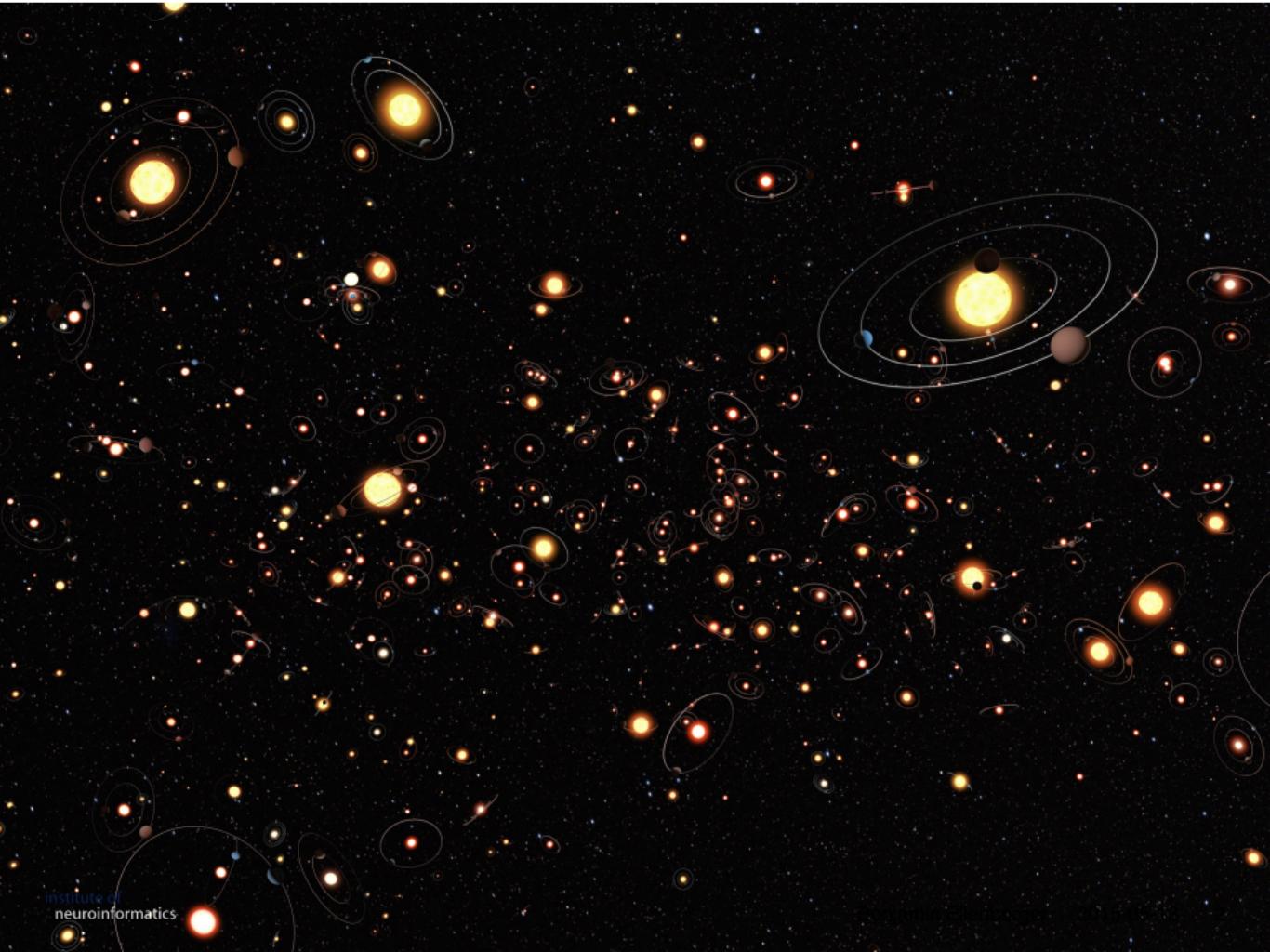


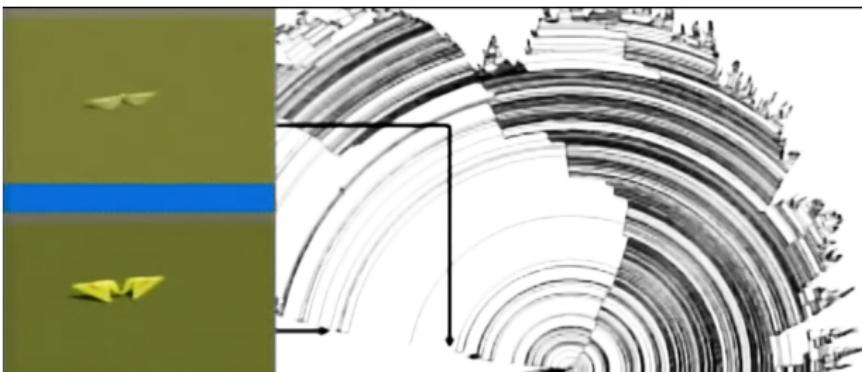
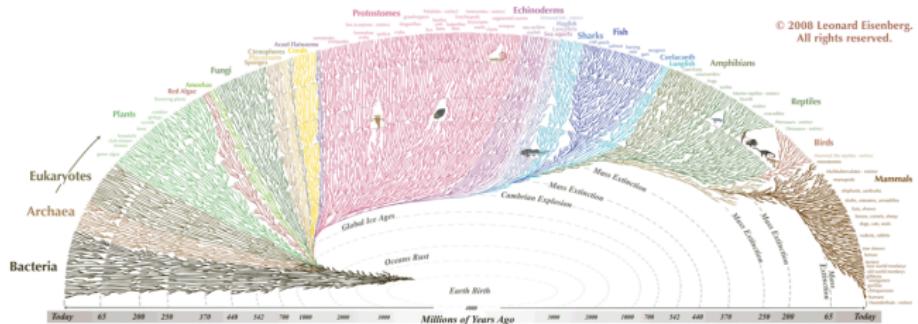


