Autonomous robots: Design and Testing using Virtual Reality and Physical Simulation

Fernando Osório, Ph.D. / IEEE CS DVP

Research group:

GRAPHIT - Computer Graphics and Vision Group (Unisinos/PUC-RS)
GPVA - Autonomous Vehicles Research Group (Unisinos)
GIA - Artificial Intelligence Research Group (Unisinos)
RBV - Rede Brasileira de Visualização [FINEP/Brazil]

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Profa. Ph.D. Soraia Musse - Computing Science / PUC-RS
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M.Sc. Milton Roberto Heinen - Ph.D. Student at UFRGS
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Applied Computing Research Post-Graduation Program - PIPCA
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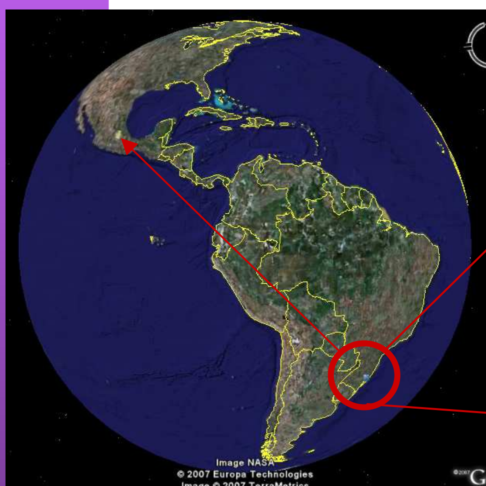
IEEE Computer Society DVP Program



UNISINOS

Jesuit University With:
- **30.000 Students**
- **900 Professors**
- **16 PPGs (post-grad programs)**

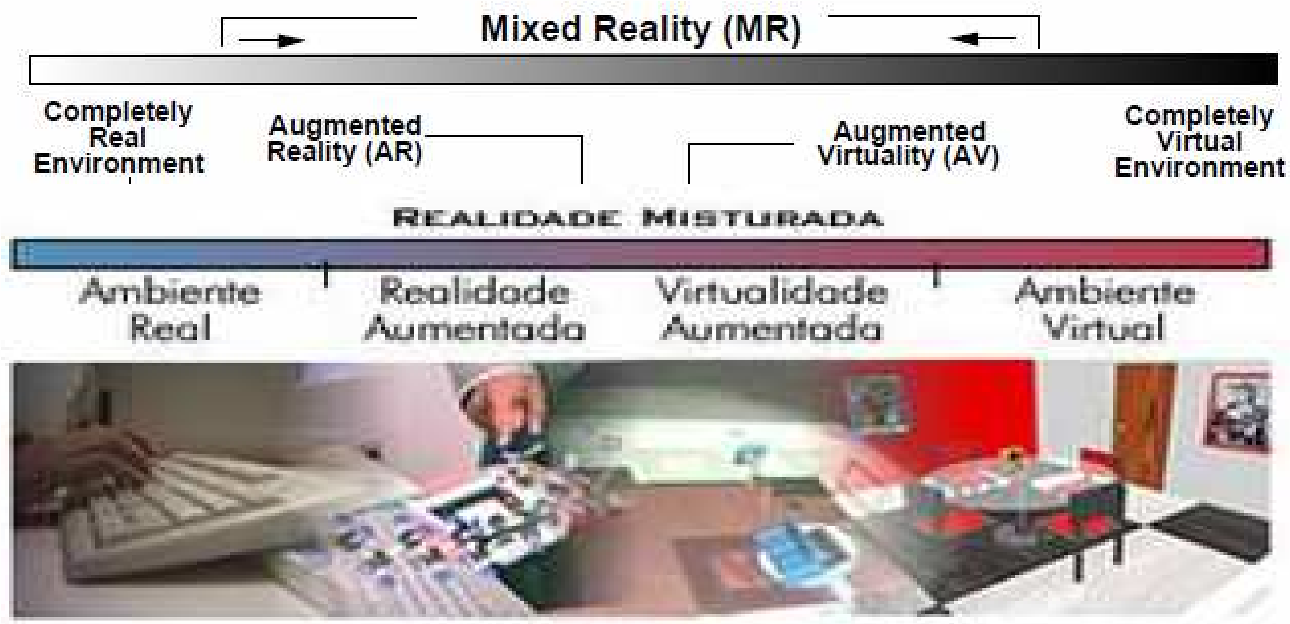
Presentation Topics

Agenda:

1. **Introduction: VR - Hierarchy of Models**
2. **VR and Simulation**
   Geometry, Physics, Behaviour, Knowledge and Cognition
3. **Physics Simulation Tools**
   Opensteer, ODE, PhysX, Deformable/Dynamic
4. **Intelligent Behaviour**
   Agents: Perception, Action, Behaviour
   Autonomous Robots and Agents - Control
   Multi-Agents Systems - Knowledge
5. **Applications: Autonomous Robots VR Simulation Tools**
6. **Conclusions and New Trends**

Vídeo Demo Web/Java

Introduction VR - Virtual Reality



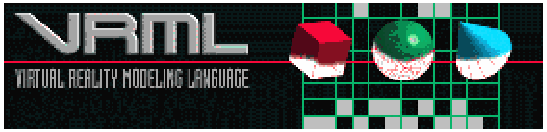
From REAL to VIRTUAL
3D + Immersion + Interaction

Introduction VR - Virtual Reality

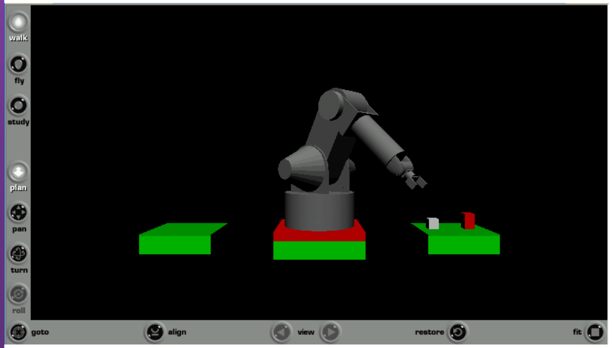
VISUALIZING 3D & VIRTUAL ENVIRONMENTS

Virtual Reality...

* **VRML** - 3D Worlds (Geometry)
* **QTVR** - Panorama 3D (Images)



\VRML



Augmented Reality

Real World Integrated with Virtual Objects

IRISA / INRIA - France
http://www.irisa.fr/lagadic/demo/demo-ar3/demo-ar3-eng.html

Virtual Reality

VISUALIZING 3D & VIRTUAL ENVIRONMENTS

Virtual Reality...

*** 3D Virtual Environment**

*** Interaction => Virtual Reality Devices**

*** Immersion => Virtual Reality Devices**

*** Realism => Graphical Realism (photo-realism)**

Movements

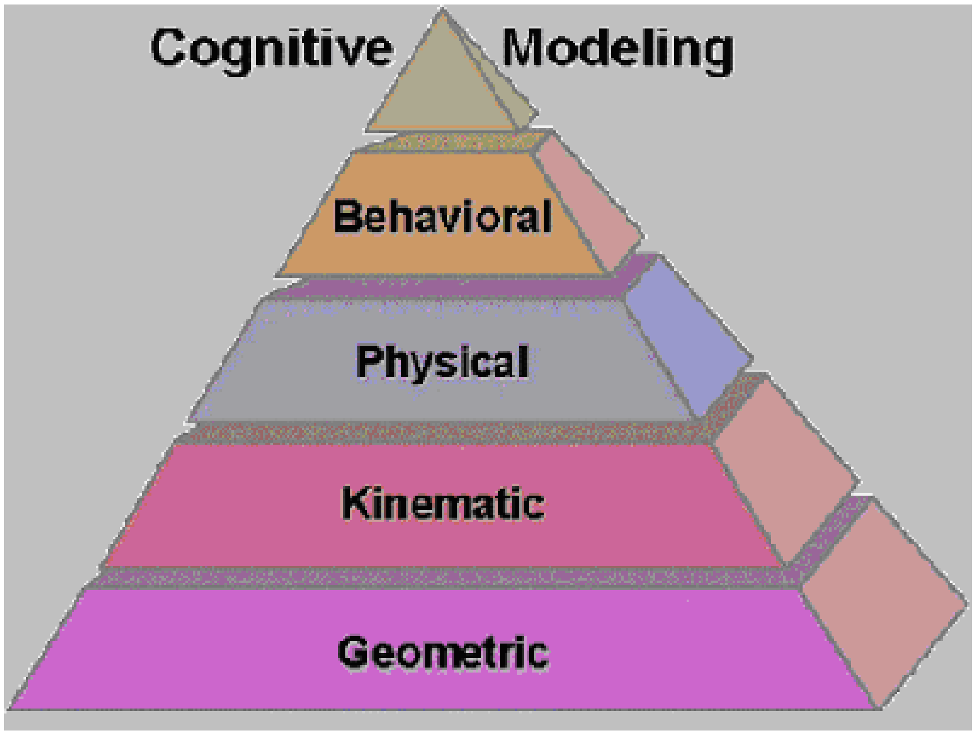
How to do it?

Interaction Real x Virtual

"Physics Realism"

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models



[Funge 1999]

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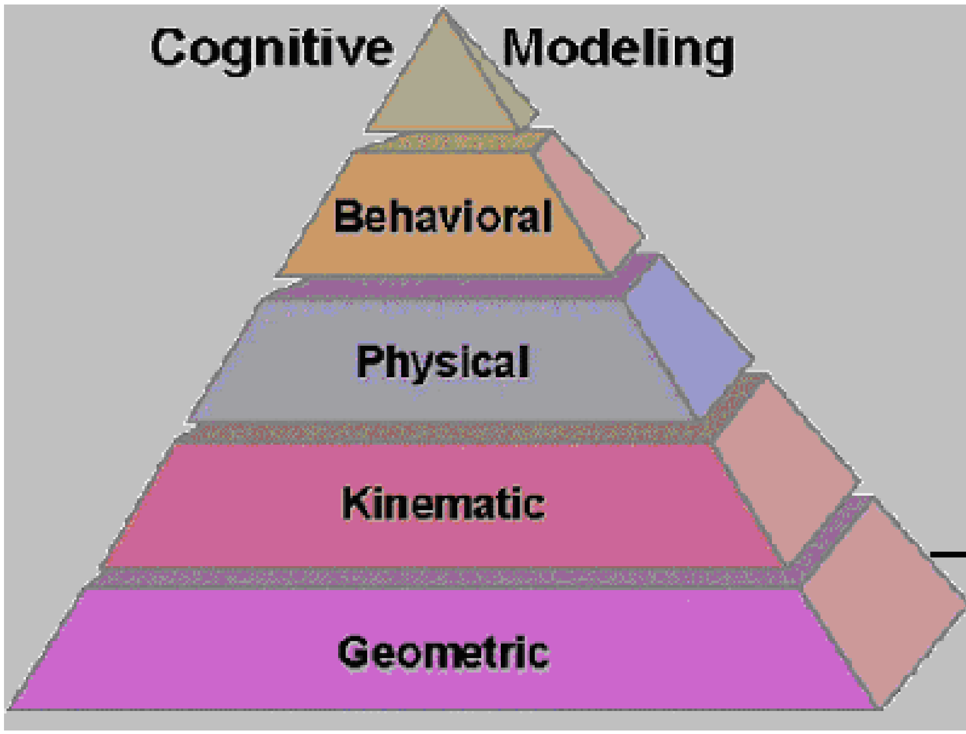

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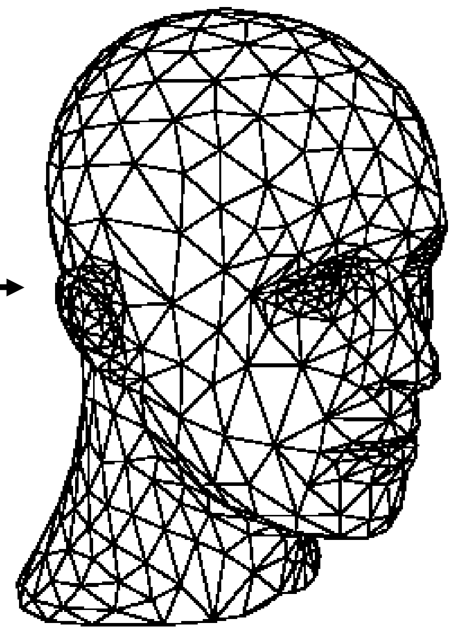
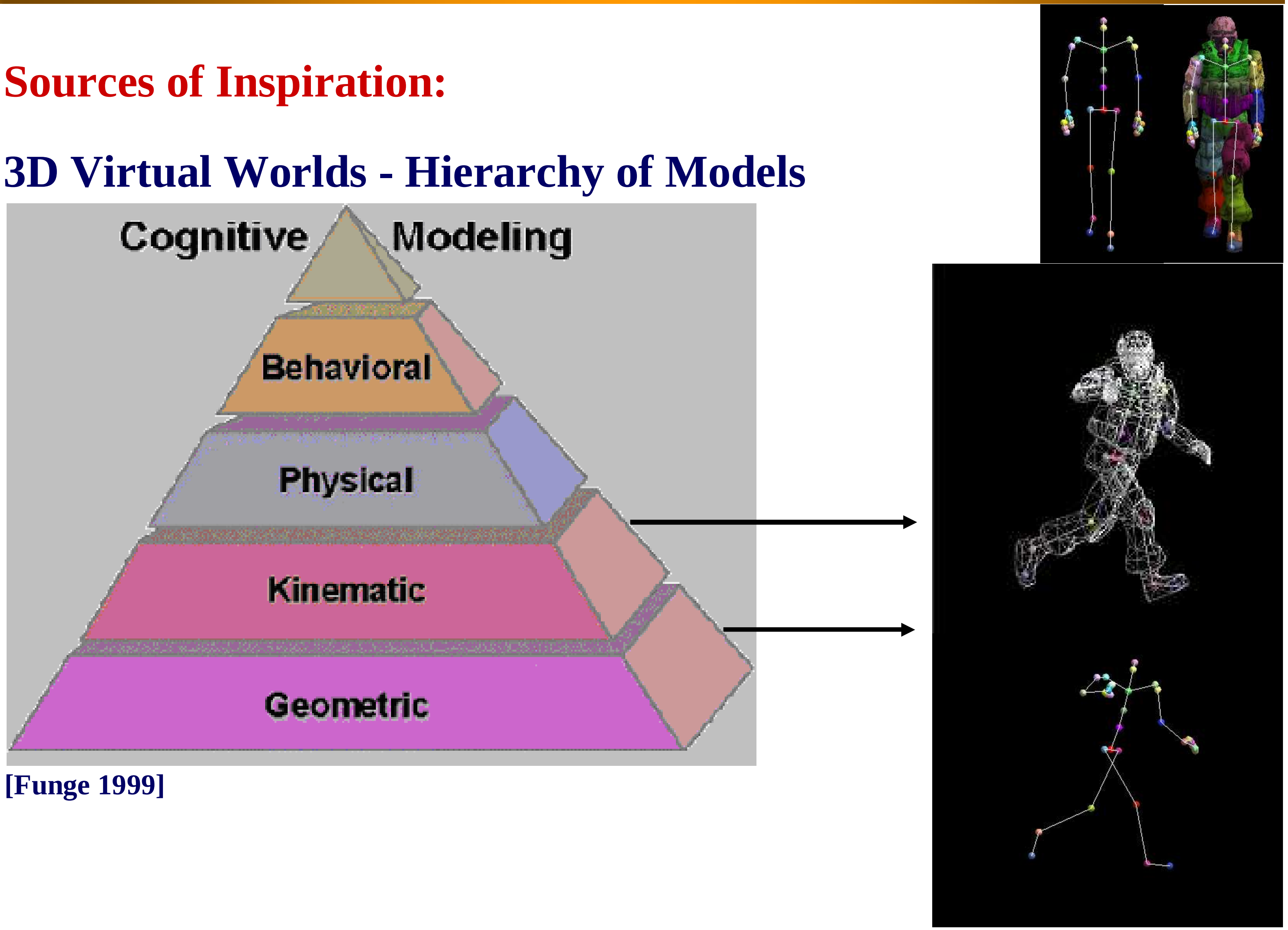


1. Introduction

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models



[Funge 1999]

