

UNISINOS - RS - Brasil
Universidade do Vale do Rio dos Sinos

UFRGS - Brasil
Universidade Federal do Rio Grande do Sul

Inteligência Artificial Aplicada no Controle do Caminhar e na Evolução da Morfologia de Robôs Móveis Simulados

Authors:

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Prof. Fernando S. Osório

Presented by:

Cássia Nino - Applied Computing / Unisinos

Agenda

- 1. Motivation / Previous work**
 - > Robots and Walking Robots
- 2. Virtual Reality Simulation**
 - > Physics Simulation: Sensors, Kinematics, Dynamic, Articulated Rigid Bodies
- 3. LegGen - Legged Robots**
 - > Learning to Walk
 - > Simulation
- 4. Evolving ANN and Robots**
 - > ANN-GA
 - > Evolving Robot Morphology
 - > Simulation Results
- 5. Conclusions and Future Work**

1. PREVIOUS WORKS - AUTONOMOUS ROBOTS

- * **Virtual Reality Environment** and Simulation of Legged Robots
"Uso de Realidade Virtual para a Simulação do Caminhar em Robôs Móveis"
SVR 2006 - Belém, Brazil
- * Evaluate different **Robot Models** (hardware configurations)
"Applying Genetic Algorithms to Control Gait of Physically Based Simulated Robots"
IEEE WCCI / CEC 2006 - Vancouver, Canadá
- * Evaluate different **Fitness Functions**
"Gait Control Generation for Physically Based Simulated Robots using Genetic Algorithms"
IBERAMIA / SBIA 2006 - Ribeirão Preto, SP
- * **Robot, Vehicles and Human Simulation**
"Increasing Reality in VR Applications: Physical and Behavioral Simulation"
Virtual Concept Summer School - Nov. 2006 - Porto Alegre, RS / VC2006 Cancun

1. MOTIVATION - AUTONOMOUS ROBOTS

Mobile Articulated Robots: Walking Machines... Insects, Animals, Humans



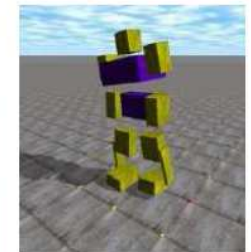
Lynxmotion Hexapod II



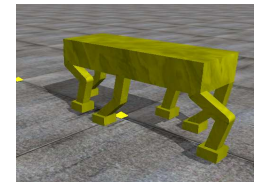
Genhis-II



(a) Robô real



(b) Robô simulado



The Sony Dream Robot
in the real world



The Sony Dream Robot
simulated into Webots



(a)



(b)

Sony Aibo



(a) Honda Asimo



(b) Sony SDR-4X



(c) Kawada H6



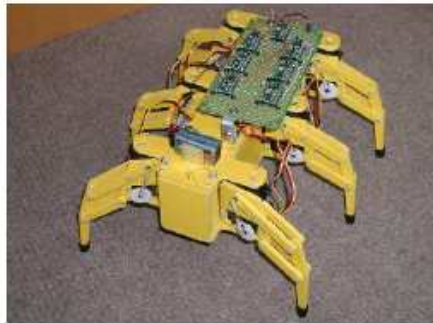
(d) Fujitsu HOAP-2

1. MOTIVATION - AUTONOMOUS ROBOTS

Mobile Articulated Robots:
Walking Machines... Insects, Animals, Humans

This Work

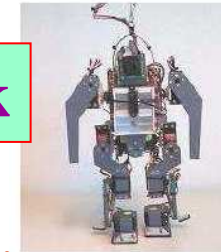
Dog
Horse ...
Tetrapod
Hexapod



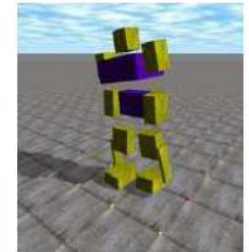
Lynxmotion Hexapod II



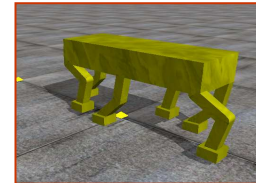
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(a) Robô real



(b) Robô simulado



The Sony Dream Robot
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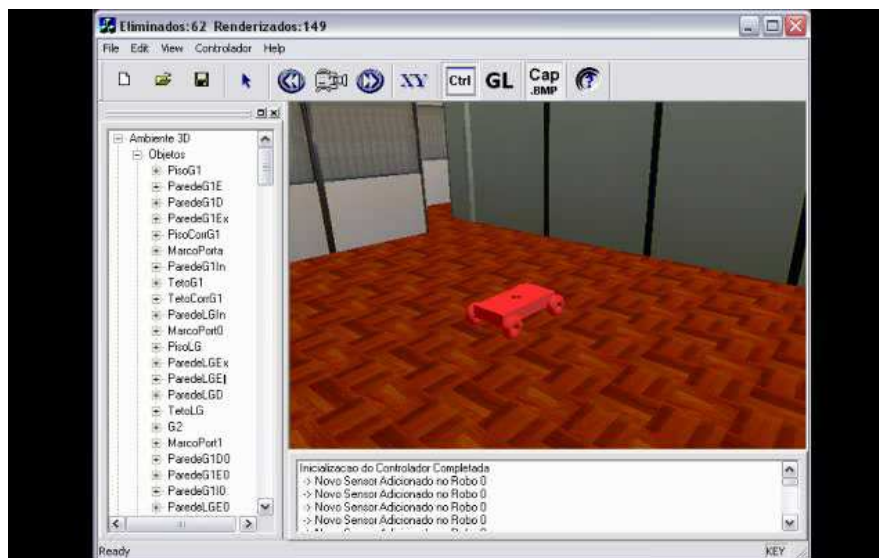
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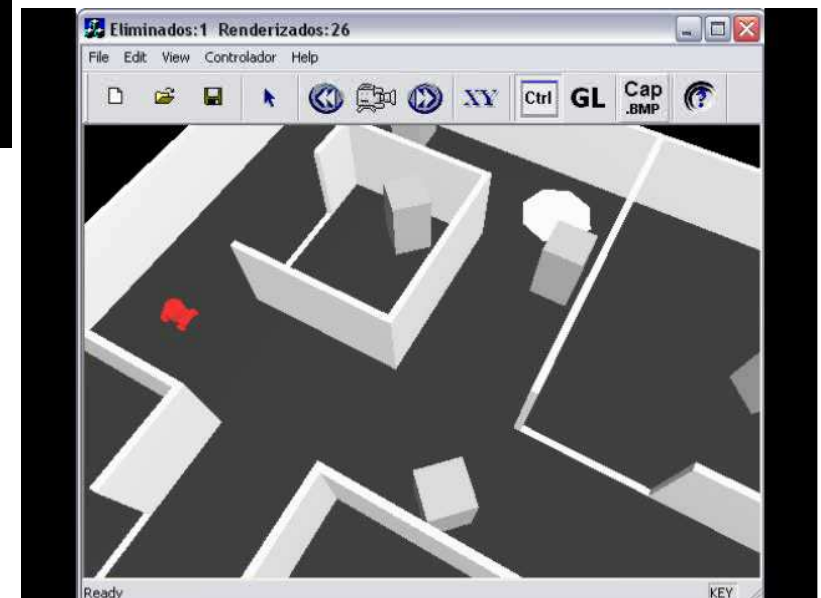
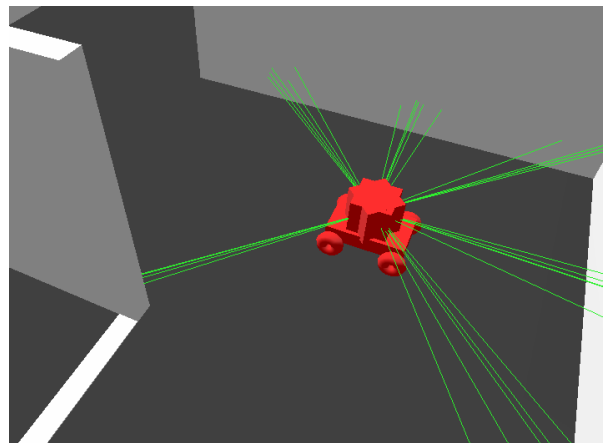
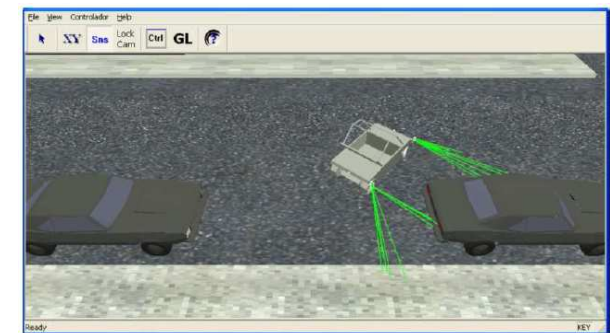
(d) Fujitsu HOAP-2