Emergent gait periodicity in artificially evolved creatures on unknown terrains

Benjamin Ellenberger



Life as it is vs. life as it could be



Goals

- Build robots that are not only capable but also more adaptive (Engineering goal)



Goals

- Build robots that are not only capable but also more adaptive (Engineering goal)
- Structures and strategies that always tend to evolve (Academic goal)



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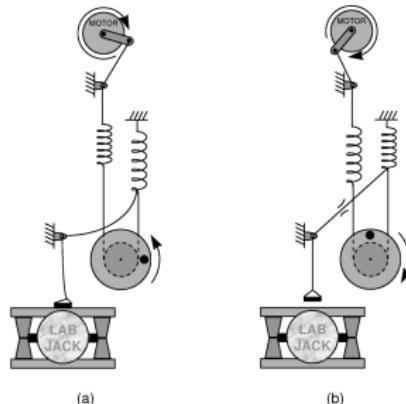
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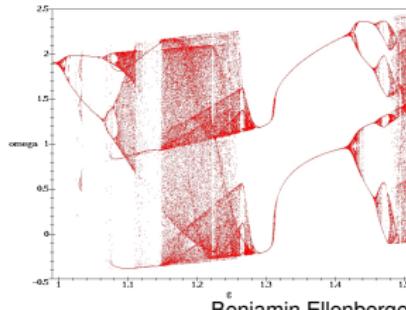
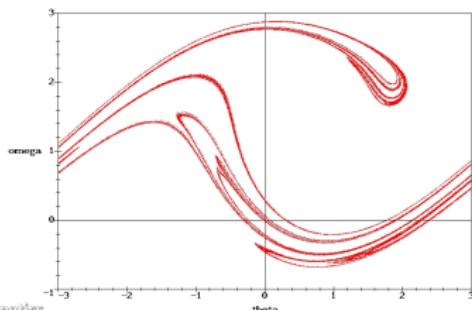
Simple limiters

- Generally the chaos controller is more complex than the system it controls



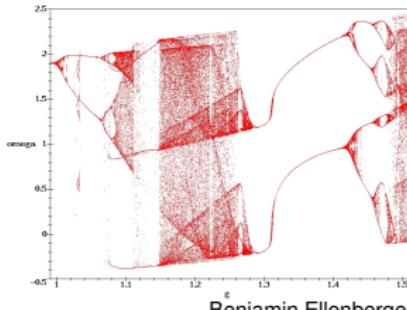
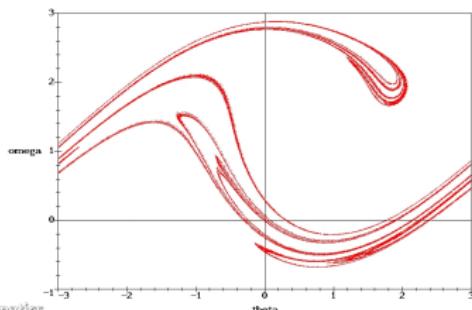
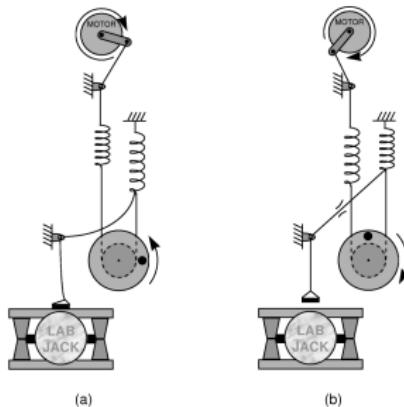
(a)

(b)



Simple limiters

- Generally the chaos controller is more complex than the system it controls
- Not true for the simple limiter



Simple limiters in nature



Simple limiters in nature

- Muscle length & joint limits



Simple limiters in nature

- Muscle length & joint limits
- The weight of the limbs



Simple limiters in nature

- Muscle length & joint limits
- The weight of the limbs
- The relative position of limbs connected by joints
(Direction of force applied to joints)