1. Introduction

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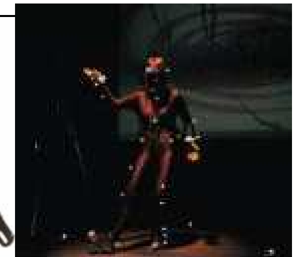
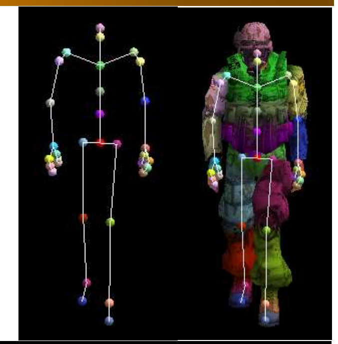
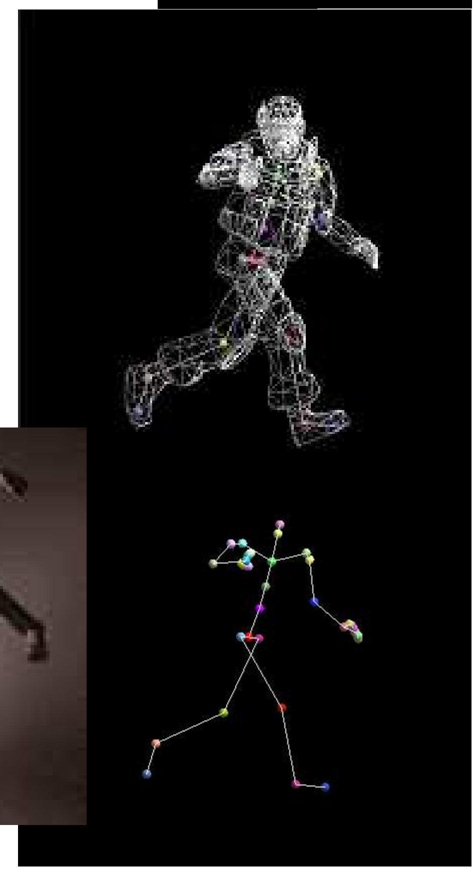
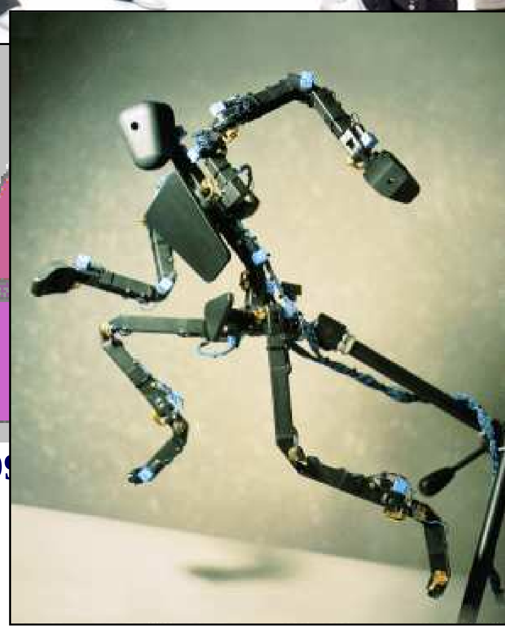
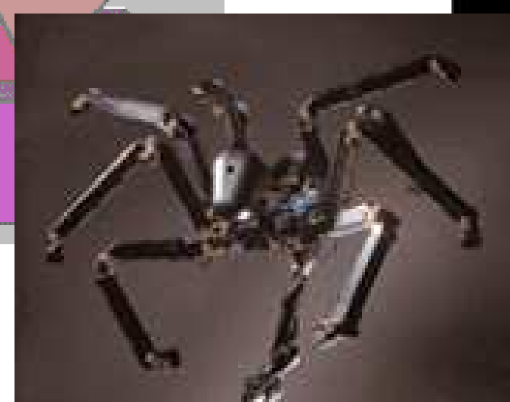
3D











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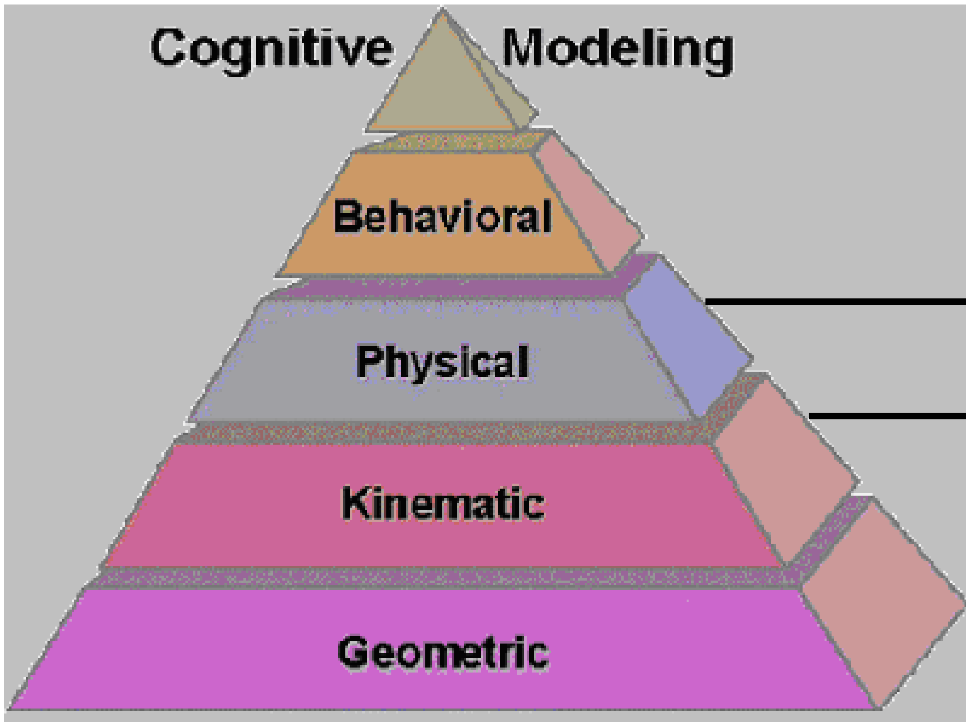

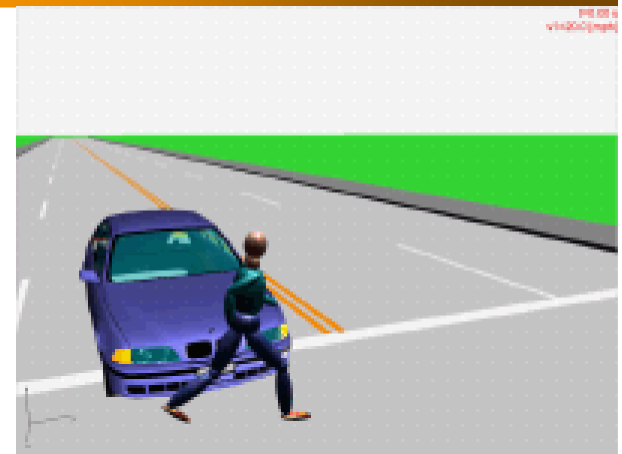

[Funge 1999]

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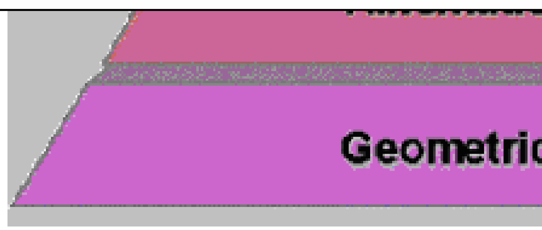

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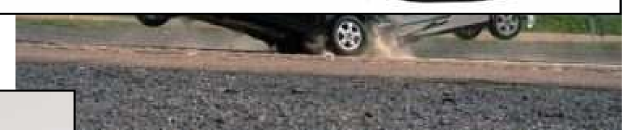

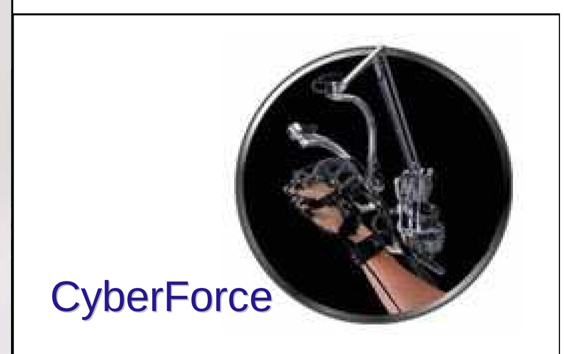

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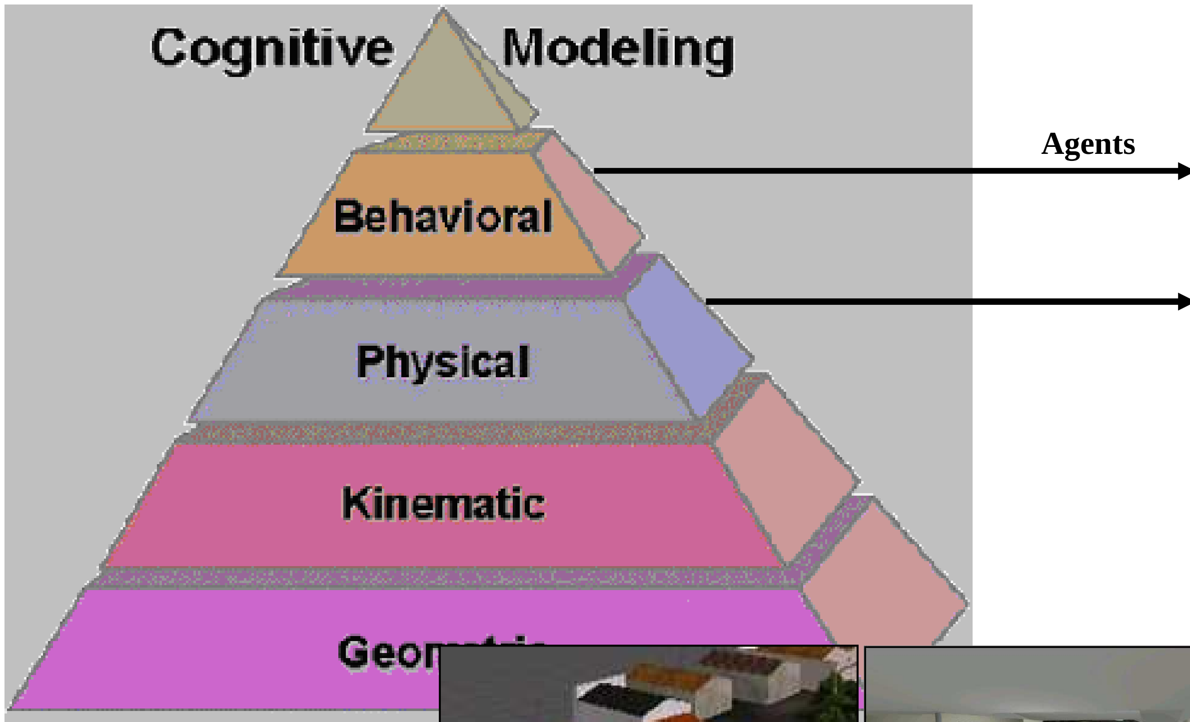
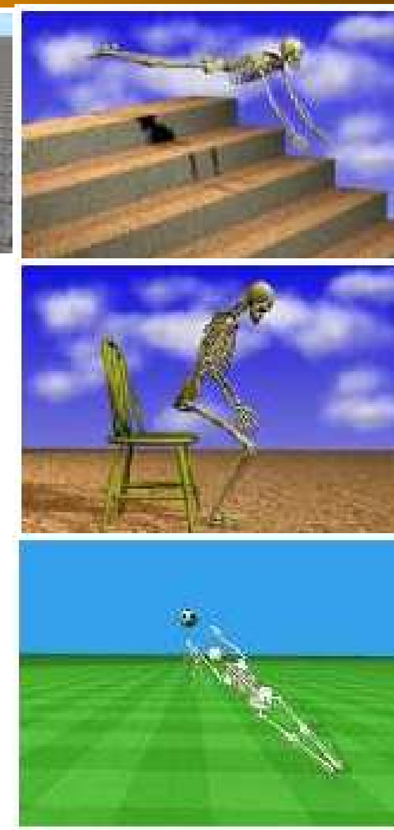
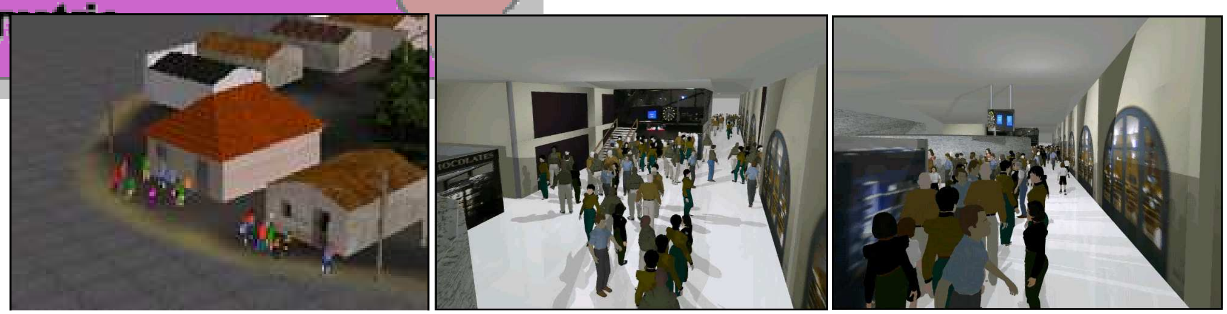


[Funge 1999]



[Ari Chapiro - Dance]



[CromosLab]

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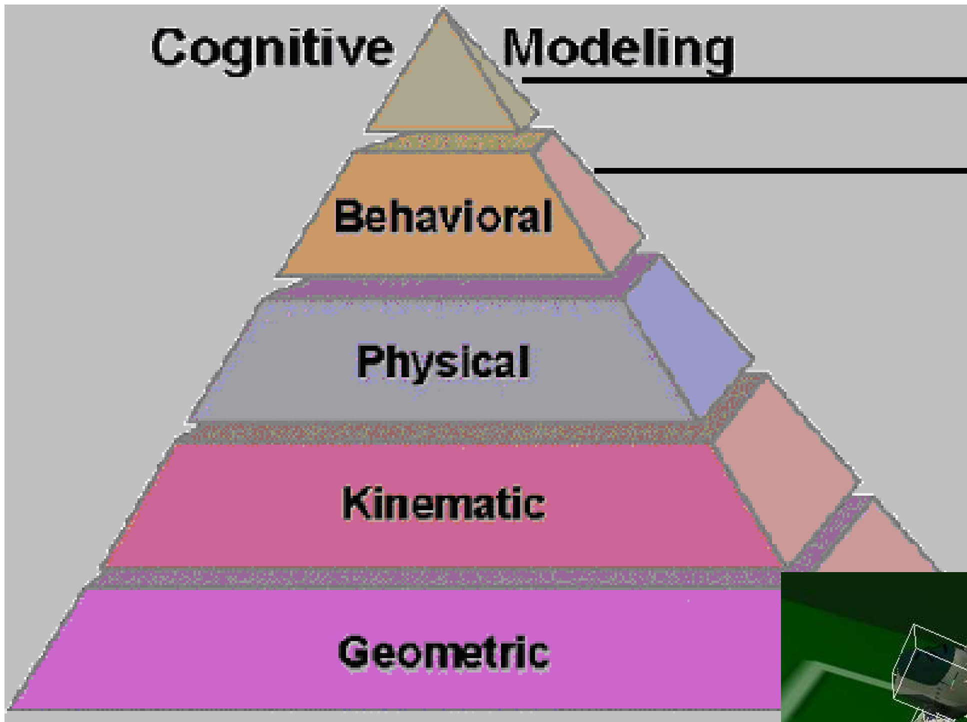
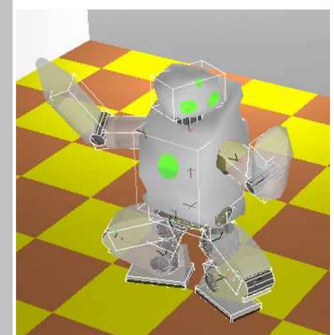
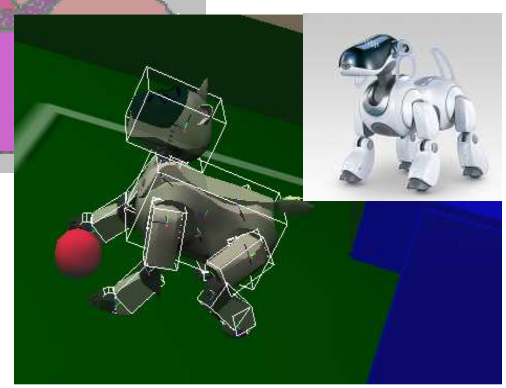
3D Virtual Worlds - Hierarchy of Models