2. ROBOT SIMULATION

Simulation of Robots: 3D Realistic Virtual Environments



SimRob3D developed at Unisinos



3. LEGGEN - ROBOT SIMULATION

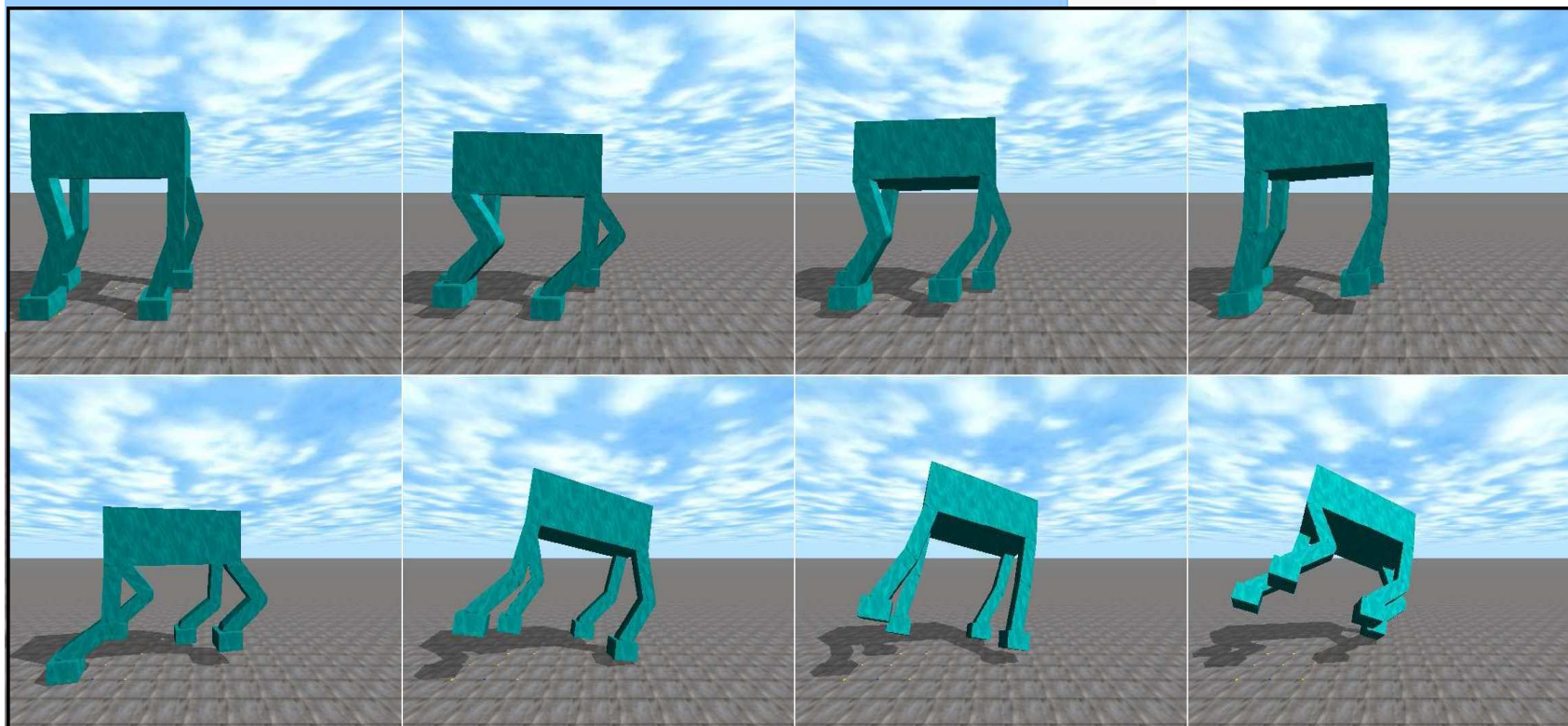
DIMENSIONS OF THE SIMULATED ROBOTS

Part	TetraL3J		
	x	y	z
Body	45.0	15.0	25.0
Thigh	5.0	15.0	5.0
Shin	5.0	15.0	5.0
Paw	8.0	5.0	9.0

Simulation of 3D Realistic Virtual Legged Robots **LEGGEN Simulator**



Genetic Evolved Control
of Articulated Robots (w/legs)



3. LEGGEN - ROBOT SIMULATION

Simulation of 3D Realistic Virtual Legged Robots

LEGGEN Simulator - Tools:

1. **OSG** - Open Scene Graph (OpenGL + Extensions)

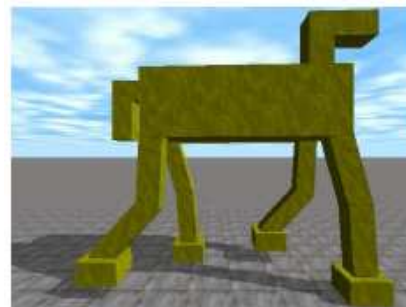
[<http://www.openscenegraph.org/>] **Graphics Engine**