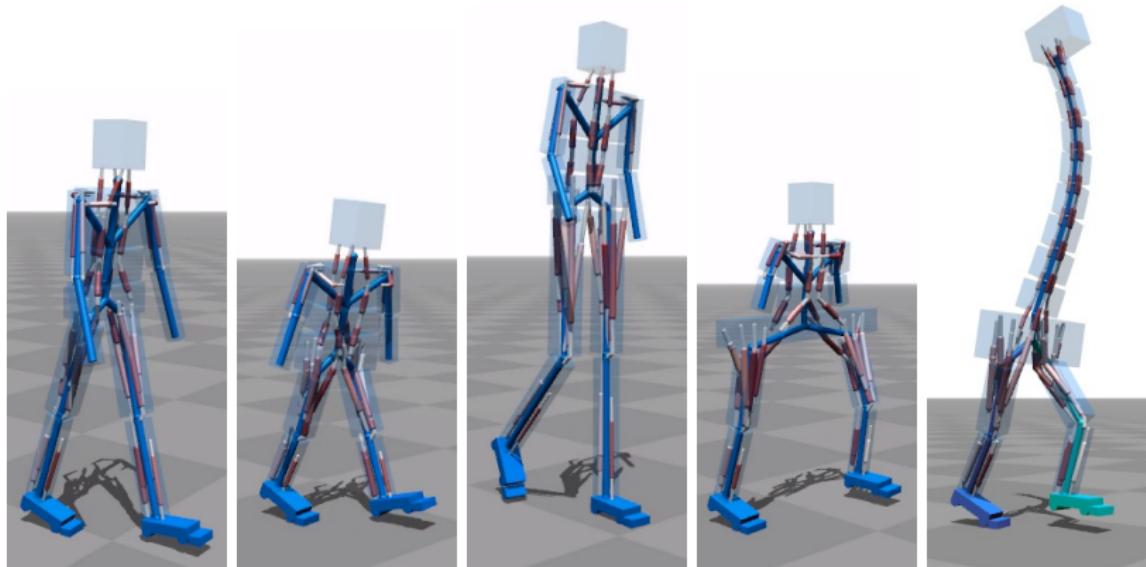


Simple limiters in nature

- Muscle length & joint limits
- The weight of the limbs
- The relative position of limbs connected by joints
(Direction of force applied to joints)
- The fact that physical objects can not interpenetrate each other

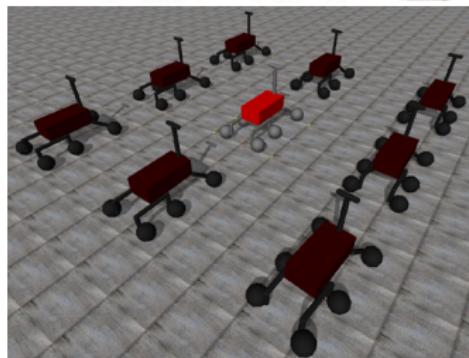
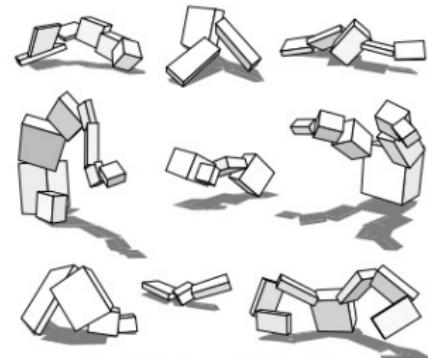


Simple limiters cont.



Source: Geijtenbeek et al. (Vol. 32, Nr. 6 SIGGRAPH 2013)

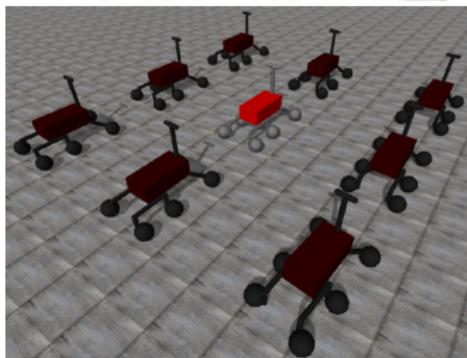
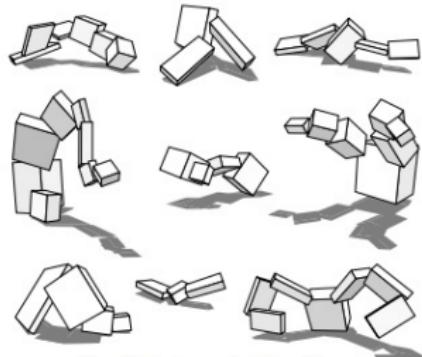
In silico¹: Will the simple limiters be used?



institute of
neuroinformatics ¹In silico = in simulation

In silico¹: Will the simple limiters be used?

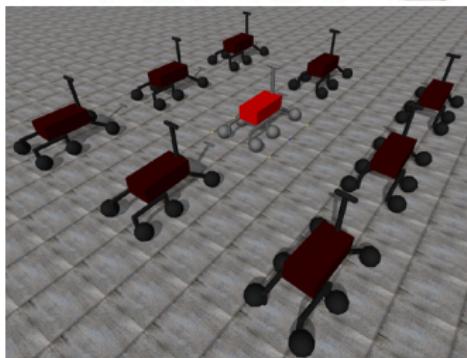
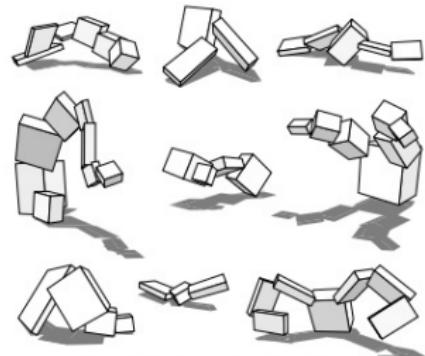
- Hypothesis 1: Simple limiters are an omnipresent feature used to reduce the control complexity and to control chaotic movement



institute of
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In silico¹: Will the simple limiters be used?