[Funge 1999]

The Sony Dream Robot simulated into Webots





The Sony Dream Robot in the real world

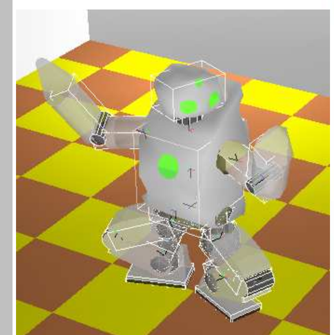
1. Introduction

Sources of Inspiration:

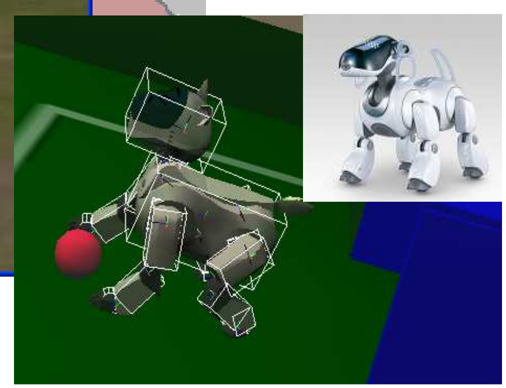
Autonomous Behaviour

The Sony Dream Robot simulated into Webots

3D Virtual Worlds - Hierarchy of Models



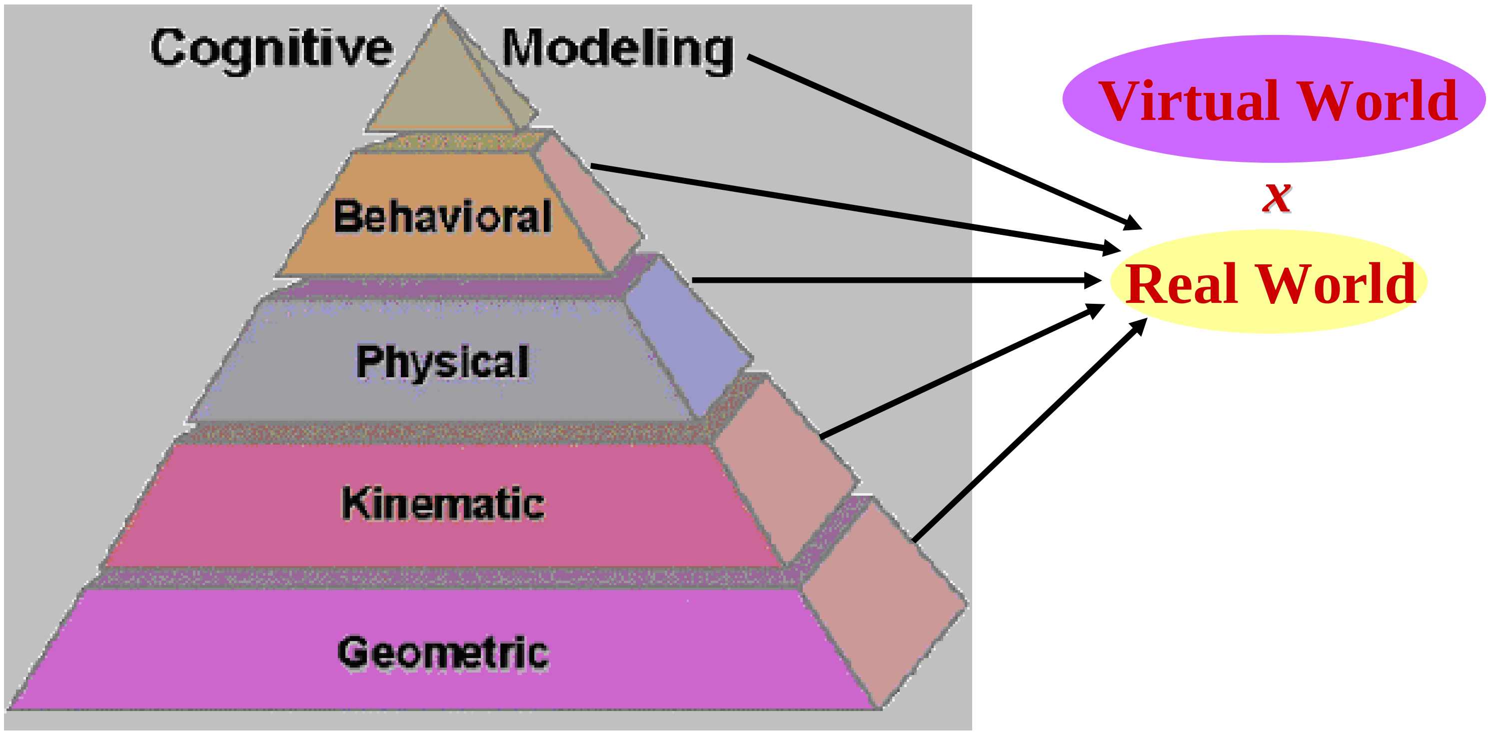
The Sony Dream Robot in the real world



Knowledge

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models



[Funge 1999]

Presentation Topics

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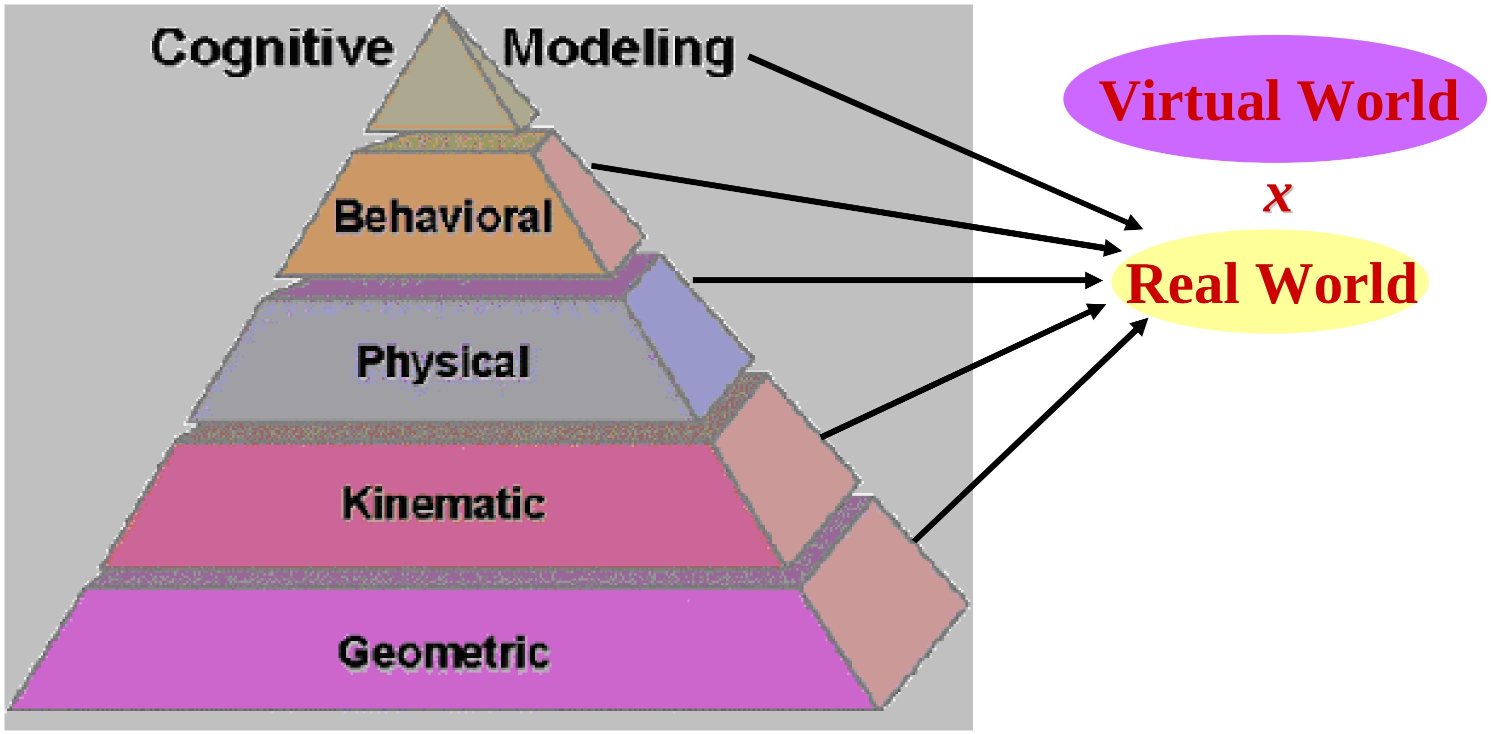
   Multi-Agents Systems - Knowledge
5. **Autonomous Robots VR Simulation Tools**
6. **Conclusions and New Trends**

Vídeo Demo Web/Java

2. VR and Simulation

Sources of Inspiration:

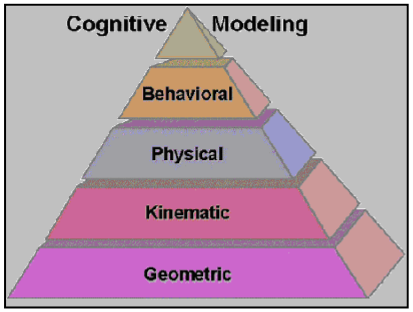
3D Virtual Worlds - Hierarchy of Models



[Funge 1999]

Increasing Reality in VR Applications: Physical and Behavioral Simulation

Realistic VR



Virtual World

x

Real World

Real World Simulation

From Simple VR Visualization Tools to Realistic VR Simulation Tools

Visualization	**Geometry** [3D Meshes]	Static Objects Animated Objects (Key-Frame)
Simulation of Motion	**Physics** [3D Objects]	Rigid Body (Physically based) Kinematics (Movement) Collision (Solid Objects) Collision Response Articulations Particles (Fire, Smoke, Water) Springs (Mass-spring Systems) Deformable Objects (Cloths, Elastic, Fluids) External Forces: Interaction Interaction Object x Object Interaction Camera x Object Interaction User x Object Interactive Control
Simulation of Behavior	Artificial Intelligence **"Simple A.I."** **Behavior** [Agents] [Characters]	Agents Control Scripts Finite State Automata (FSA) Perception (Sensorial) Action (Motor) Control: Reactive Control: Deliberative Control: Modular / Hybrid Memory, Beliefs, Intentions,... Biomechanics Simple Autonomous Agents
Simulation of Intelligent Behavior	Artificial Intelligence **"Advanced A.I."** **Cognitive** [Autonomous Agents] [Multi-Agents]	Knowledge Reasoning Cognition Communication Cooperation Coordination Adaptation: Learning, Optimization, Evolution Robust Autonomous Agents

: Models and Components of a Virtual Reality Environment applied into Realistic Simulations

3. Physics Simulation Tools

Simulation Tools:

*** ODE - Open Dynamics Engine**

*** OpenSteer**

*** PhysX AGEIA**

*** Deformable Objects and Fluids:**
- **Finite Elements Methods**
- **Spring-Mass Systems**
- **CFD (Computational Fluid Dynamics)**
- **Level Set Methods**

VR Simulation: Some important questions...

3. Physics Simulation Tools

Simulation Tools:

*** ODE - Open Dyna**

*** OpenSteer**

*** PhysX AGEIA**

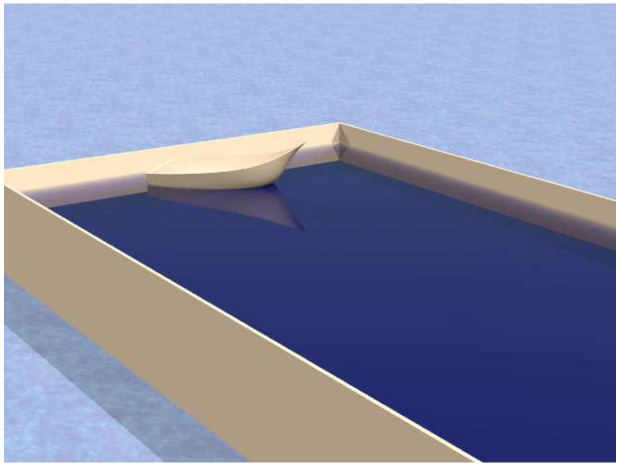
*** Deformable Object**
- Finite Elements M
- Spring-Mass Sys
- CFD (Computati
- Level Set Methods

Physics:

Physical structure: resistance, mass, density, elasticity;
Position and orientation in the 3D space;
Kinematics and Dynamics;
Linear and angular velocities;
Motion (w/ forces and torques), trajectories;
Acceleration, deceleration;
Attraction and repulsion;
Gravity, friction, inertia;
Kinetic and potential energy;
Laws of energy conservation, linear and angular momentum;
Collisions and reaction to collisions;
Steering models (wheeled cars, aircrafts, projectiles, boats and ships);
Articulated Rigid Bodies Simulation (skeleton, robotic arm);
Dynamic Simulation of Deformable Objects: elastic objects;
Fluid simulation and Particle Systems (fire, smoke, clouds and liquids).

VR Simulation: Some important questions...

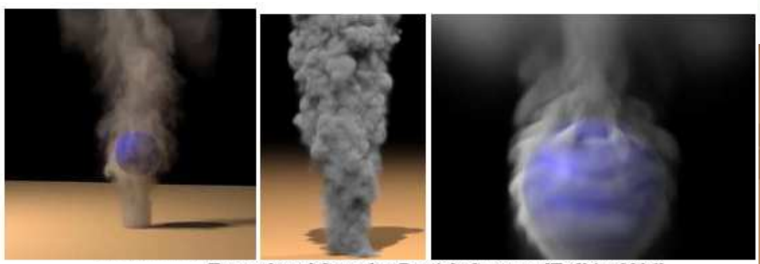
3. Physics Simulation Tools



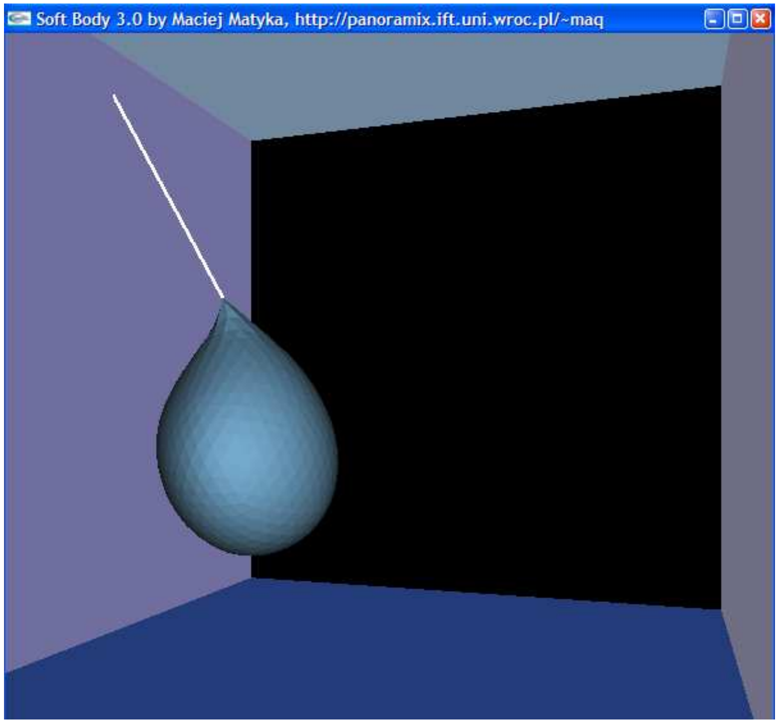
*** Deformable Objects and Fluids**

- Finite Elements Methods
- Spring-Mass Systems
- CFD (Computational Fluid Dynamics)
- Level Set Methods

Examples of Complex Deformable Objects [Fedkiw 2006]



Examples of Complex Particle Systems [Fedkiw 2006]



3. Physics Simulation Tools

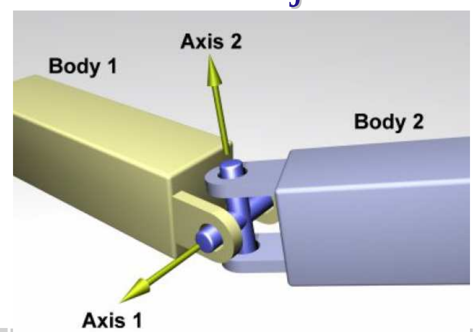
*** ODE - Open Dynamics Engine**

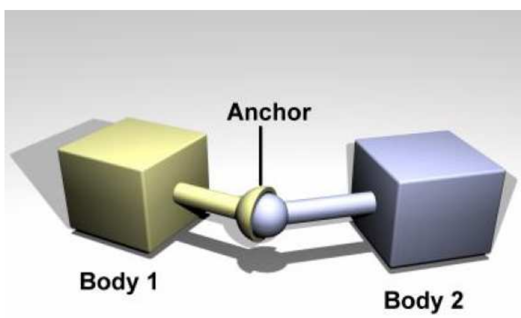
Simulation of Articulated Rigid Body Dynamics

Open Source Library (C/C++ API)

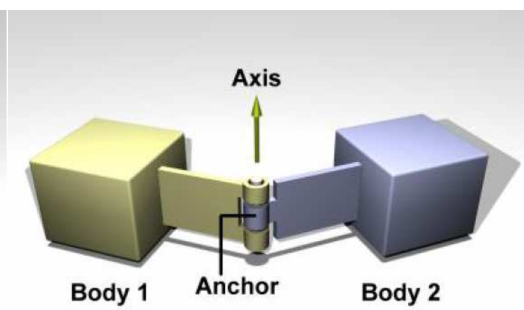
Used with OSG, Ogre3D, CrystalSpace, ...