2. **ODE** - Open Dynamics Engine

Rigid Body Physics Simulation

(gravity, inertia, friction, collision, joints, etc)

[<http://www.ode.org/>] **Physics Engine**



Parte	Dimensões		
	<i>x</i>	<i>y</i>	<i>z</i>
Corpo	45,0cm	15,0cm	25,0cm
Coxa	5,0cm	15,0cm	5,0cm
Canela	5,0cm	15,0cm	5,0cm
Pata	8,0cm	5,0cm	9,0cm

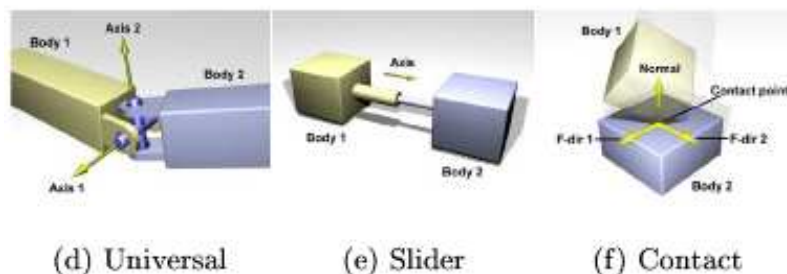
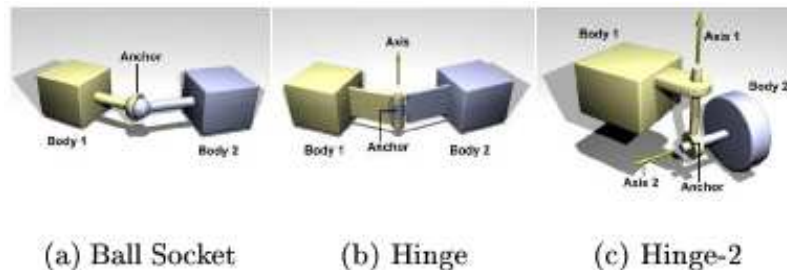
3. LEGGEN - ROBOT SIMULATION

Simulation of 3D Realistic Virtual Legged Robots LEGGEN Simulator - Tools:

1. OSG - Open Scene Graph (OpenGL + Extensions)

[<http://www.openscenegraph.org/>]

2. ODE - Open Dynamics Engine



3. GALib

Genetic Algorithms Simulation
<http://www.lancet.mit.edu/ga/>

4. Robot Control: Joint Angles

Finite State Machine
Artificial Neural Nets

3. LEGGEN - ROBOT SIMULATION

Simulation of 3D Realistic Virtual Legged Robots

LEGGEN Simulator - Tools:

1. **OSG** - Open Scene Graph (OpenGL + Extensions)

[<http://www.openscenegraph.org/>]

2. **ODE** - Open Dynamics Engine

Control:

- Joints with motors
- Activate motors to set a specific angle for each joint
- Sequence of angles = Walk!

3. **GALib**

Genetic Algorithms Simulation

<http://www.lancet.mit.edu/ga/>

4. **Robot Control: Joint Angles**

Finite State Machine

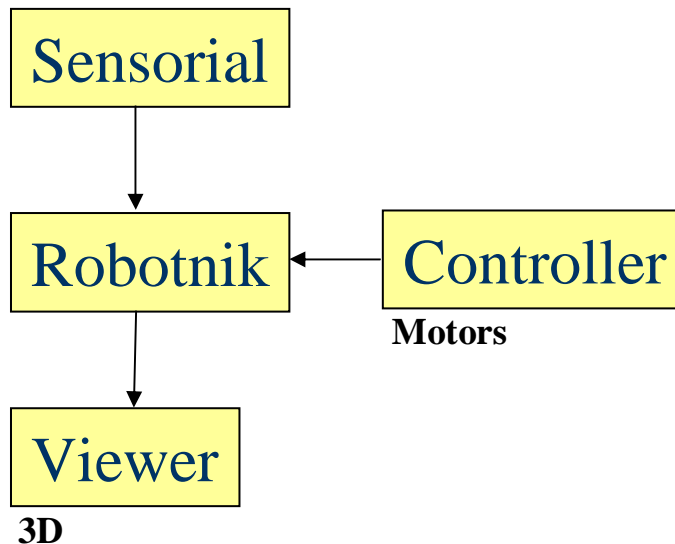
(Table with sequence of target angles - GA)

Artificial Neural Nets

(Input: present angle => Output: next angle)