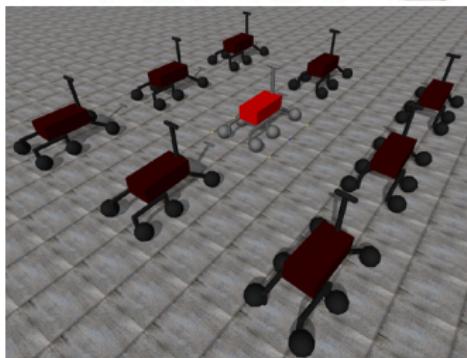
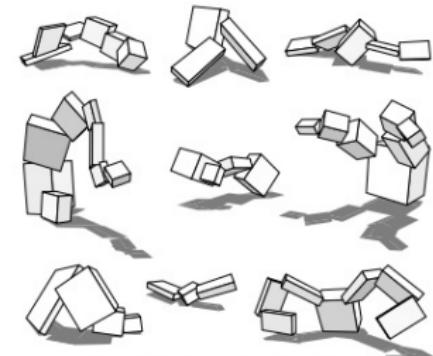
- Hypothesis 1: Simple limiters are an omnipresent feature used to reduce the control complexity and to control chaotic movement
- Hypothesis 2: If the world is flat then less simple limiters are used, if the world is dynamic and bumpy then more simple limiters are used.



institute of
neuroinformatics ¹In silico = in simulation

In silico¹: Will the simple limiters be used?

- Hypothesis 1: Simple limiters are an omnipresent feature used to reduce the control complexity and to control chaotic movement
- Hypothesis 2: If the world is flat then less simple limiters are used, if the world is dynamic and bumpy then more simple limiters are used.
- Question remains: Can you live limitless?



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Evolving Virtual Creatures

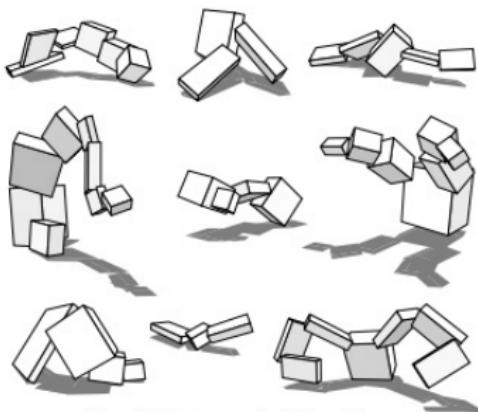


Figure 7: Creatures evolved for walking.

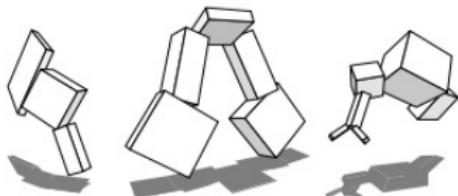


Figure 8: Creatures evolved for jumping.

Evolving Virtual Creatures

- Creatures are built from 3D Primitives and Joints

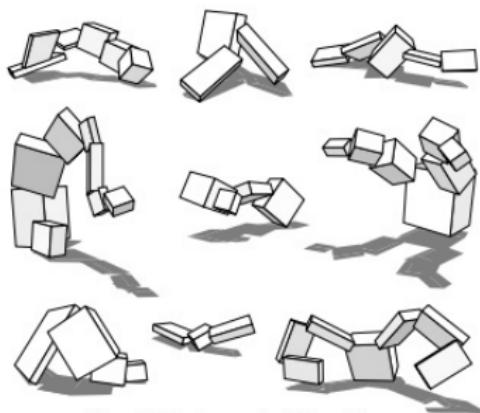


Figure 7: Creatures evolved for walking.

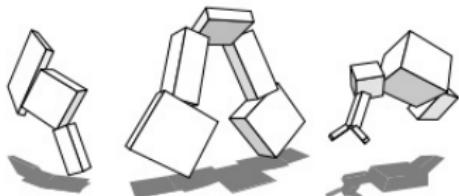


Figure 8: Creatures evolved for jumping.

Evolving Virtual Creatures

- Creatures are built from 3D Primitives and Joints
- Sensors, Controller and Effectors make it move

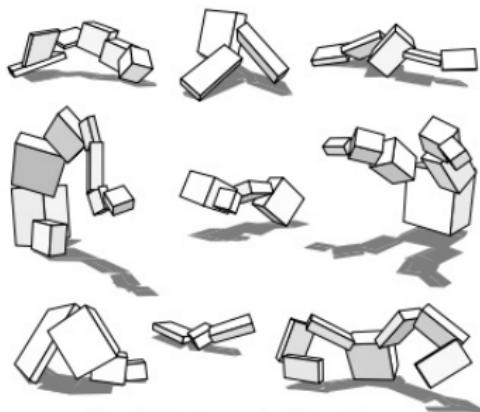


Figure 7: Creatures evolved for walking.

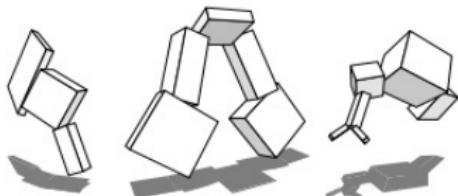


Figure 8: Creatures evolved for jumping.

