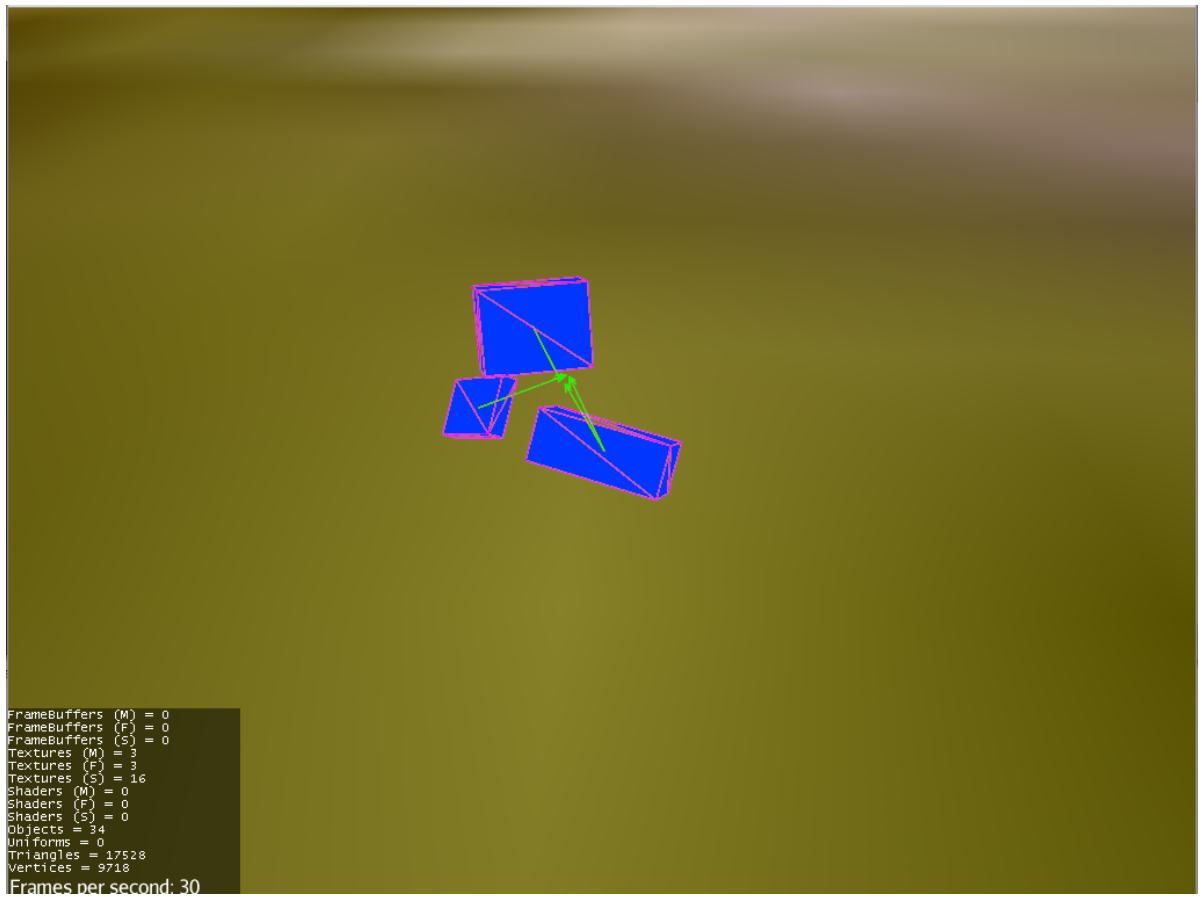
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Triangles = 17528
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Contents

Optimization & Extension

- The framework was written in a quick & dirty manner
- Several components need to be reimplemented properly to provide a more scalable environment
- The system does not use any parallelization
- The phenotype could be more natural
- The genotype to phenotype transcription does not include any additional developmental parts (no embryogenesis)
- More sensor types
- More logging for data analysis

Other settings & fitness functions

- Island genetic algorithm
- Competitions of individuals
- Implicit fitness functions (survival of the fittest in a virtual world)
- Information theoretic measures such as the transfer entropy

References

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- Hill, A.V. The heat of shortening and dynamics constants of muscles (1938)
- Stoop R. - Theory and Simulation of Neural Networks (2014)