Universal joint

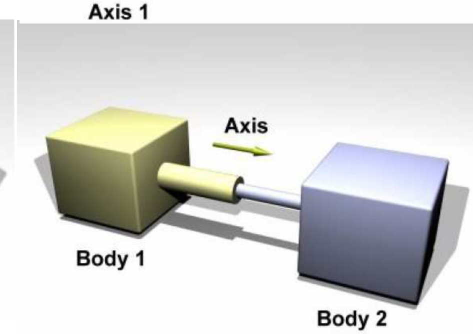




Ball and socket joint



Hinge joint

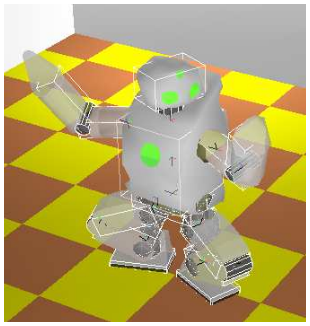


Slider joint

3. Physics Simulation Tools

* ODE - Open Dynamics Engine

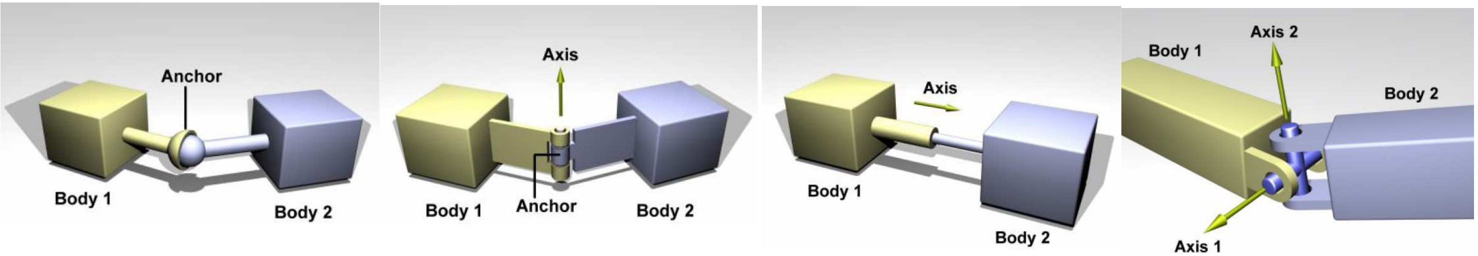
Webbots uses ODE [Cyberbotics]



Simulation of Articulated Rigid Body Dynamics

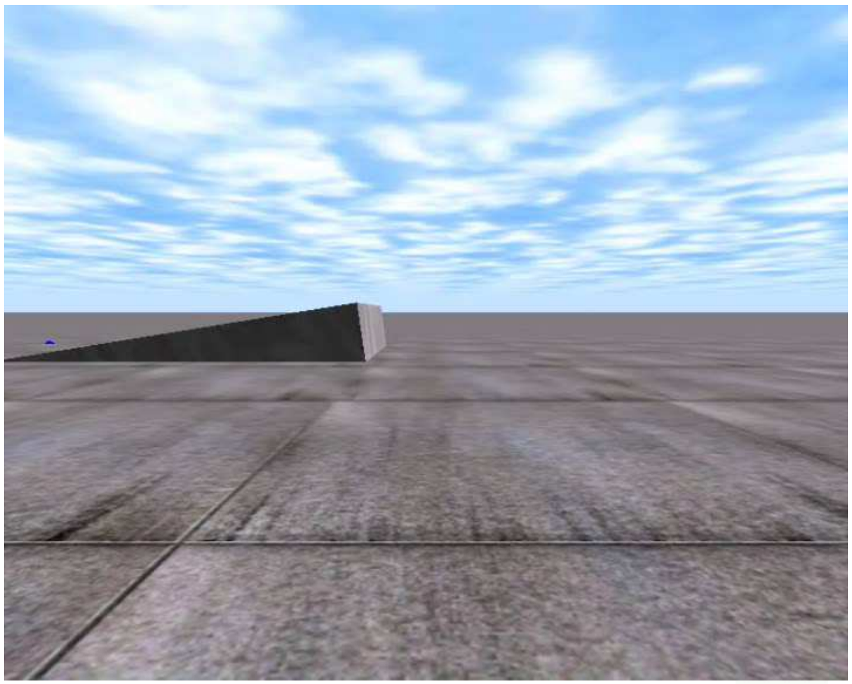
Physics Simulation:

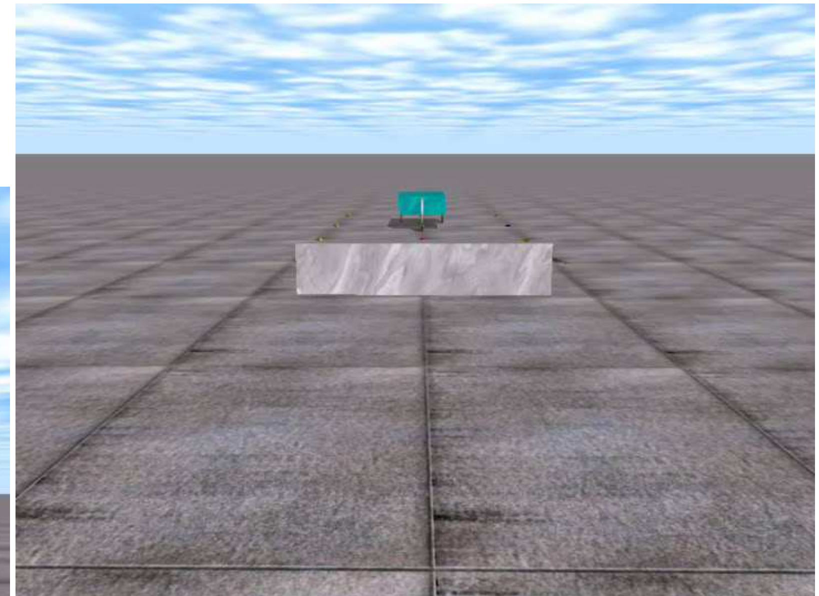
- Gravity, friction, acceleration, deceleration;
- Generation of motion: applying forces and torques (motors);
- Collision avoidance and treatment (reaction, object bounce);
- Kinematics models and rigid body dynamics simulation;
- Different types of joints with actuators (motors)

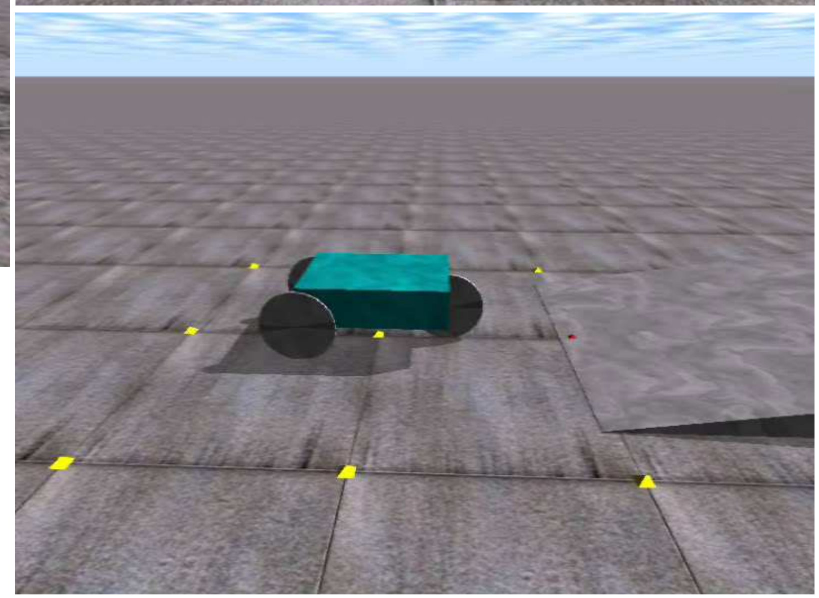


3. Physics Simulation Tools

* ODE - Open Dynamics Engine







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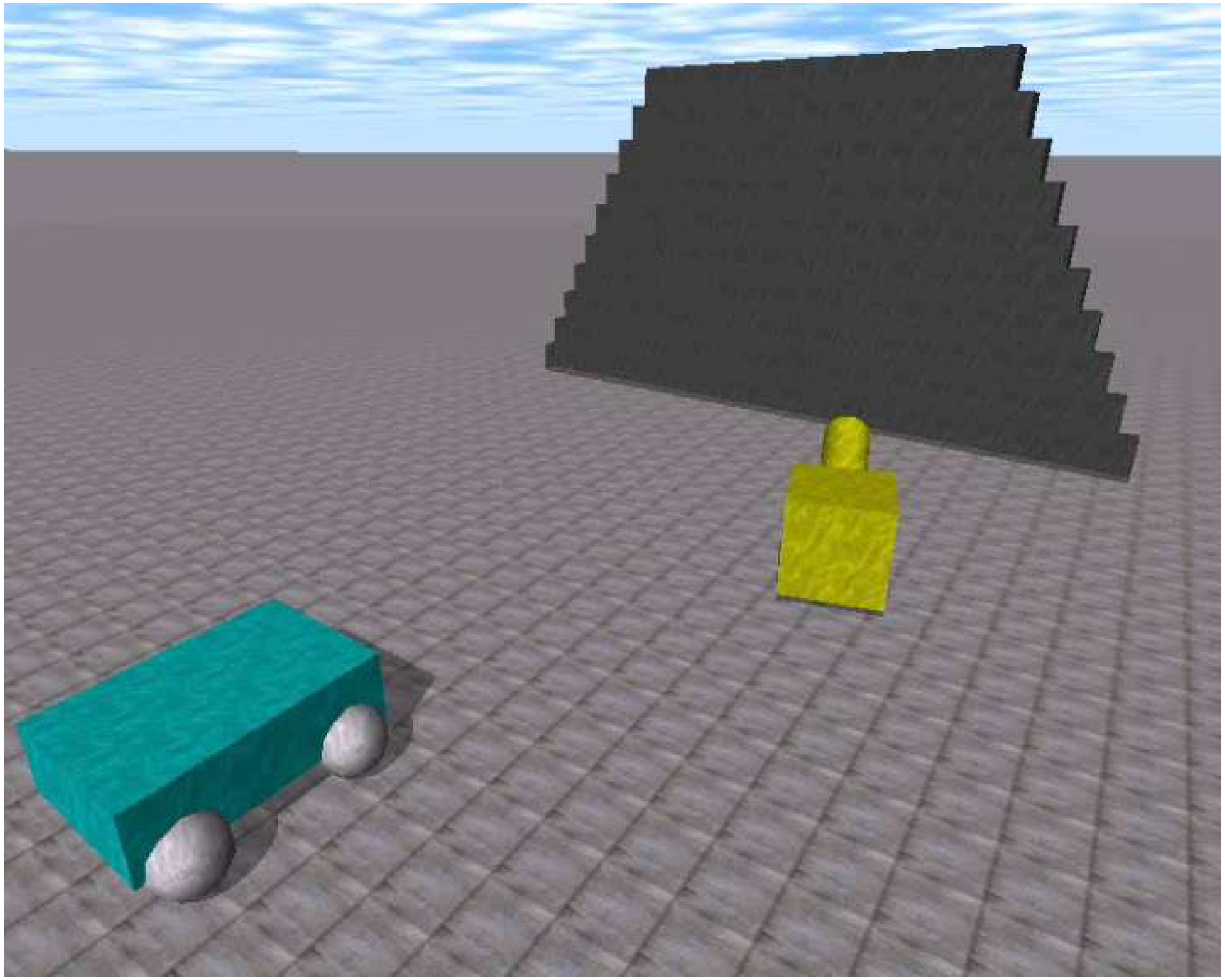
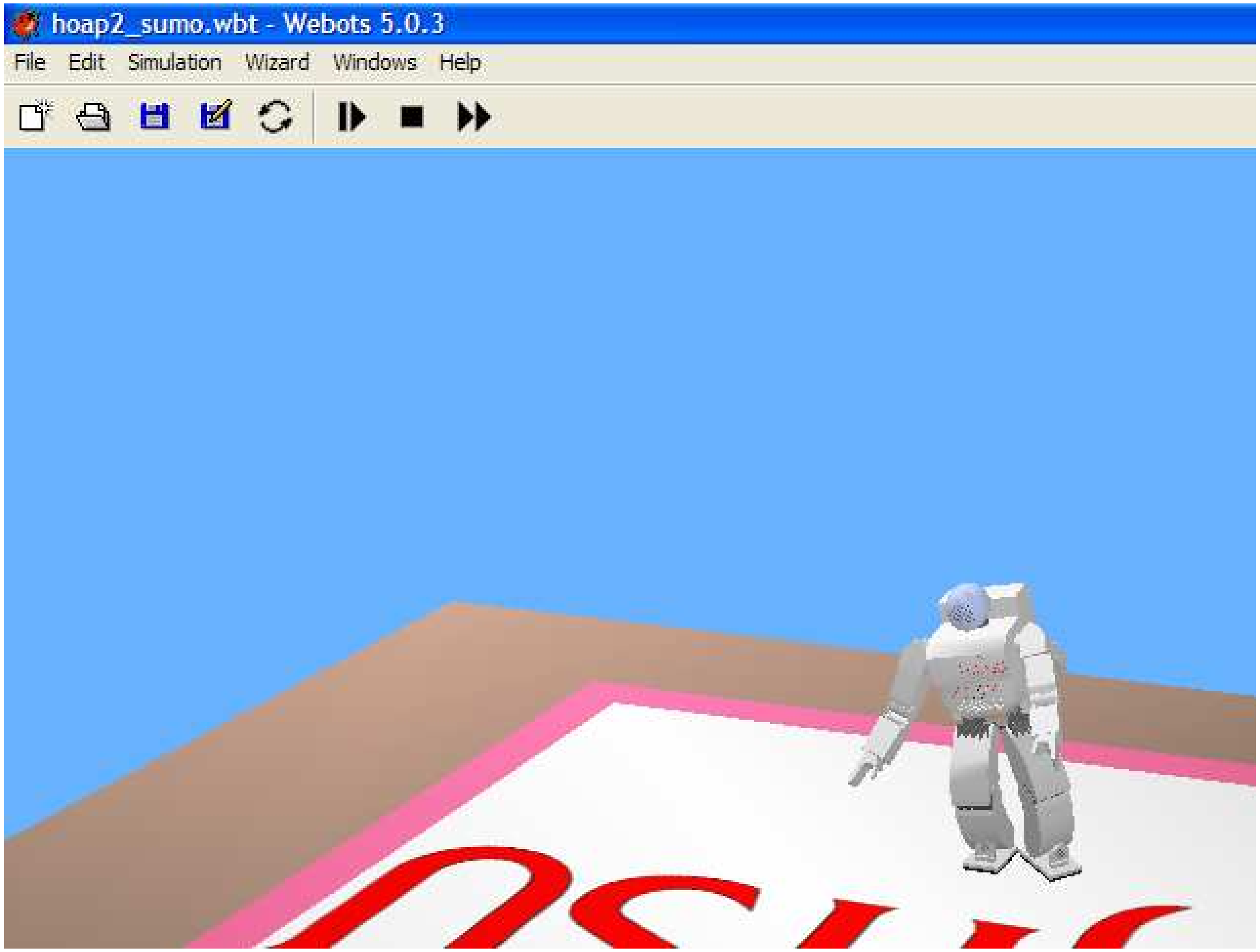