Evolving Virtual Creatures

- Creatures are built from 3D Primitives and Joints
- Sensors, Controller and Effectors make it move
- Body and controller co-evolved

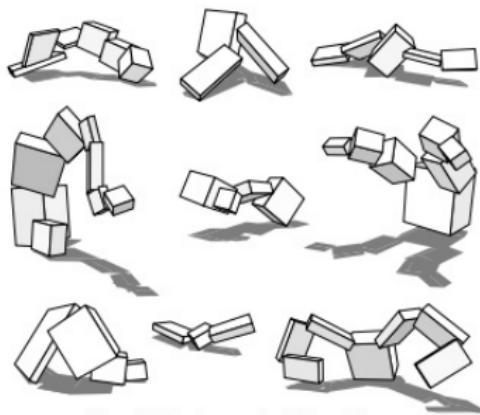


Figure 7: Creatures evolved for walking.

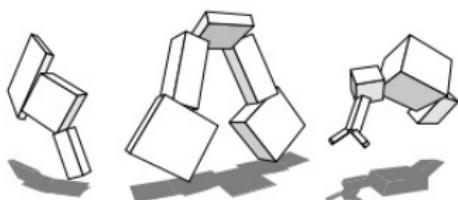
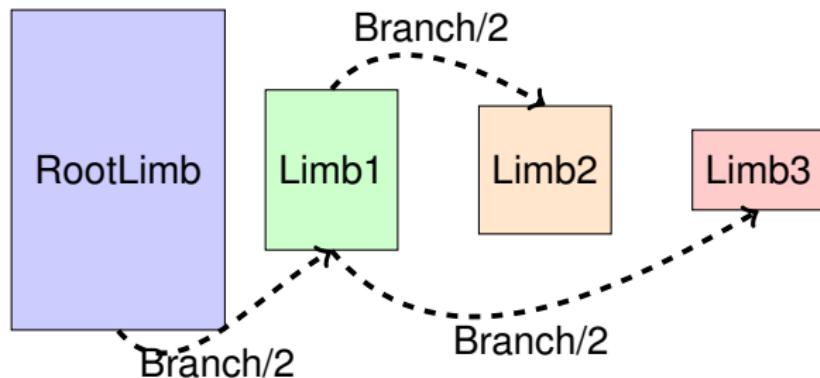


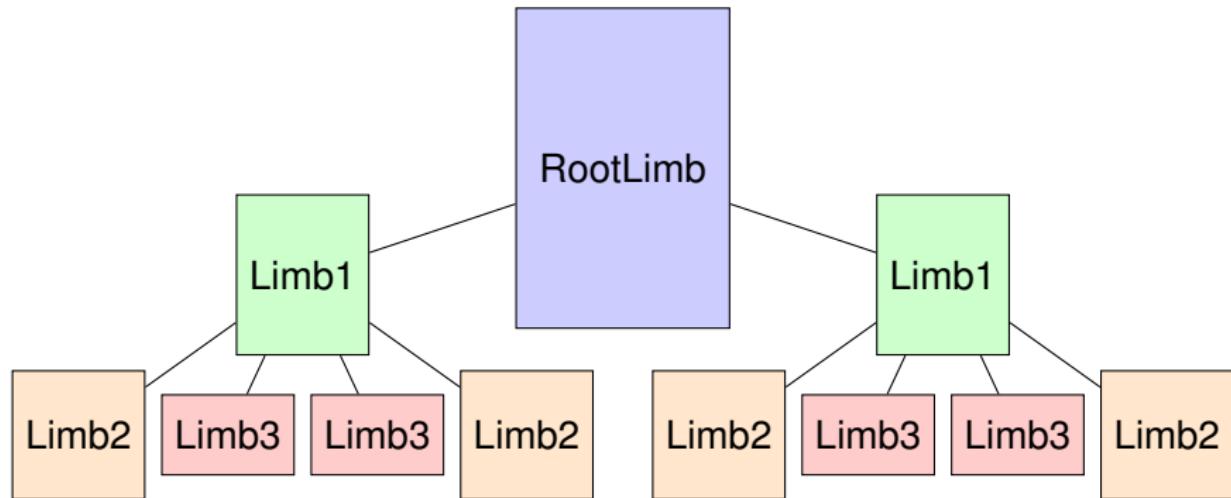
Figure 8: Creatures evolved for jumping.