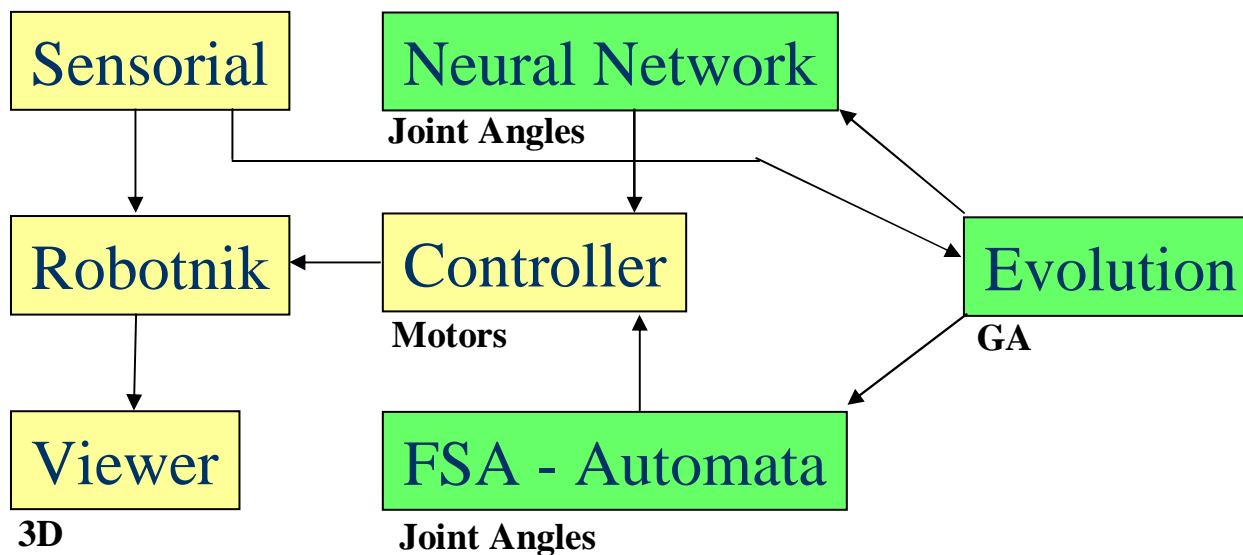
3. LEGGEN - ROBOT SIMULATION

Simulation of 3D Realistic Virtual Legged Robots **LEGGEN Simulator - Tools:**

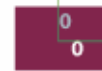


3. LEGGEN - ROBOT SIMULATION

Simulation of 3D Realistic Virtual Legged Robots **LEGGEN Simulator - Tools:**



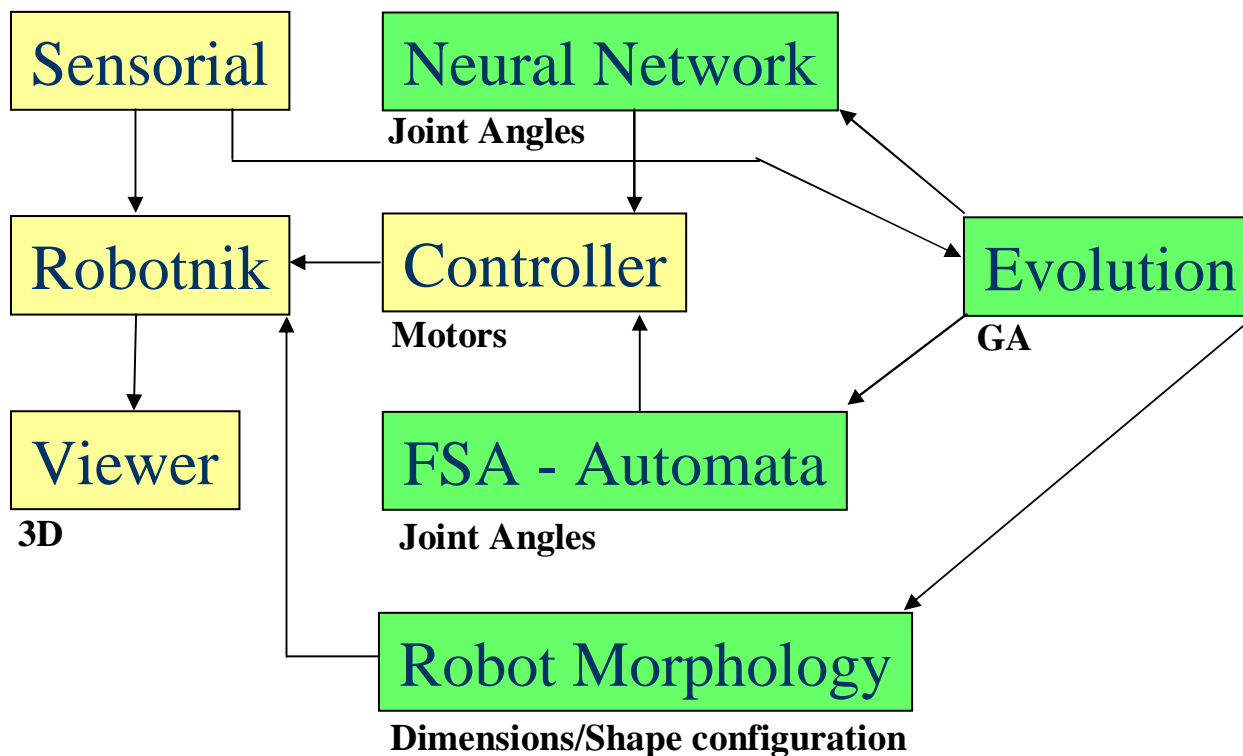
Evolve Control +
Visualization



3. LEGGEN - ROBOT SIMULATION

Simulation of 3D Realistic Virtual Legged Robots

LEGGEN Simulator - Tools:



**Evolve Robot +
Evolve Control +
Visualization**

3. LEGGEN SIMULATOR - GA

Genetic Algorithms Simulation

Algorithm 1 Pseudocode of the GA

```
F ← FitnessFunction  
G ← NumberOfGenerations  
M ← SizeOfPopulation  
pc ← FrequencyOfCrossover  
pm ← FrequencyOfMutation  
Population ← RandomPopulation(M)  
CalculateFitness(Population)  
while GenerationNum < G do  
    Parents ← Population  
    Children ← Crossover(Parents, pc)  
    NewPopulation ← Mutation(Children, pm)  
    Population ← NewPopulation  
    CalculateFitness(Population)  
end while  
return (BestIndividual)
```

GA Parameters:

Cross-Over: 0.80

Mutation: 0.08

Population: 350

Generations: 700

Genome:

Evolve FSA

Evolve ANN

3. LEGGEN SIMULATOR - GA

Genetic Algorithms Simulation

Fitness Function:

$$F = \frac{D}{1 + B + a \times G}$$

F = Fitness

D = Walked Distance

B = Bumpers (paws touching ground ~ stability)

G = Gyro (gyroscope/accelerometers ~ stability)

$$B = \sum_{i=1}^P \left(\frac{n_i}{N} - \frac{1}{2} \right)^2$$

where

P = paws

n_i = bumper contacts of paw i

N = total bumper sensor readings

$$G = \sqrt{\frac{\sum_{i=1}^N (x_i - \bar{x})^2 + \sum_{i=1}^N (y_i - \bar{y})^2 + \sum_{i=1}^N (z_i - \bar{z})^2}{N}}$$

G = Sum of x, y, z instability

where

$$\bar{x} = \frac{\sum_{i=1}^N x_i}{N}, \quad \bar{y} = \frac{\sum_{i=1}^N y_i}{N}, \quad \bar{z} = \frac{\sum_{i=1}^N z_i}{N}$$

GA Parameters:

Cross-Over: 0.80

Mutation: 0.08

Population: 350

Generations: 700

Walking time: 30

3. LEGGEN SIMULATOR - FSA

GA Finite State Machine

- The robot is placed in the starting position and orientation in the simulation environment;
- The genome is read and the robot control FSM table values are set;
- The physical simulation is executed during a predefined amount of time (sixty seconds in our experiments);
- Gait information and sensor data are captured during each individual physical simulation;
- Fitness is calculated and returned to the GAlib;