3. Physics Simulation Tools

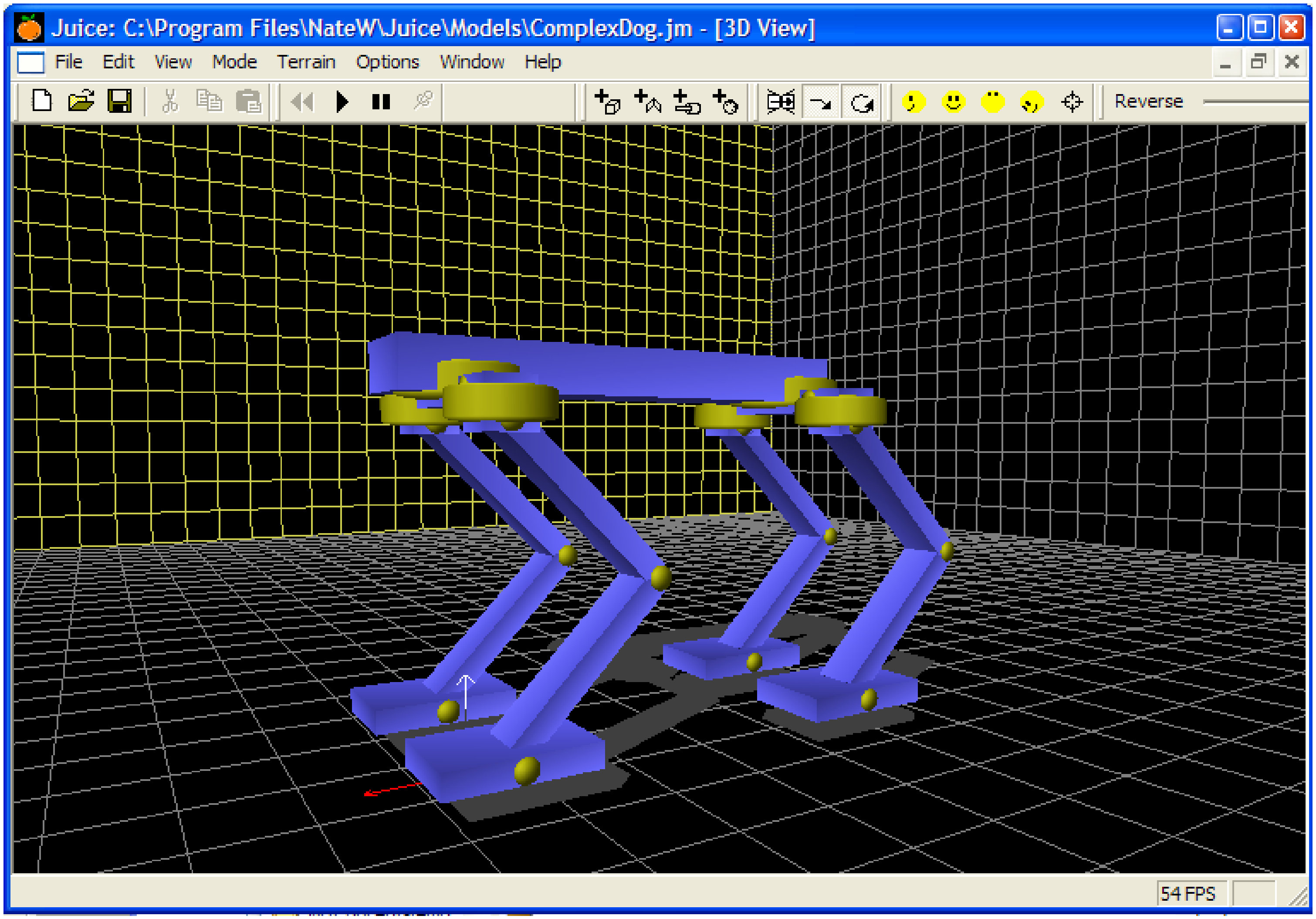
* ODE - Open Dynamics Engine



Webots
Cyberbotics

3. Physics Simulation Tools

* ODE - Open Dynamics Engine



Juice
[Nate W.]

3. Physics Simulation Tools

Simulation Tools:

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*** OpenSteer**

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- **Finite Elements Methods**
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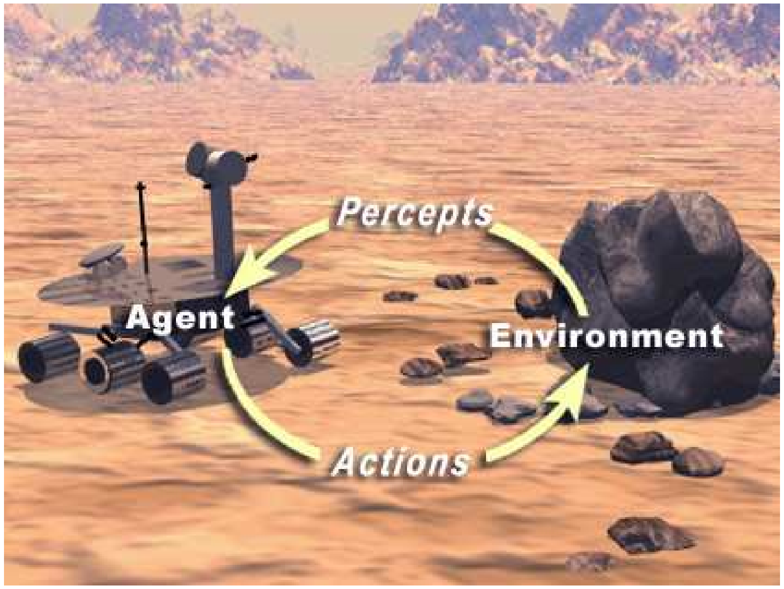
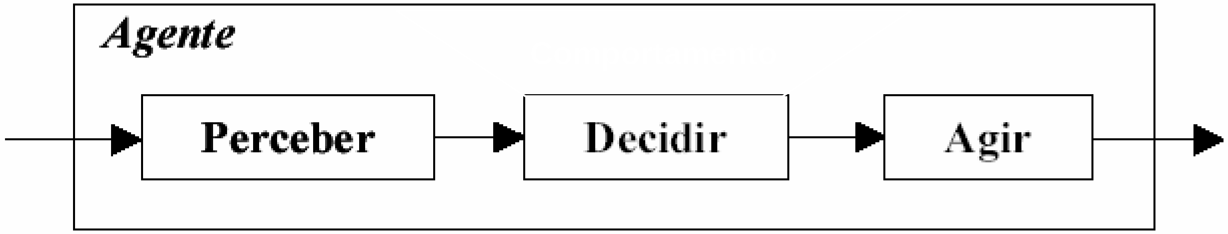
VR Simulation: Some important questions...
REAL TIME SIMULATION

4. Intelligent Behaviour

Intelligent Agents:



Agents: Perception, Action
Agent Behaviours
Control Architectures
Autonomous Agents
Multi-Agents Systems
Knowledge / Reasoning

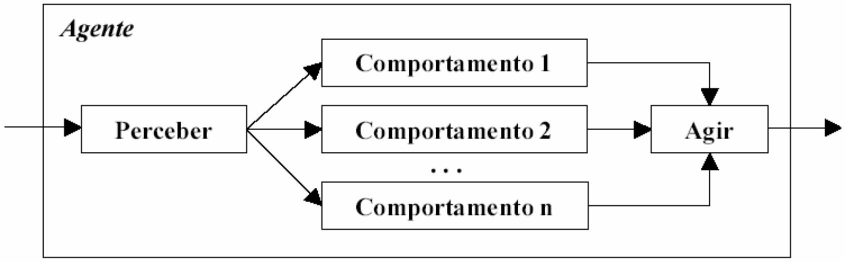


Arquitetura puramente reativa

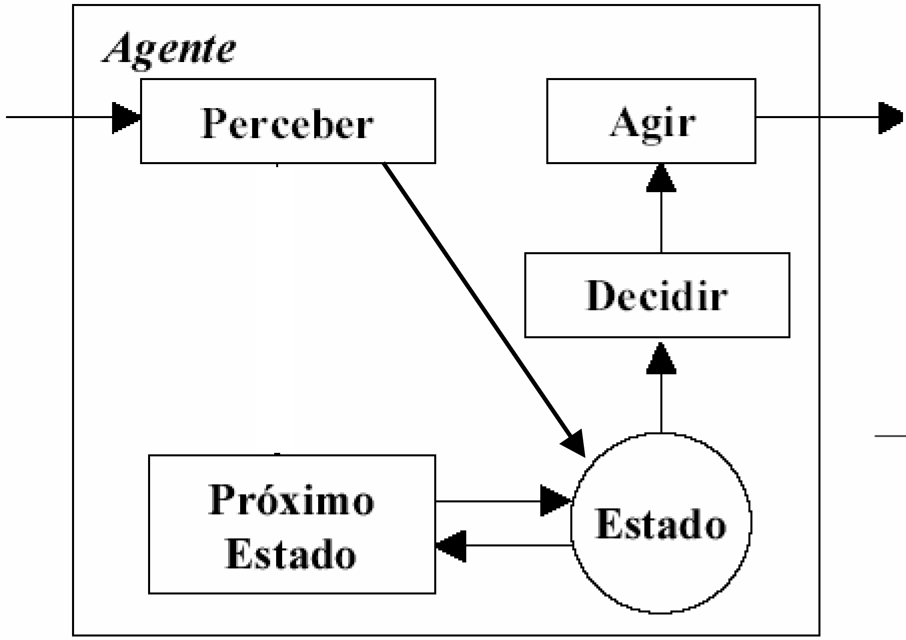
4. Intelligent Behaviour

Intelligent Agents:

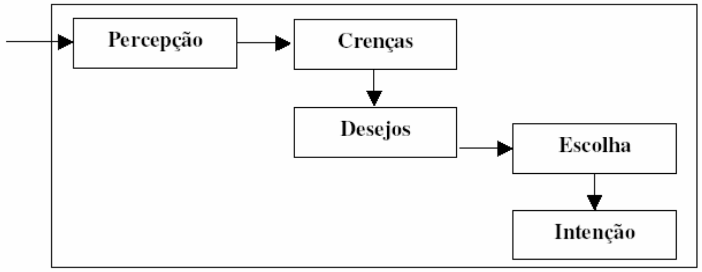
Agents: Perception, Action
Agent Behaviours



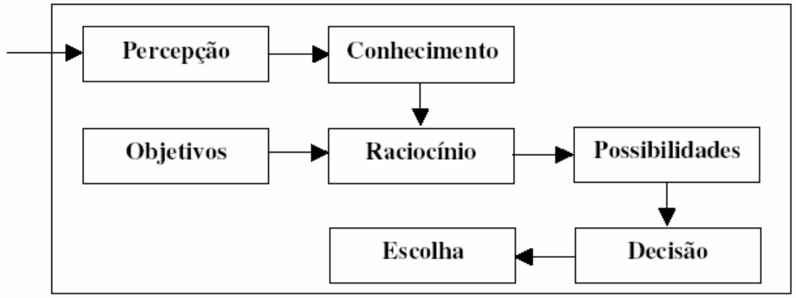
Hybrid Architecture



Arquitetura com Estado Interno



Architecture BDI (Beliefs-Desires-Intentions)



Reactive-Deliberative Architecture

Control Architectures: Reactive, Deliberative, Hierarchical, Hybrid

F. Osório et al.
[Virtual Concept 2005]

4. Intelligent Behaviour

Intelligent Agents:

Agents: Perception, Action

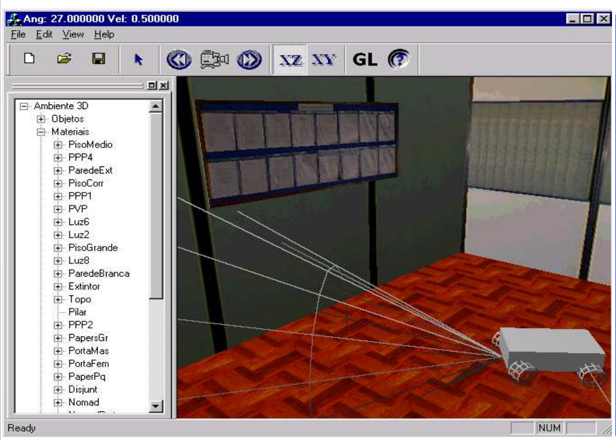
Agent Behaviours

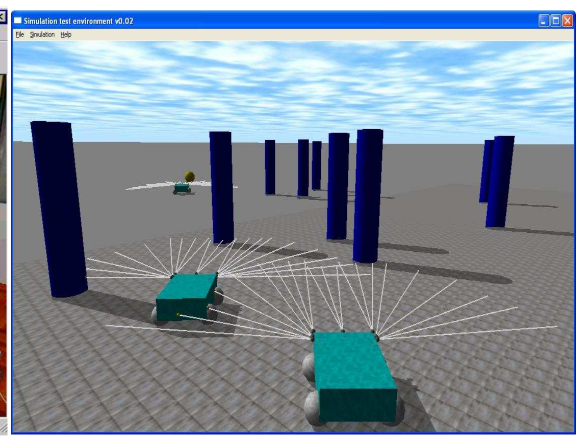
Control Architectures

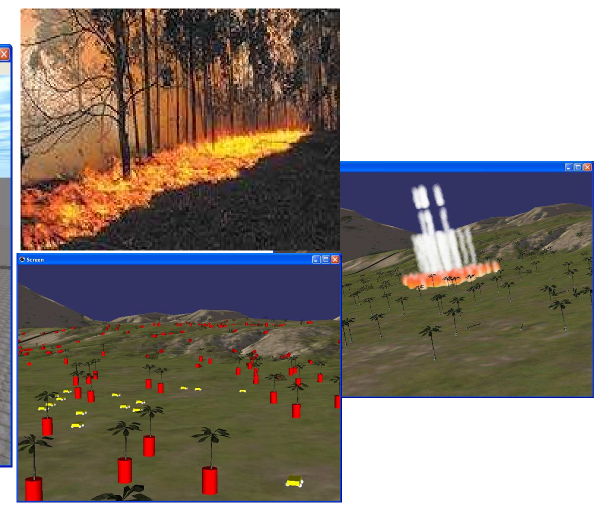
Autonomous Agents → **Robotic**

Multi-Agents Systems → **Teams, Squads, Swarms**

Knowledge / Reasoning → **Artificial Intelligence Tools**







Agenda:

1. Introduction: VR - Hierarchy of Models
2. VR and Simulation
   Geometry, Physics, Behaviour, Knowledge and Cognition
3. Physics Simulation Tools
   Opensteer, ODE, PhysX, Deformable/Dynamic
4. Intelligent Behaviour
   Agents: Perception, Action, Behaviour
   Autonomous Robots and Agents - Control
   Multi-Agents Systems - Knowledge
5. **Applications: Autonomous Robots VR Simulation Tools**
6. **Conclusions and New Trends**

Applications @ Unisinos

1. **Autonomous Robots in VR Environments**

SimRob3D - Mobile Robots Simulator

SEVA 3D - Autonomous Vehicle Parking

LEGGEN - Legged (articulated) Robots Simulator

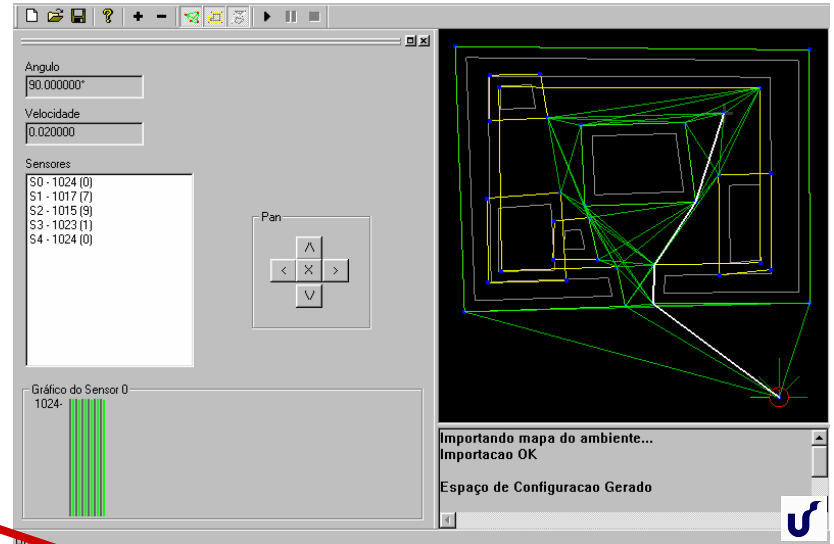
Robombeiros - Multi-Robots Fire Fighting