Genetic language: Genotype

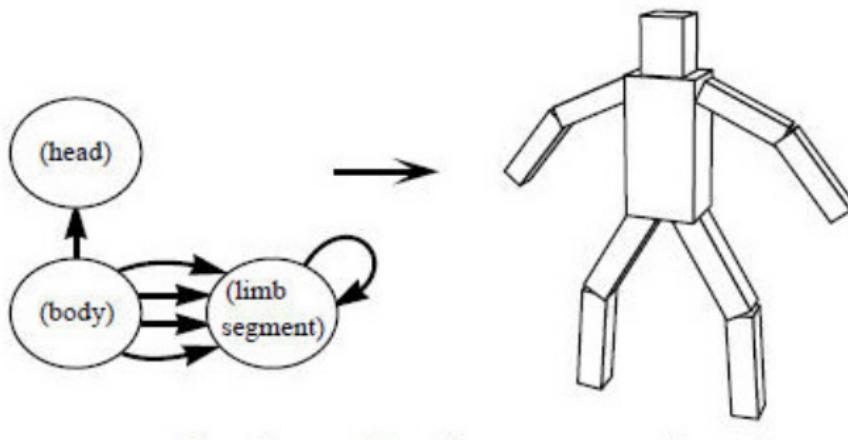


- **Limb** Part of creature body

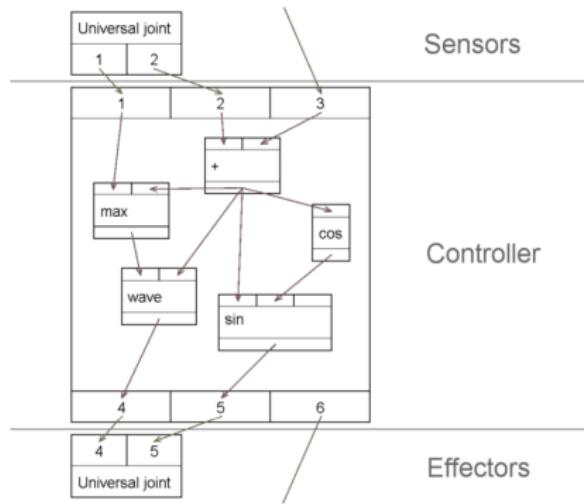
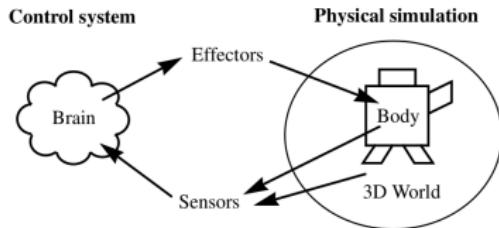
Genetic language: Phenotype



Genetic language: Phenotype cont.



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
- Could evaluate multiple fitness functions at the same time

Velocity as the fitness function

- Sampling of position over time and average over all limbs
- Moved distance in a certain time interval
- Continuous average
- Expectations: Some really moving creatures and some finding an exploit to the fitness function

Evolution

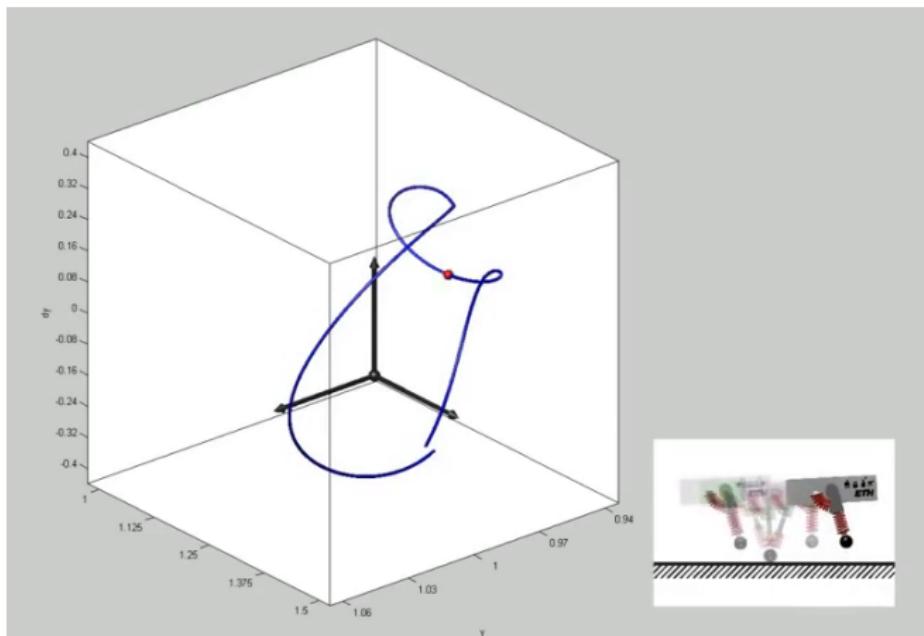
- Selection: Only a certain percentage of creatures are selected for new generation
- Cross-over: Only certain percentage of creatures are allowed to breed
- Mutation
 - Other creatures are subject to mutation
 - Mutation of gene
 - Mutation of gene attributes
 - Mutation of gene branches
- Successful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

Controller

- Sine-wave controller taking frequency, amplitude, X-shift, Y-shift as input which are determined evolutionarily.



Why Periodicity?