EXAMPLE OF A GENOTYPE

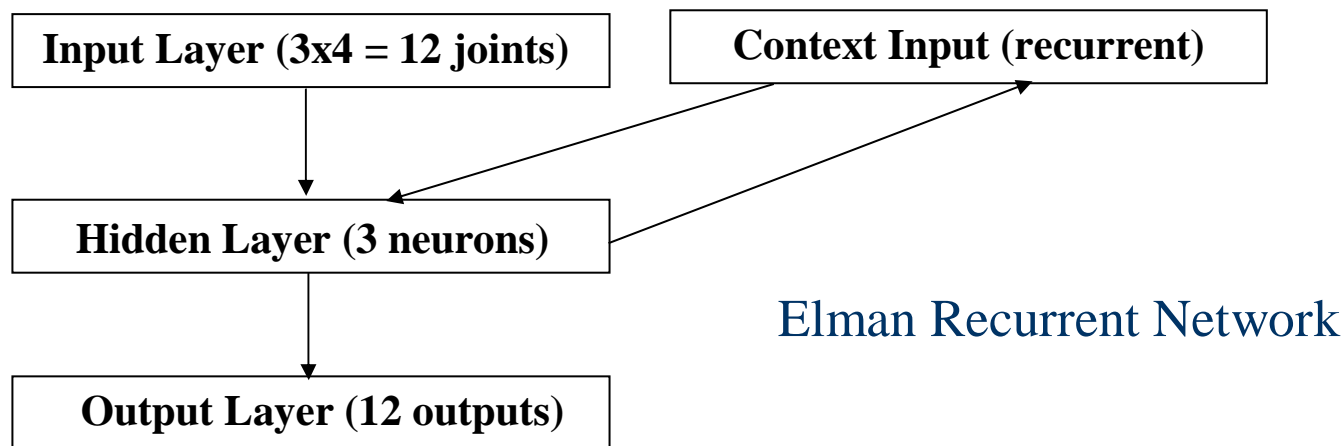
	State 1	State 2	State 3	State 4
Reference velocity	1.1703	2.0705	1.2499	1.5901
Front legs - hip	0.0698	-0.6283	-0.1570	-0.0698
Front legs - knee	1.0473	0.7504	0.2268	0.4363
Front legs - ankle	-1.1172	-0.1221	-0.0698	-0.3665
Rear legs - hip	-0.1570	-0.0698	0.0698	-0.6283
Rear legs - knee	0.2268	0.4363	1.0473	0.7504
Rear legs - ankle	-0.0698	-0.3665	-1.1172	-0.1221

Genome:

- * FSM: Table of *Target States* (Sequence of Actions)
- * Target angles + Reference Angular velocity
- * Adjust velocity
- * Fitness Function: Sensor based

3. LEGGEN SIMULATOR - ANN

GA Artificial Neural Network



Input: joint angles at time t $[-1:+1]$

Output: joint angles at time $t+1$ $[-1:+1]$

Temporal sequence of joint angles.

Learning: adjust ANN weights - **Not supervised**

=> Genetic Algorithm weight adjust

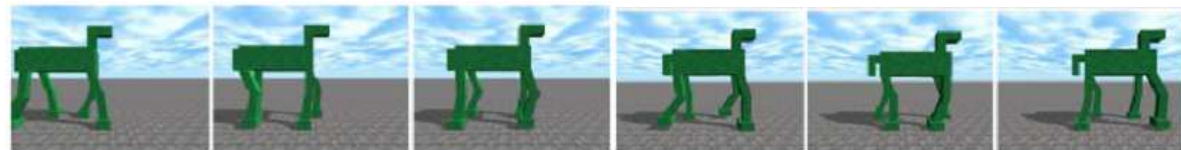
4. EVOLVING ANN AND ROBOTS

Simulation main goals:

Evaluate robot control...

1. Using evolved FSA (automata - sequence of target angles)
2. Using evolved ANN (sequence of joint angles)

Evolution:



FSA - Target angles evolved using a Genetic Algorithm

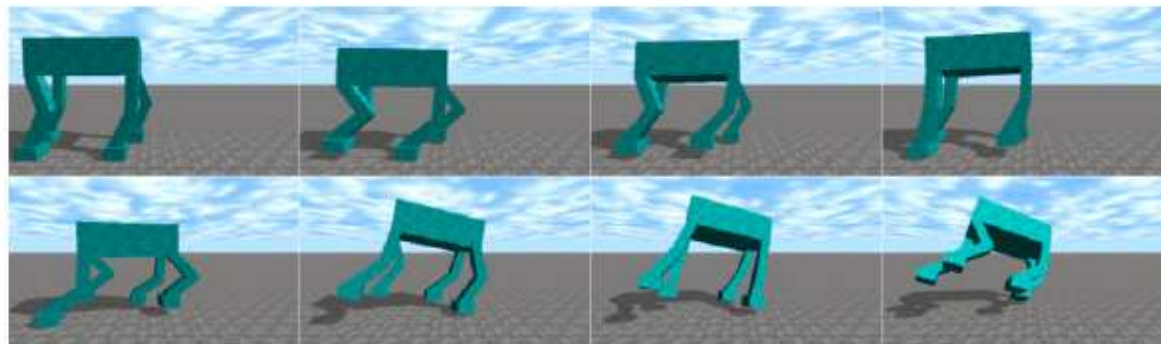
ANN - Weights evolved using a Genetic Algorithm

Robot Morphology - Dimension/Shape evolved by a GA

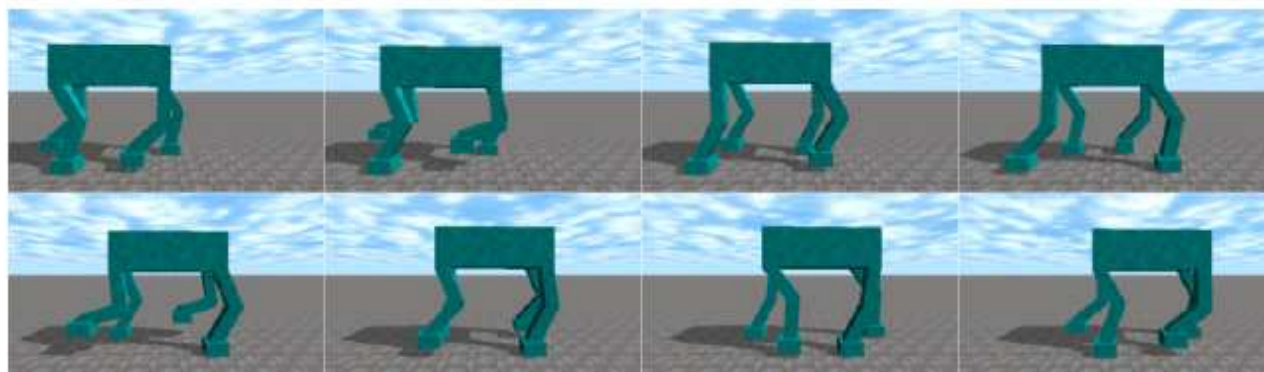
Fitness - Sensors (physical simulation)

4. EVOLVING ANN AND ROBOTS

Results: Evolving only ANN based robot control...



ANN => "Learning to Walk"



4. EVOLVING ANN AND ROBOTS

Results:

Evolving morphology...