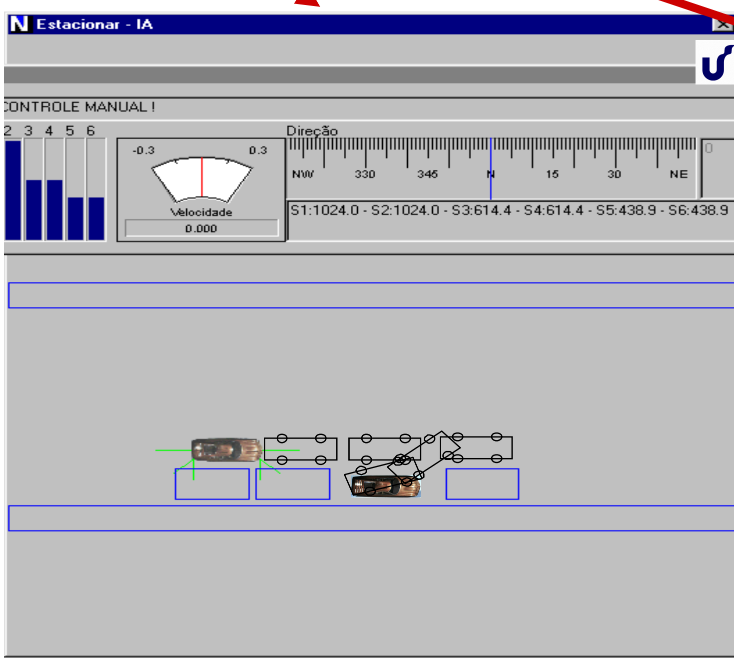
5. Applications: VR Simulation Tools

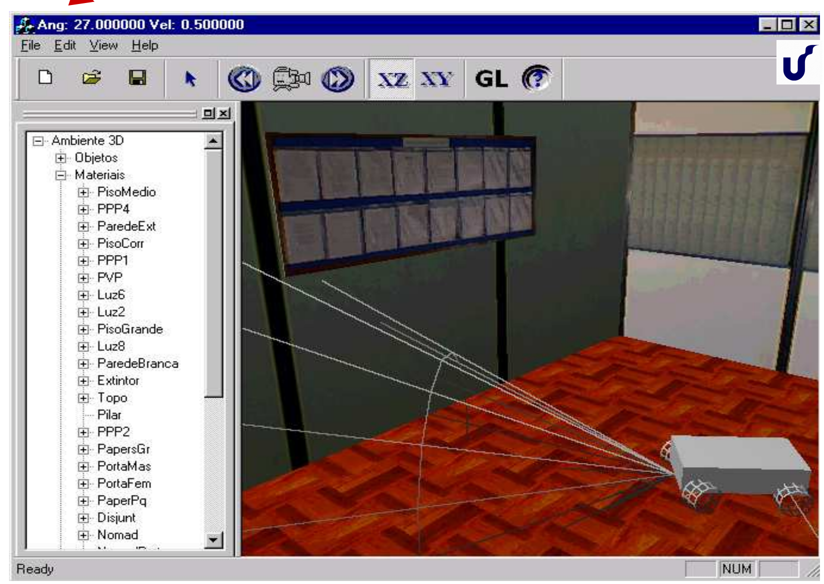
Autonomous Robots in VR Environments

SimRob3D

- **Our Simulation Tools:**
  - **SimRob2D (Khepera)**
  - **SimRob3D**
  - **Seva2D**







5. Applications: VR Simulation Tools

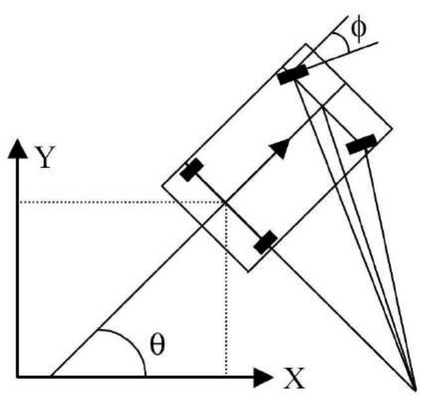
Autonomous Robots in VR Environments

SimRob3D Simulator

> Sensors: Infrared, Sonar, Bumper

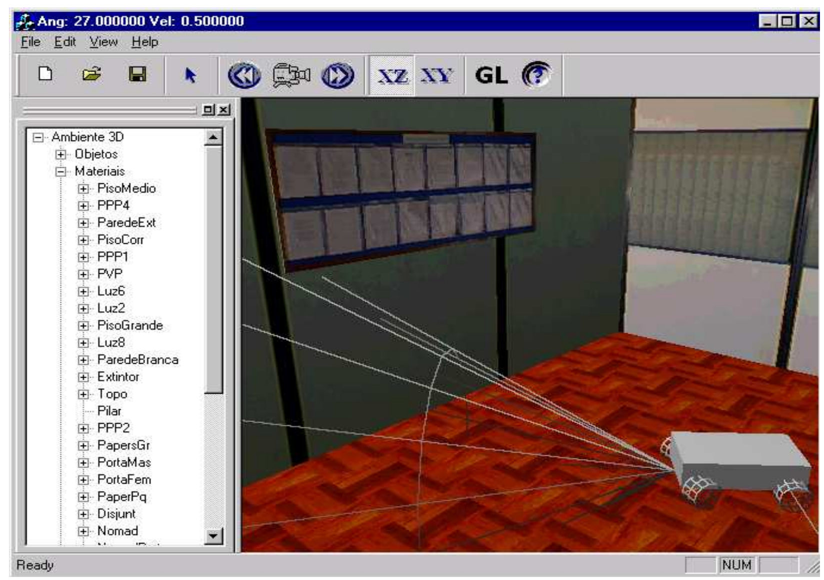
> Actuators / Kinematics: Differential, Ackerman

> Realistic Simulation Model:
3D World + noise / error (imprecise sensors and actuators)



$$\begin{cases} \dot{x} = v\,\cos\phi\,\cos\theta \\ \dot{y} = v\,\cos\phi\,\sin\theta \\ \dot{\theta} = \frac{v}{L}\,\sin\phi \end{cases}$$

Kinematics model

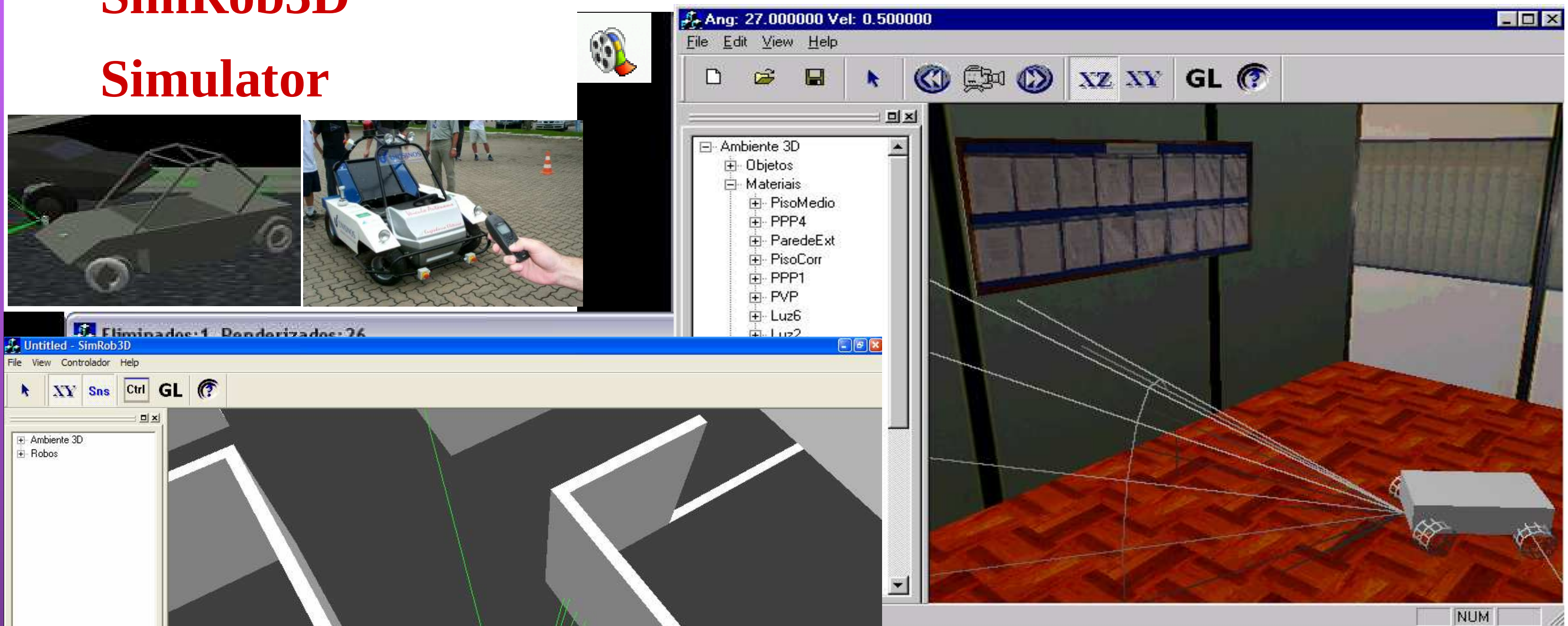


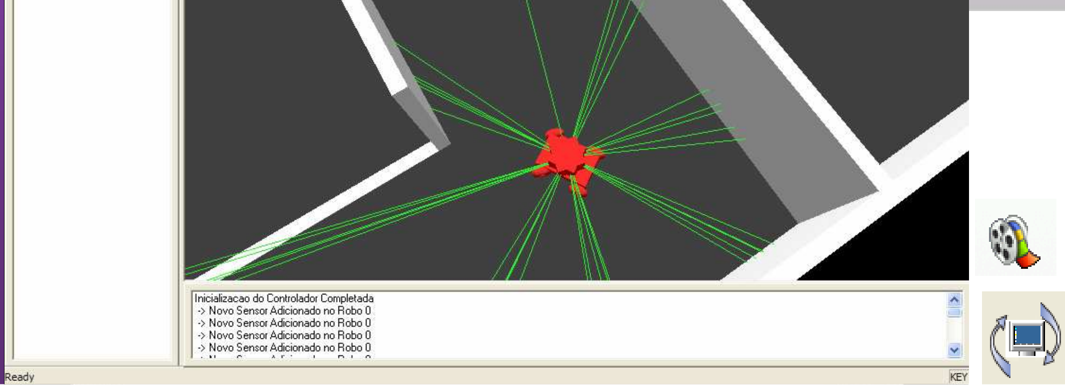
5. Applications: VR Simulation Tools

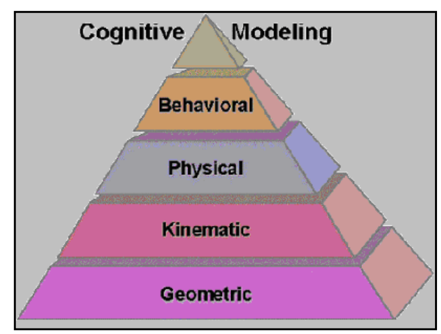
Autonomous Robots in VR Environments

SimRob3D

Simulator







5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

SEVA 3D - "Sistema de Estacionamento de Veículos Autônomos"

Sources of Inspiration:

**- Baja Buggy remotely controlled by a cell phone
C. Kelber - UNISINOS, Brazil**

**Published at:
IEEE WCCI
IJCNN 2006**

UNISINOS

IJCNN 2006

IEEE World Congress on Computational Intelligence
Sheraton Vancouver Wall Centre Hotel, Vancouver, BC, Canada
July 16-21, 2006

SEVA3D: Using Artificial Neural Networks to Autonomous Vehicle Parking Control

Applied Computing Research Post-grad Program - PIPCA
Autonomous Vehicles Research Group
[Grupo de Pesquisas em Veículos Autônomos - GPVA]
UNISINOS University - Brazil

Web: http://inf.unisinos.br/~osorio/seva3d
or Google: veiculos autonomos

IEEE WCCI - IJCNN 2006
Vancouver, July 2006

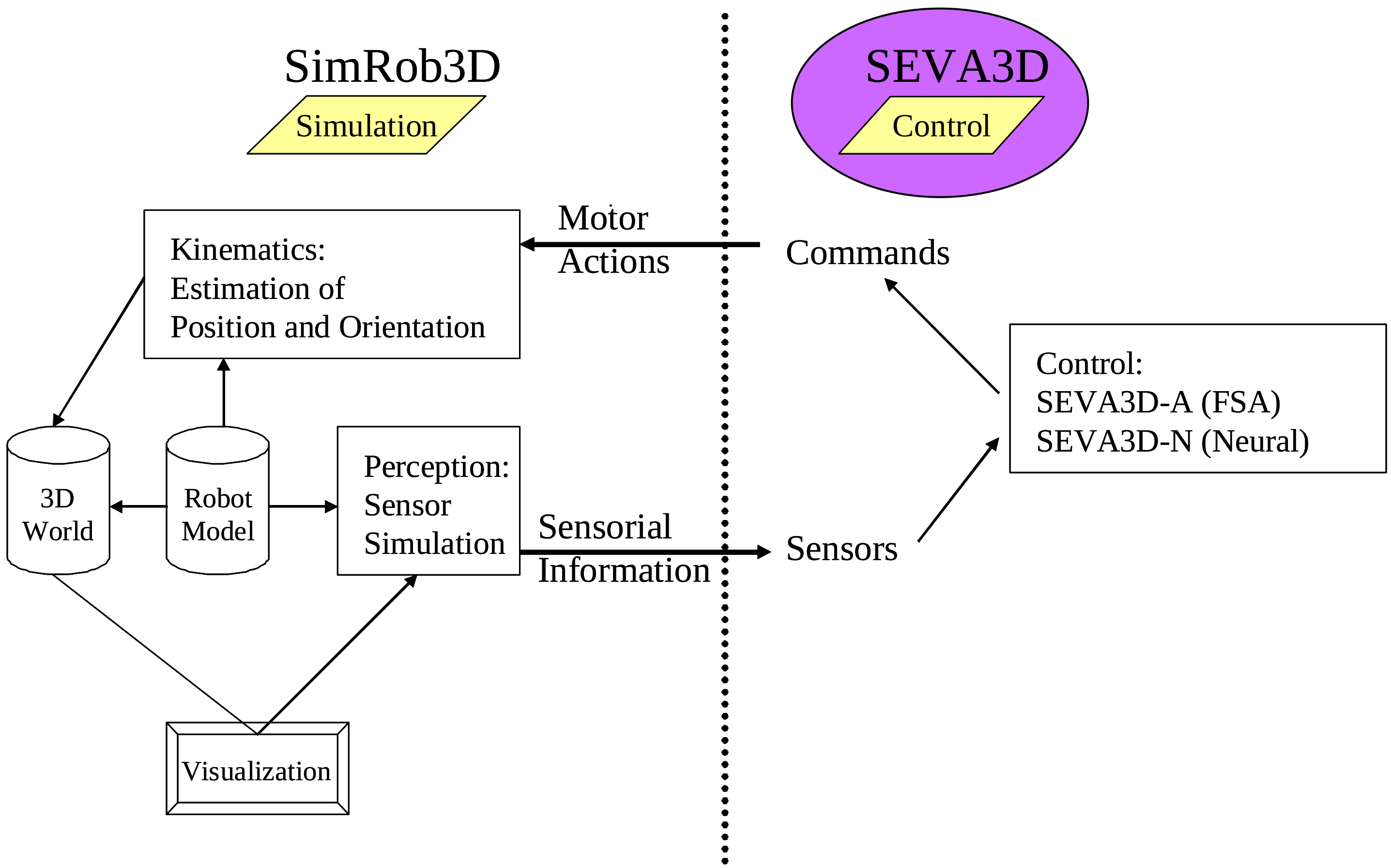
Milton Roberto Heinen - Applied Computing / Unisinos
Prof. Dr. Fernando S. Osório - Applied Computing / Unisinos
Prof. M.Sc. Farlei José Heinen - Computer Engineering / Unisinos
Prof. Dr. Christian Kelber - Electrical Engineering / Unisinos