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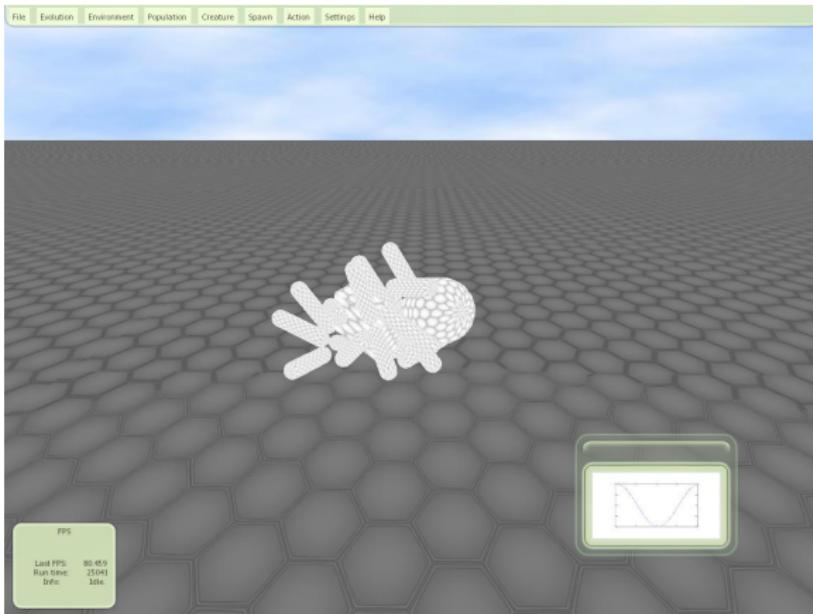
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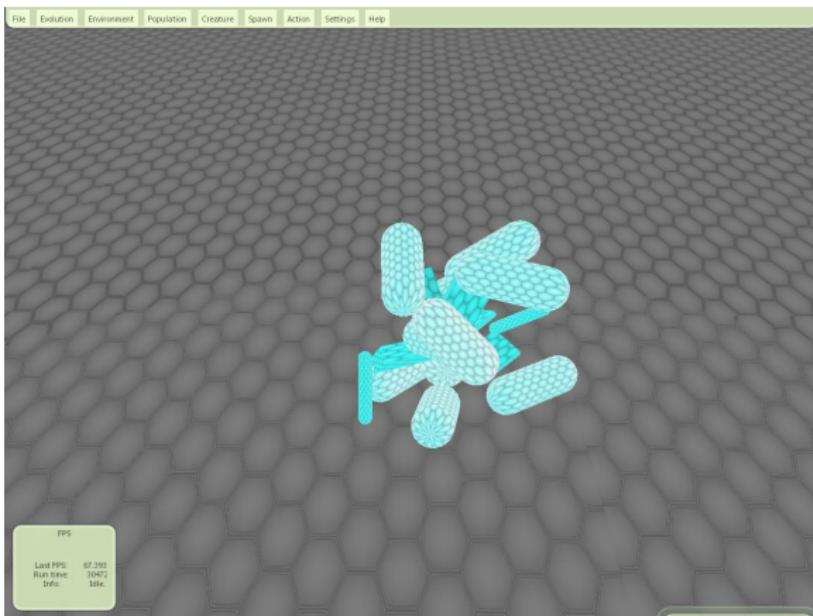
Extensions: Controllers