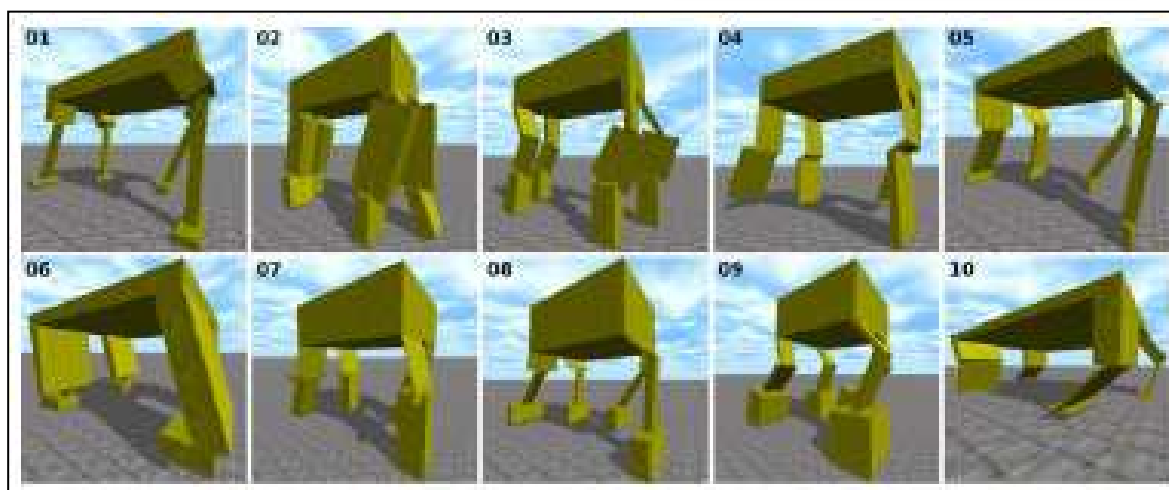
The chromossome includes x, y, z size for each segment

DIMENSIONS OF THE SIMULATED ROBOTS

TetraL3J			
Part	x	y	z
Body	45.0	15.0	25.0
Thigh	5.0	15.0	5.0
Shin	5.0	15.0	5.0
Paw	8.0	5.0	9.0



**Typical
Robot**



**Robots with
Evolved
Morphology**

4. EVOLVING ANN AND ROBOTS

Results:

Evolving Control and Morphology... GA Fitness

Only Control

Control + Morphology

Table 2: Resultados obtidos nos experimentos realizados

	Somente controle				Morfologia e controle			
E	F	D	B	G	F	D	B	G
1	16.265	29.189	0.0019	0.0793	18.802	38.028	0.0105	0.1012
2	16.635	28.306	0.0070	0.0695	17.903	32.959	0.0940	0.0747
3	16.991	27.850	0.0085	0.0631	19.839	39.525	0.0057	0.0987
4	16.678	27.915	0.0017	0.0672	17.801	37.858	0.0017	0.1125
5	16.157	28.201	0.0076	0.0738	20.093	27.409	0.0572	0.0307
6	15.965	31.126	0.0218	0.0928	15.902	32.802	0.0091	0.1054
7	17.335	29.629	0.0048	0.0704	18.869	41.132	0.0134	0.1167
8	16.654	29.038	0.0060	0.0738	18.498	36.218	0.0074	0.0951
9	16.289	30.151	0.0022	0.0849	19.078	39.162	0.0023	0.1050
10	16.227	29.808	0.0039	0.0833	15.572	37.397	0.0057	0.1396
μ	16.520	29.121	0.0065	0.0758	18.235	36.249	0.0207	0.0979
σ	0.420	1.075	0.0059	0.0091	1.504	4.096	0.0304	0.0288

4. EVOLVING ANN AND ROBOTS

Evolve robots structure and control **at the same time**

Table 6: Evolução da morfologia e do controle

E	Morfologia e controle			Somente controle		
	F	D	G	F	D	G
1	24,83	56,4	0,127	9,64	28,2	0,190
2	27,28	56,3	0,106	16,01	36,0	0,124
3	24,14	55,3	0,129	12,80	32,0	0,148
4	24,06	97,3	0,304	14,79	26,3	0,077
5	23,35	72,5	0,210	14,86	31,7	0,113
6	20,14	59,2	0,194	16,00	29,1	0,082
7	24,23	71,7	0,195	17,32	29,5	0,070
8	22,51	70,6	0,213	16,55	35,3	0,113
9	27,46	99,5	0,262	11,58	28,9	0,148
10	21,25	42,2	0,098	12,14	34,5	0,184
μ	23,93	68,1	0,184	14,17	31,2	0,125
σ	2,32	18,5	0,068	2,50	3,3	0,042

Does it works??