5. Applications: SEVA 3D

Autonomous Robots in VR Environments

SEVA 3D Simulator

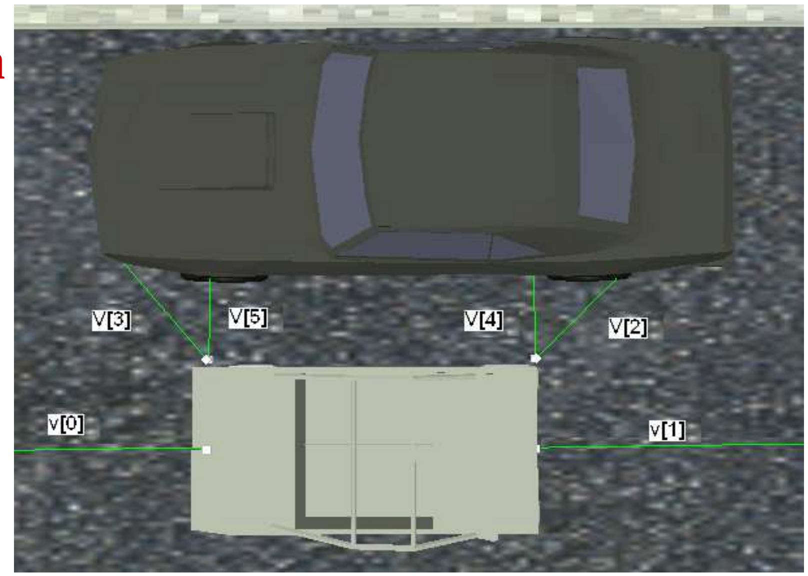
> Vehicle Simulation *x* Vehicle Control



5. Applications: SEVA 3D

Autonomous Robots in VR Environments

SEVA: FSA - Finite State Automaton



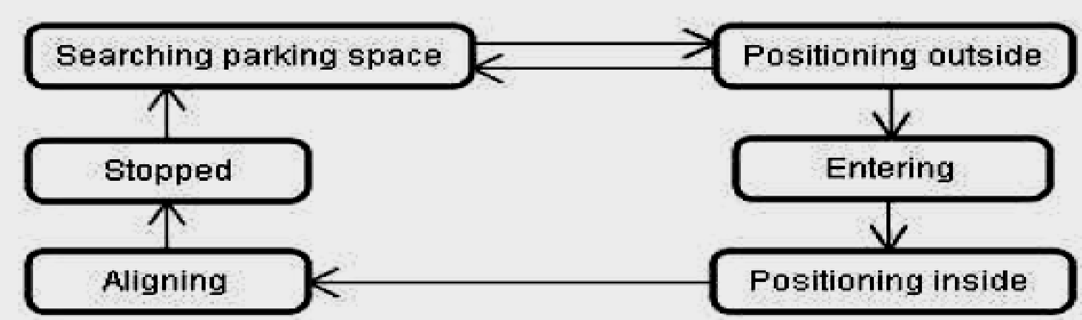
Inputs:

- Sonar Sensors:
Stochastic ray-casting / 3D cone)

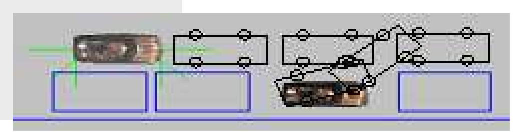
Outputs:

- Steering Wheel Angle
- Gas pedal (car speed + direction: fwd, back)

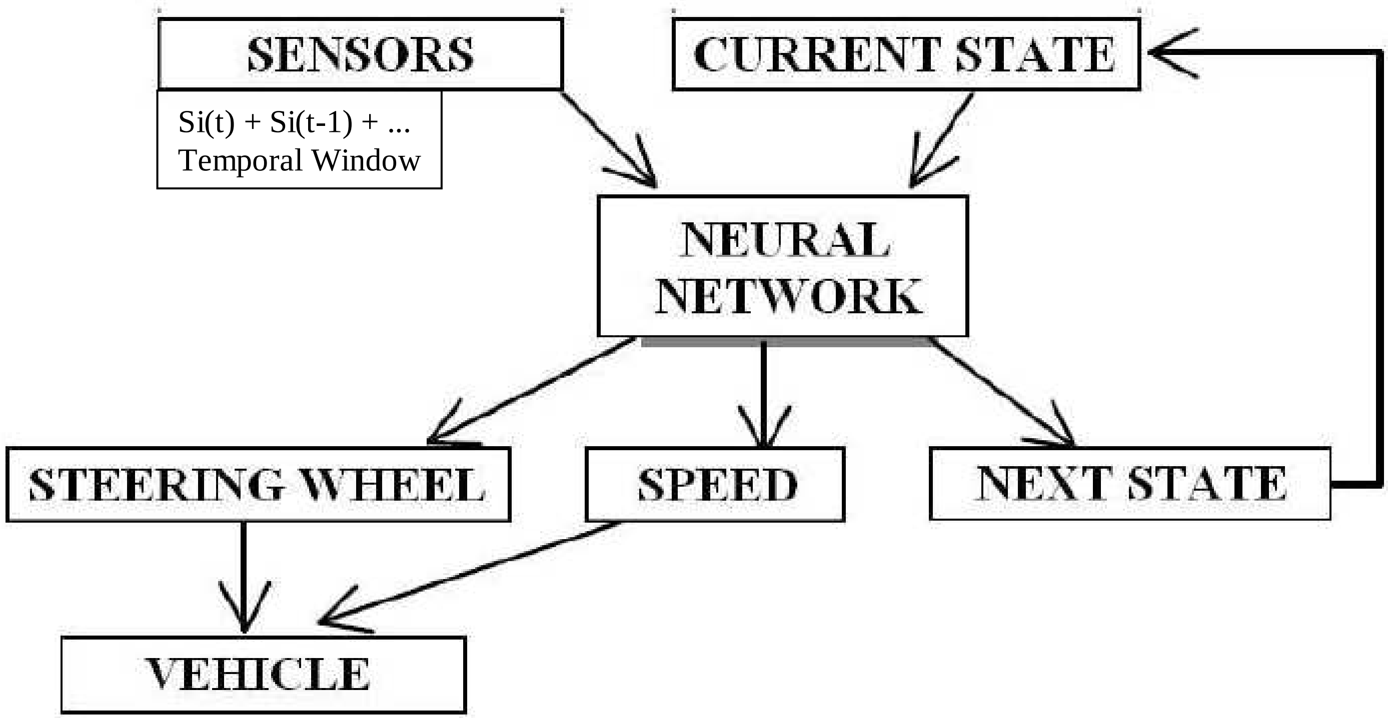
States:



Automaton states



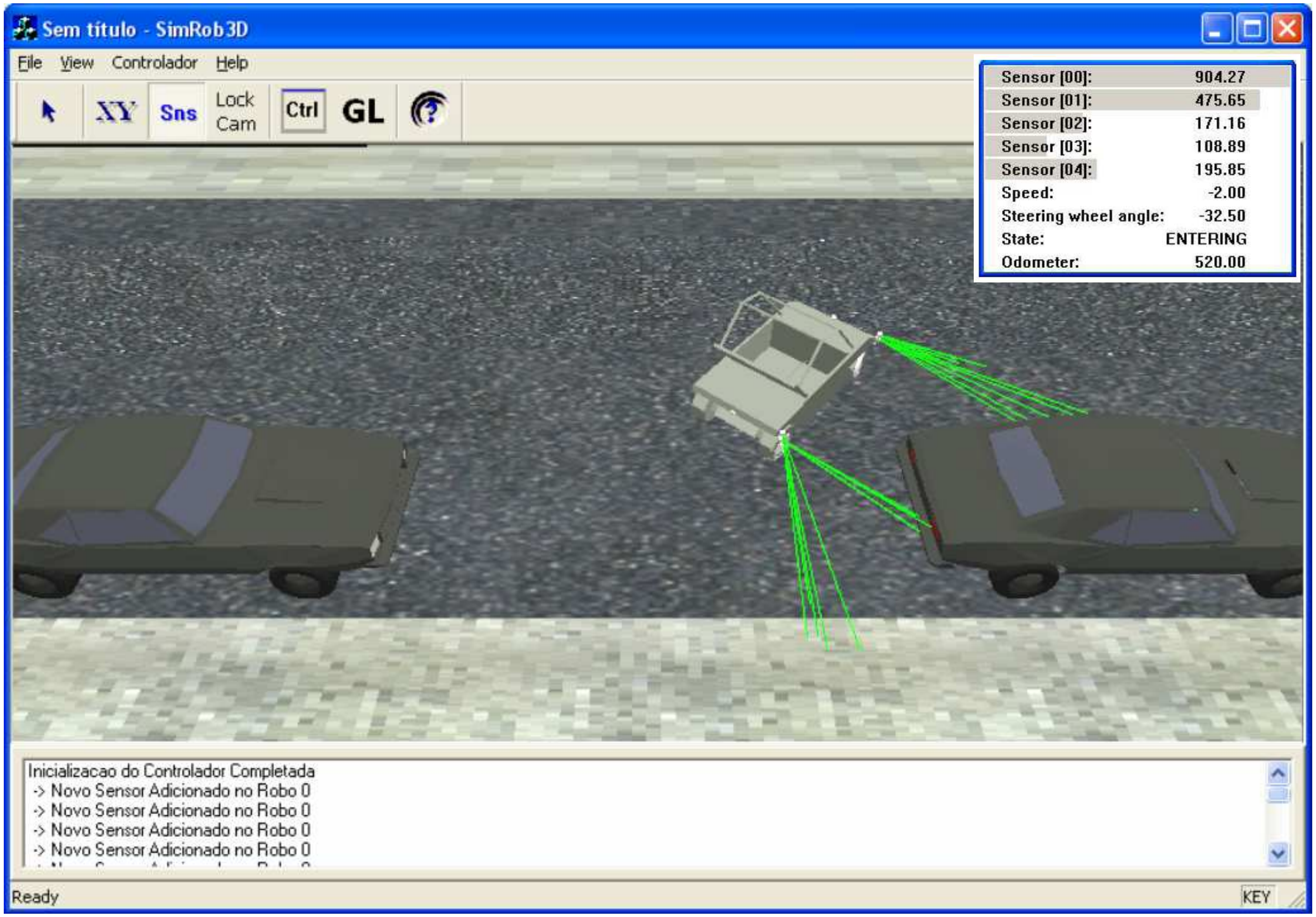
SEVA: NEURAL FSA - Learning the FSA...



Artificial neural network model scheme
Adapted Jordan-Net using RProp Learning

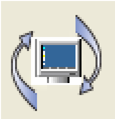
5. Applications: SEVA 3D

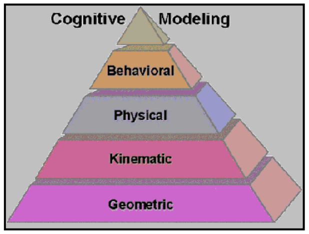
SEVA3D - Autonomous Vehicle Parking Simulator



3D

Sensors
Actuators
Kinematics
FSA Ctrl
ANN Ctrl





5. Applications: VR Simulation Tools

Applications @ Unisinos

1. **Autonomous Robots in VR Environments**

SimRob3D - Mobile Robots Simulator

SEVA 3D - Autonomous Vehicle Parking

➡ **LEGGEN - Legged (articulated) Robots Simulator**

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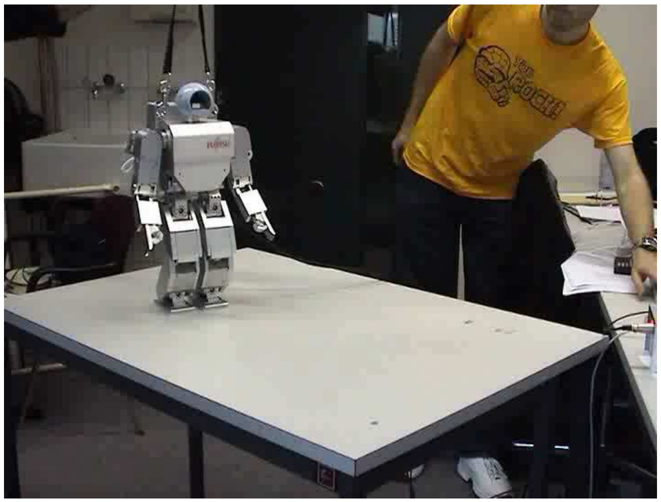
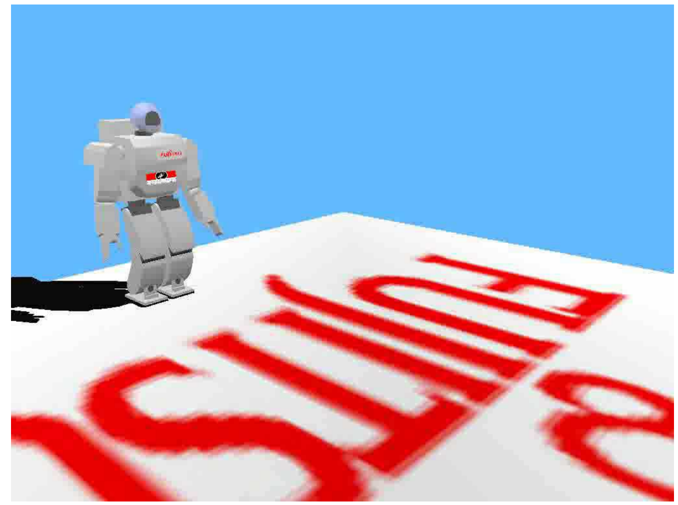
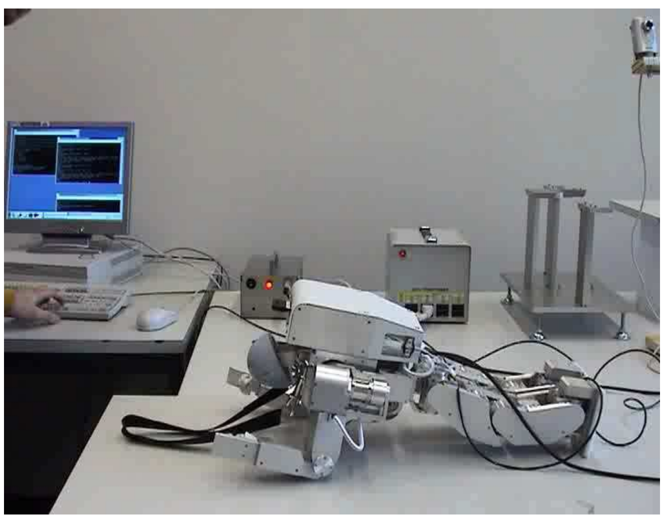
5. Applications: VR Simulation Tools

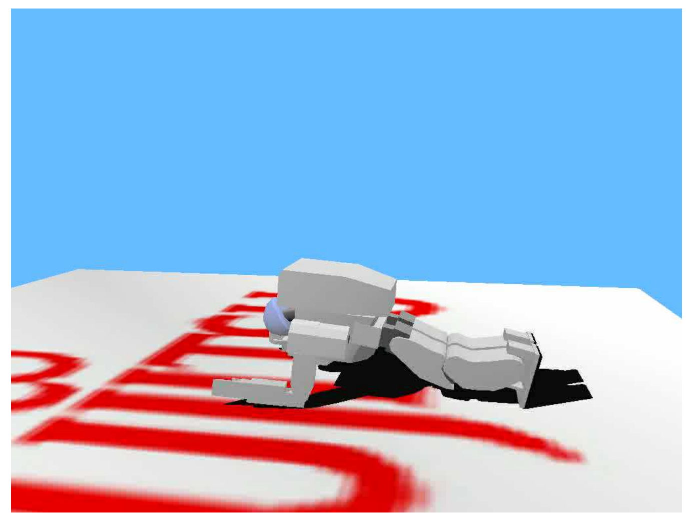
Autonomous Robots in VR Environments

Legged Robots Evolution and Walking Control









[EPFL]

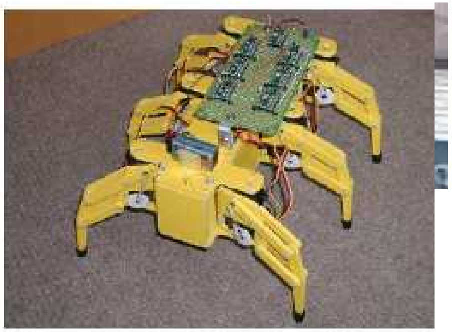
5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