Other settings

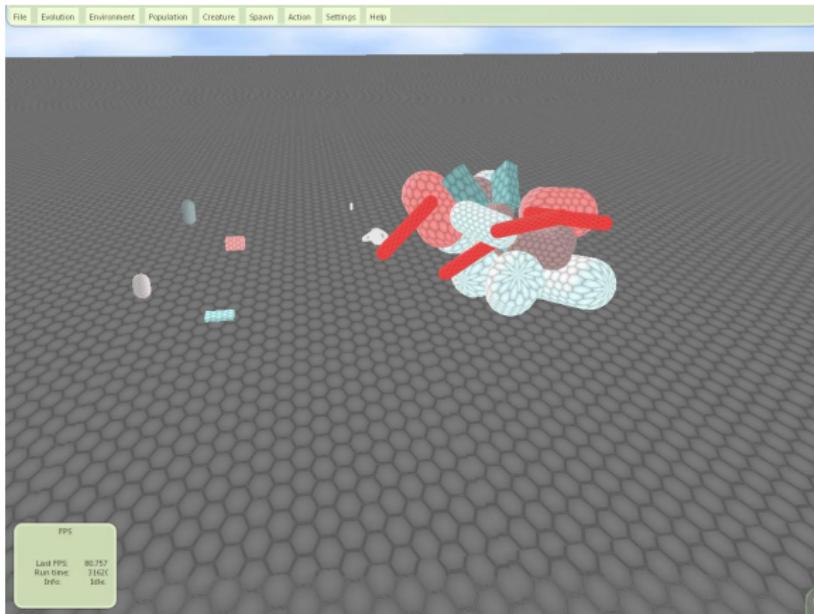
Creatures



Creatures



Creatures



Creatures

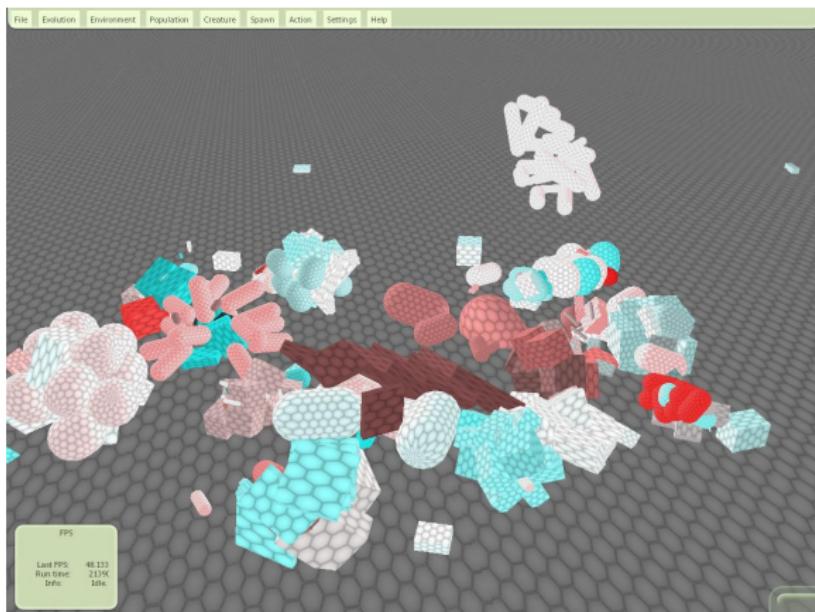


Figure : Simulate 50 creatures at the same time

Creatures

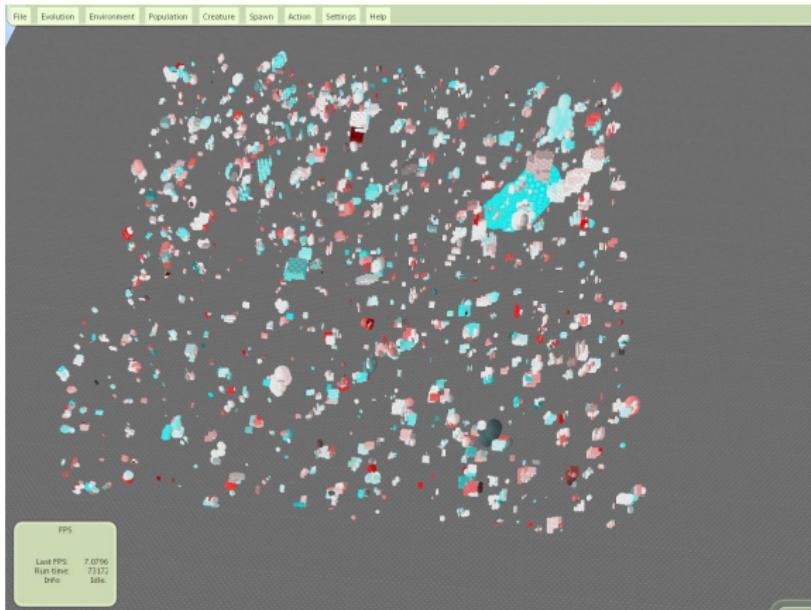


Figure : Simulate 1000 creatures at the same time

Creatures

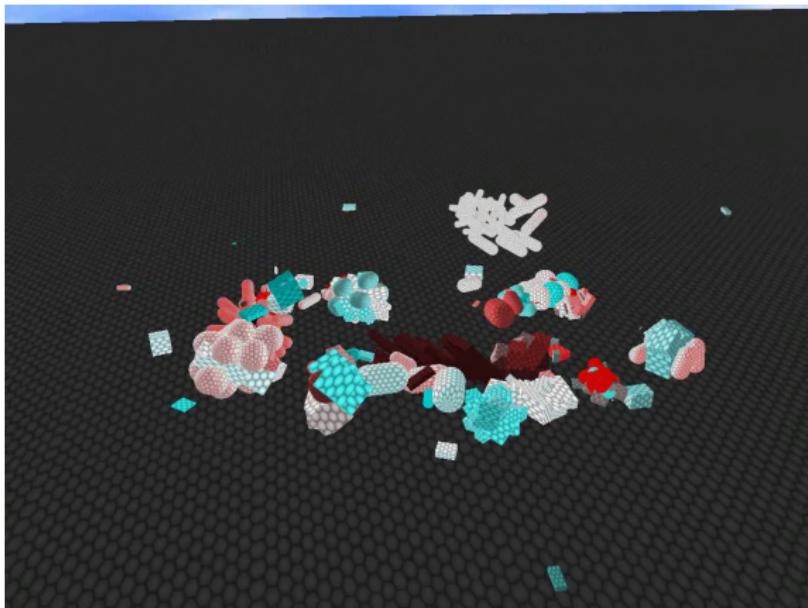


Figure : Short video

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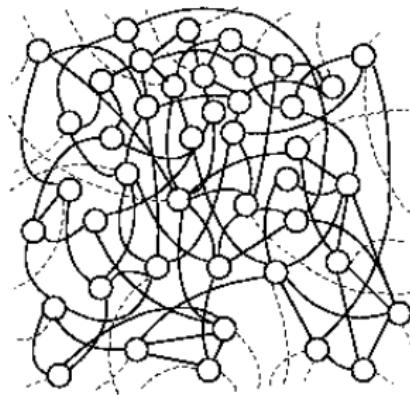
Other settings

Extensions: Evolutionary Algorithm

- Different types of evolutionary selection and evaluation
- The system does not use any parallelization
- The phenotype could be more natural
- Sensor and actuator types
- More logging for data analysis (different live-views)

Extensions: Controllers

- Different types of controllers taking sensors as inputs
- Deep Neural Networks especially the LSTM neural network
- Other ideas I have until then



Other settings

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



- Any questions?
- What experiments would you have in mind?
- What else would you change, extend, enhance, improve etc.?
- If you have any ideas later, email me:
`be.ellenberger@gmail.com`
- You can look at my progress:
`https://github.com/benelot/minemonics`

References

- Sims K. - Evolving Virtual Creatures (1994)
- Sims K. - Evolving 3D Morphology and Behavior by Competition (1994)
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