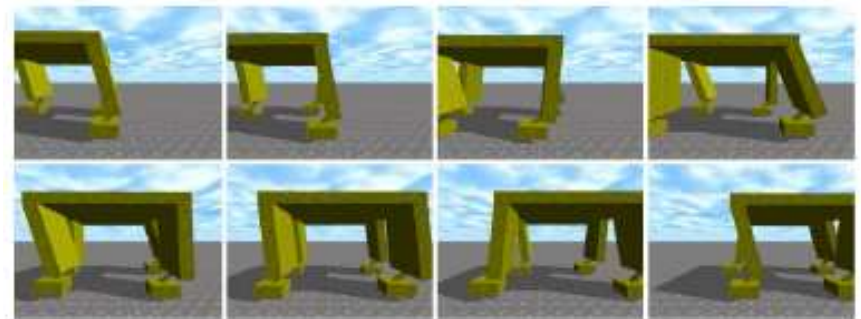


Figure 12: Robô evoluído no experimento 06

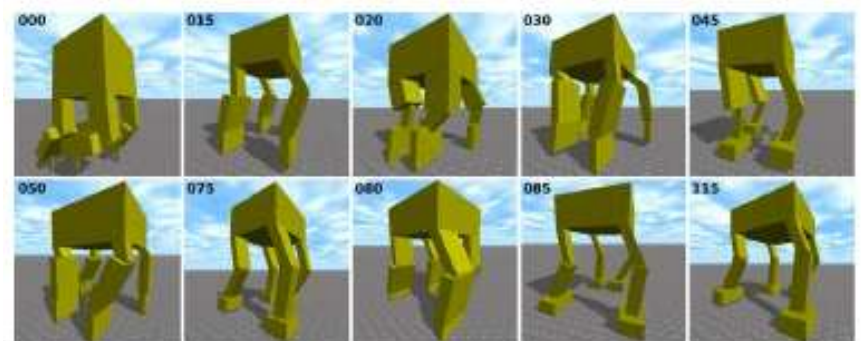
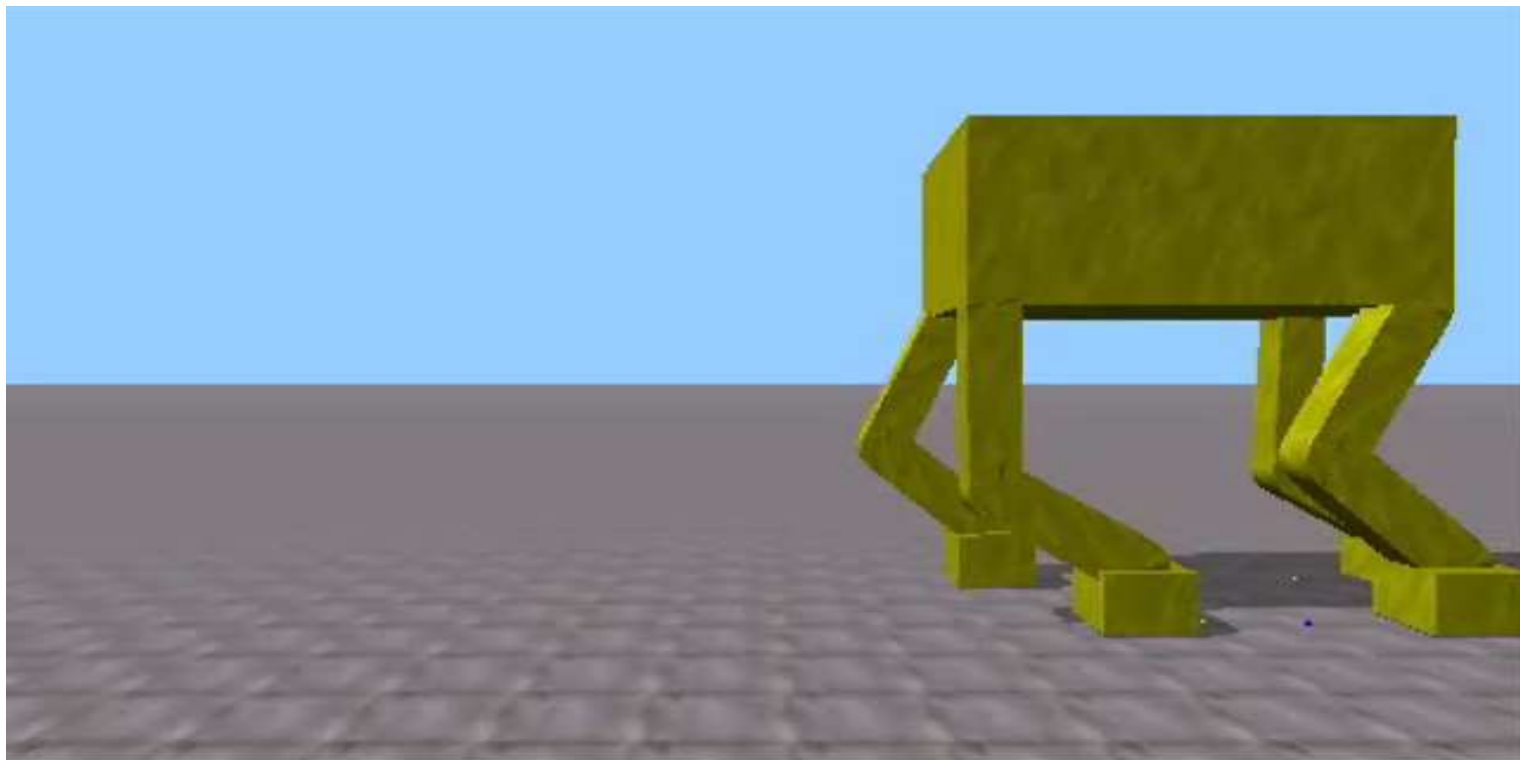


Figure 13: Progresso da evolução da morfologia

4. EVOLVING ANN AND ROBOTS

Simulation RESULTS:

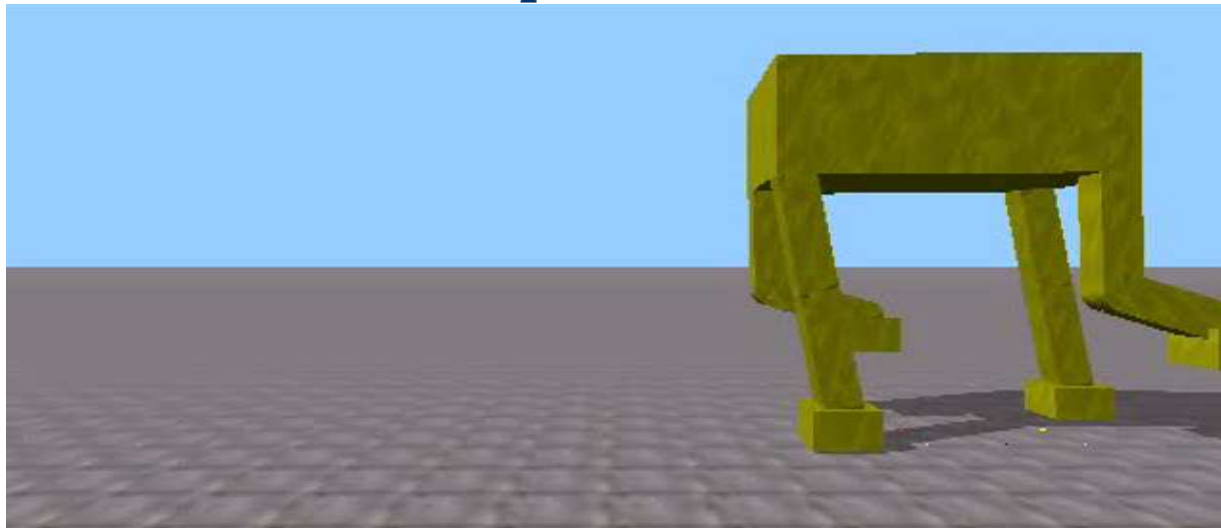
Tetrapod Video



4. EVOLVING ANN AND ROBOTS

Simulation

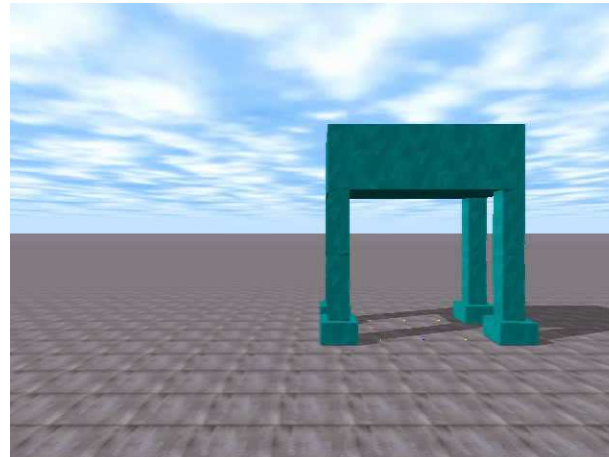
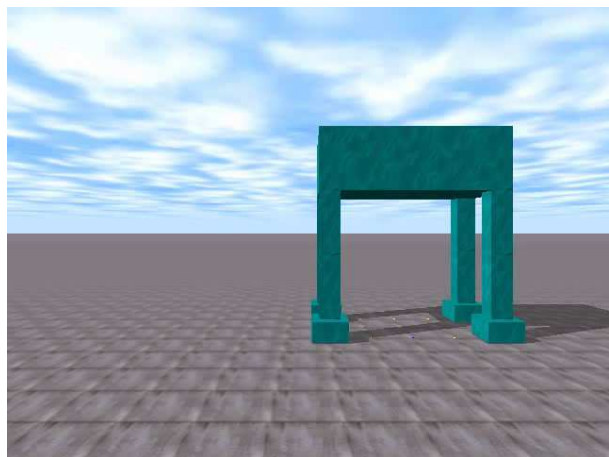
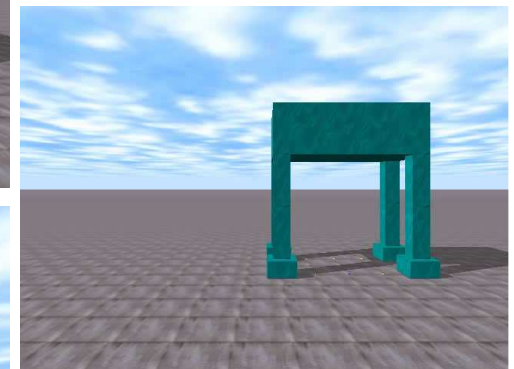
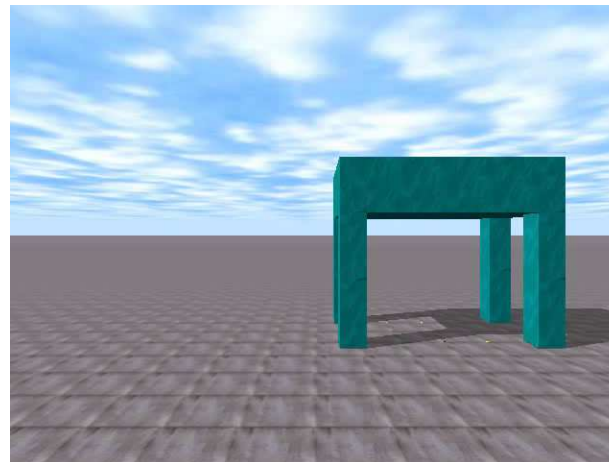
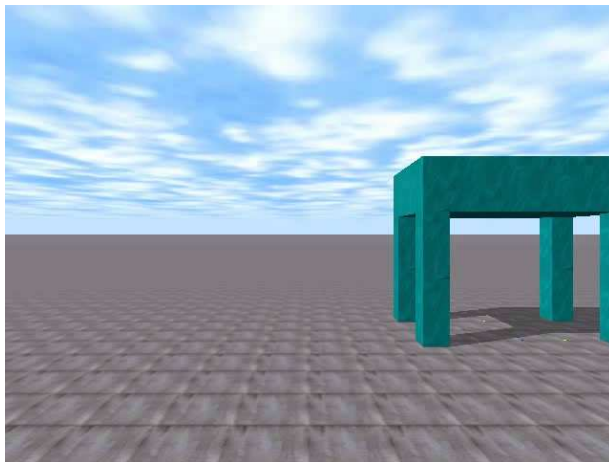
RESULTS: *Tetrapod Video*



4. EVOLVING ANN AND ROBOTS

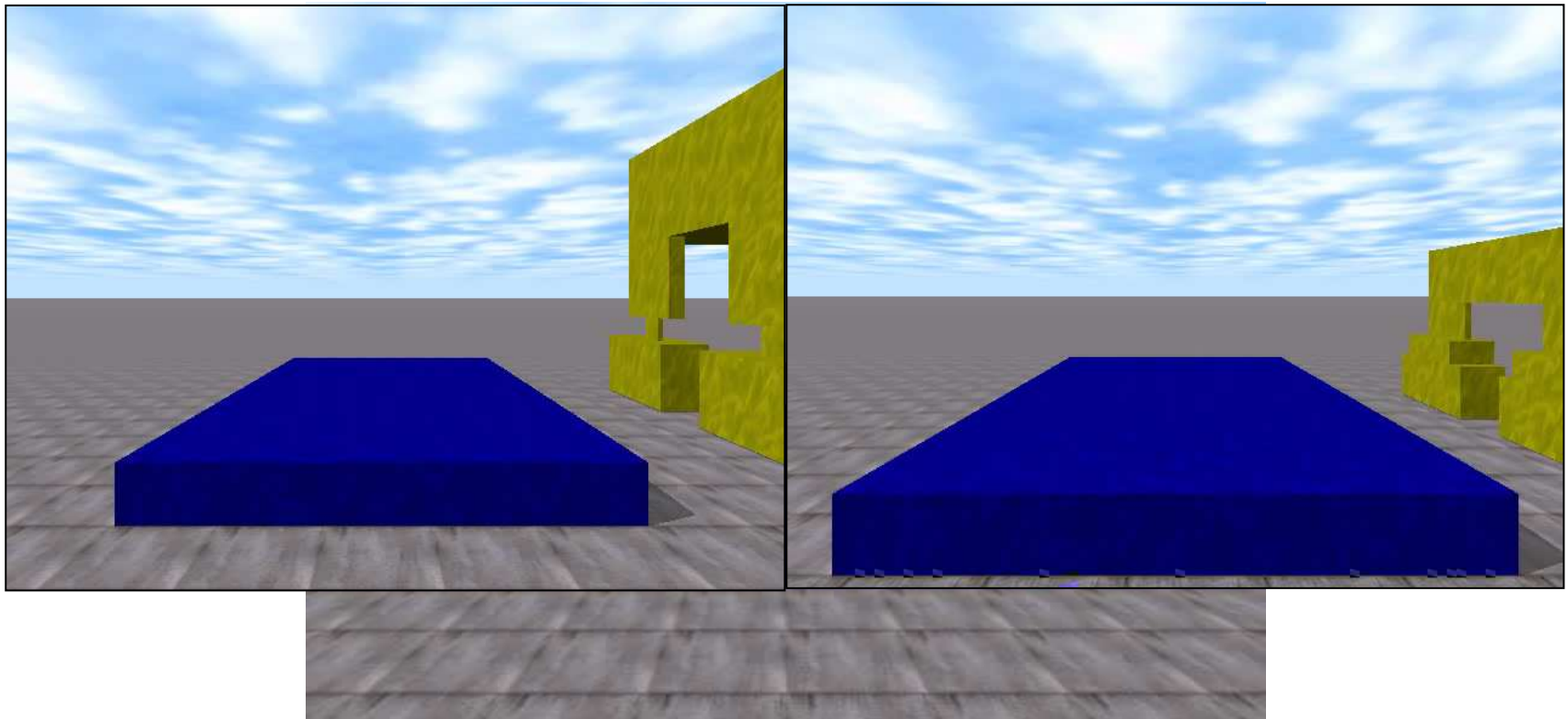
Simulation

RESULTS: *Tetrapod Video - "bloopers"*



4. EVOLVING THE MORPHOLOGY (*NEW*)

Evolve robots structure and control **at the same time**



Does it works? Yes...it seems to work very well!

5. CONCLUSIONS

Conclusions...

- We achieved *very good results* in the robot control (stable/robust)... ANN is better!
- Genetic Algorithms helped us to study and design better robots:
Joints, Actuators, Sensors,
Speed \times Stability \times Cost
- Genetic Algorithms +
3D Physically Realistic Simulation +
Evolved Finite State Machine Control +
Fitness Function selection +
Hardware configuration = **LEGGEN Framework**