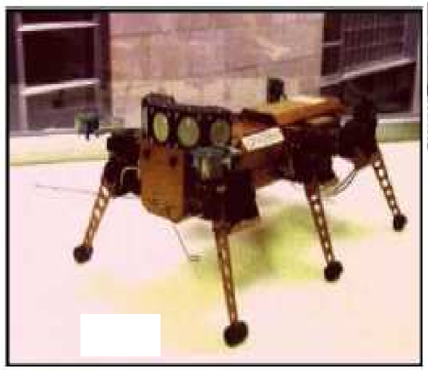
Legged Robots Evolution and Walking Control

Sources of Inspiration:

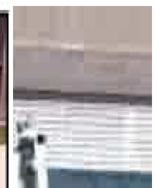
LEGGEN - Published at:
IEEE WCCI CEC 2006
SBIA 2006



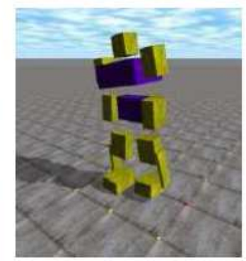
Robô Lynxmotion Hexapod II



Robô Genghis-II

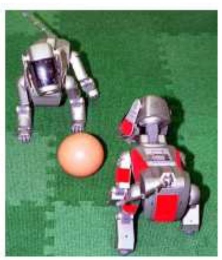


(a) Robô real



(b) Robô simulado

(a)



(b)

Figı ıo [95]

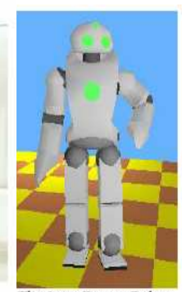
(Asimo

(b) Sony SDR-4X

(c) Kawada H6

(d) Fujitsu HOAP-2

The Sony Dream Robot in the real world



The Sony Dream Robot simulated into Webots

UNISINOS

iberamia SBIA SBRN

International JOINT Conference 2006

IBERAMIA / SBIA - 18th Brazilian AI Symposium

Pós-Graduação em Computação Aplicada - PIPCA
Grupo de Pesquisas em Veículos Autônomos - GPVA
>> Autonomous Vehicles Research Group <<
UNISINOS University - Brazil

Web: http://inf.unisinos.br/~osorio/leggen
or Google: veiculos autonomos

Gait Control Generation for Physically based Simulated Robots using Genetic Algorithms

IBERAMIA / SBIA / SBRN International Joint Conferences
SBIA - Brazilian Artificial Intelligence Symposium
Ribeirão Preto, October 2006

Prof. Dr. Fernando S. Osório - Applied Computing / Unisinos
Milton Roberto Heinen - Applied Computing / Unisinos

5. Applications: VR Simulation Tools

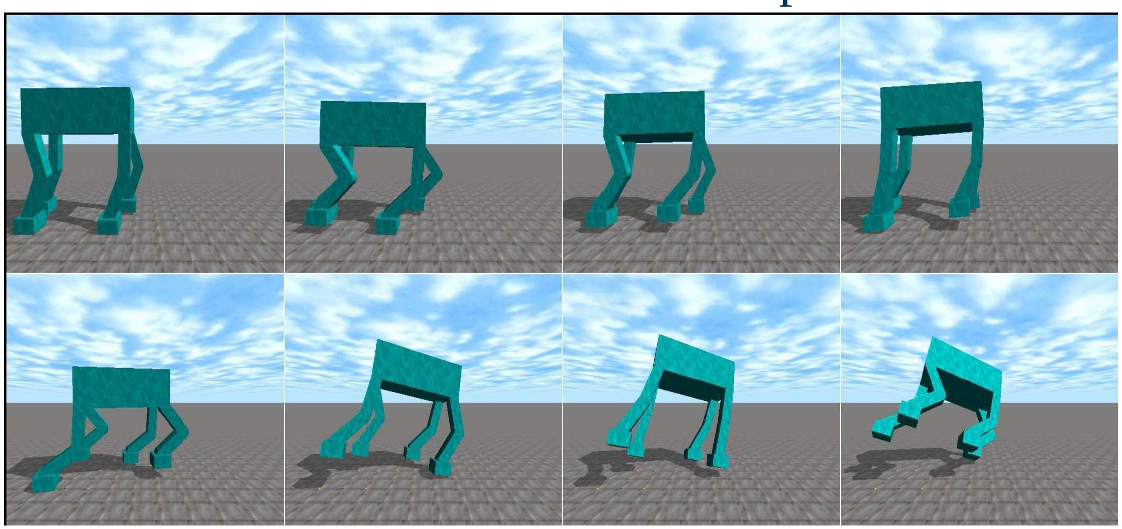
Autonomous Robots in VR Environments

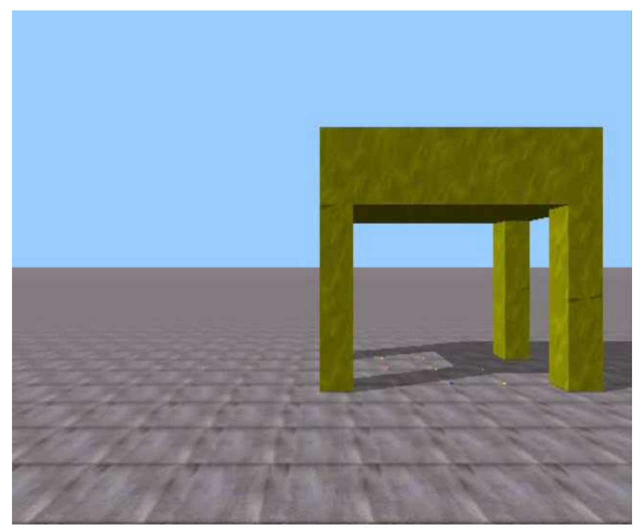
LEGGEN - Legged Robots Evolution and Walking Control

Simulation of Robots: 3D **Realistic** Virtual Environments
- Sensors: infrared, sonar, bumpers, gyro (accelerometers), GPS, compass, light and vision sensors, etc.
- Actuators: legs and arms with angular motors (joints)
- Physics: collision, kinematics, rigid body dynamics

Simulation of Legged Autonomous Robots:
- Robot Control Architectures Implementation

Genetic Evolved Control of Articulated Robots (w/legs)



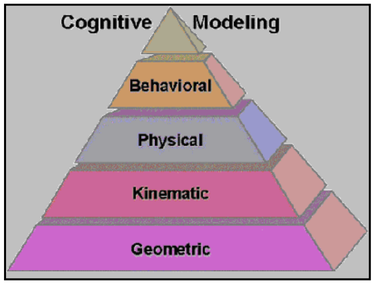


5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

LEGGEN - Legged Robots Evolution and Walking Control

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**
   Rigid Body Physics Simulation
   (gravity, inertia, friction, collision, joints, etc)
   [http://www.ode.org/]

3. **GALib - Genetic Algorithms Simulation**
   [http://www.lancet.mit.edu/ga/]

4. **Robot Control FSM: Finite State Machine = Sense + Act**

5. Applications: VR Simulation Tools

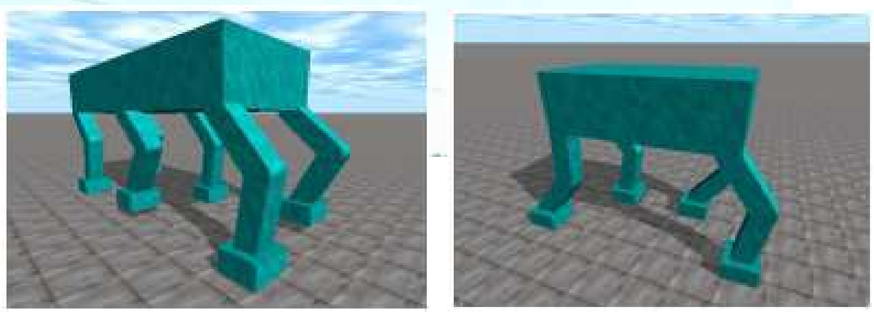
Autonomous Robots in VR Environments

LEGGEN - Legged Robots Evolution and Walking Control

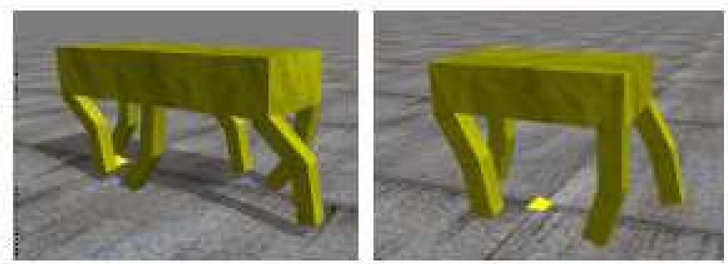
Simulation main goals:

- **Evaluate different *Robot Models* (hardware configurations)**
  IEEE WCCI / CEC 2006 - Vancouver, Canadá
- **Evaluate different *Fitness Functions***
  IBERAMIA / SBIA - Ribeirão Preto, SP

Robot Models



(a) HexaL3J (b) TetraL3J

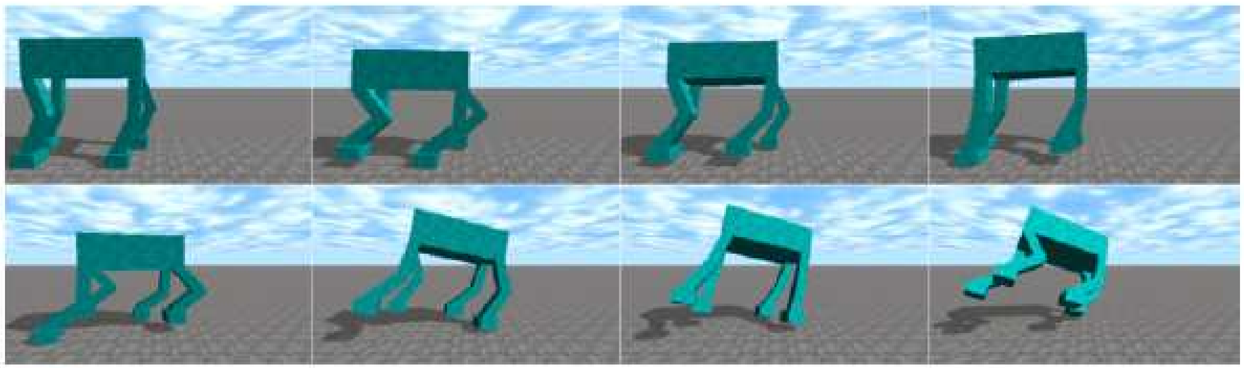


(c) HexaL2J (d) TetraL2J

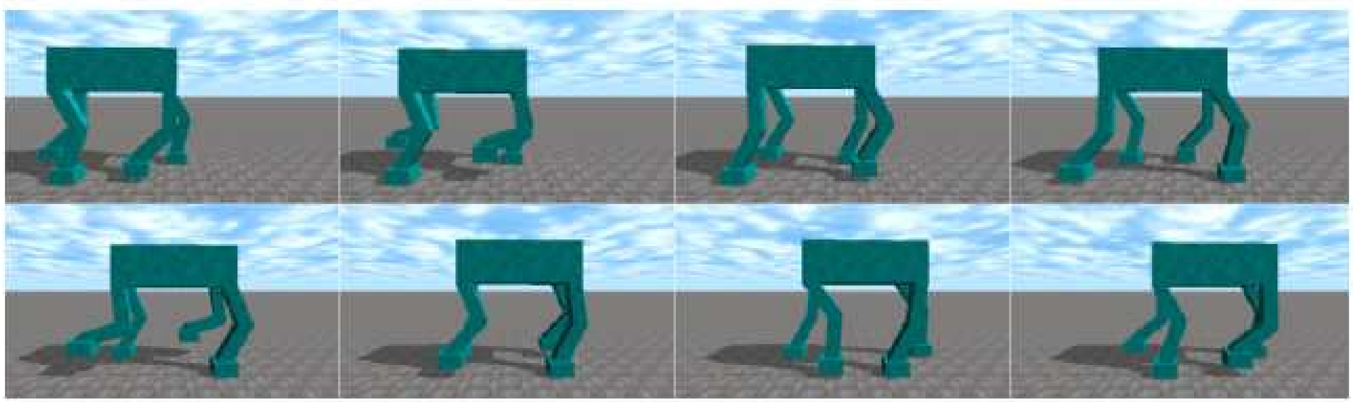
Evaluate different robot models in order to select a better hardware configuration

Boston Dynamics

Simulation Results:



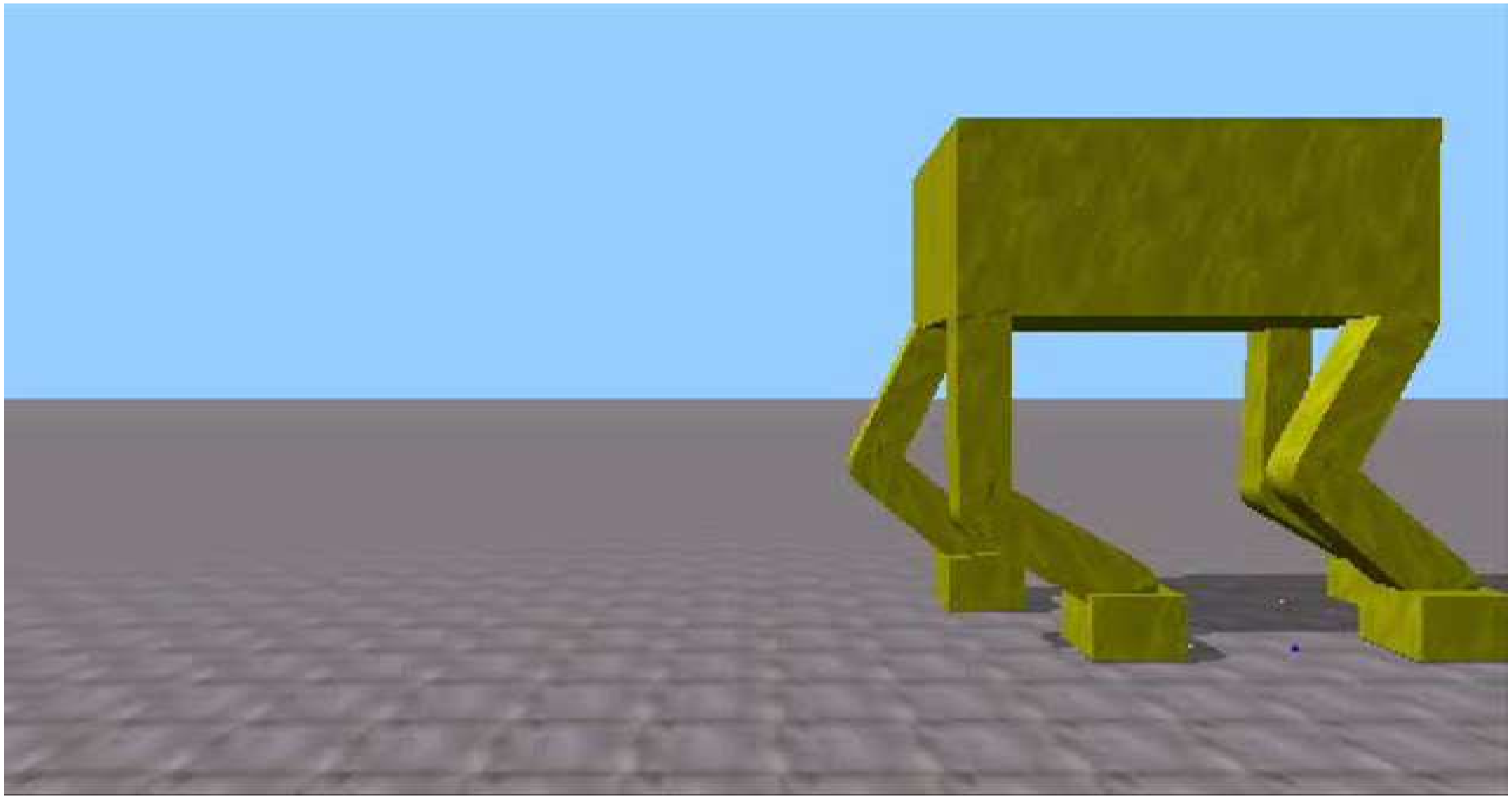
Example of a generated gait (experiment 01)



Example of a generated gait (experiment 04)

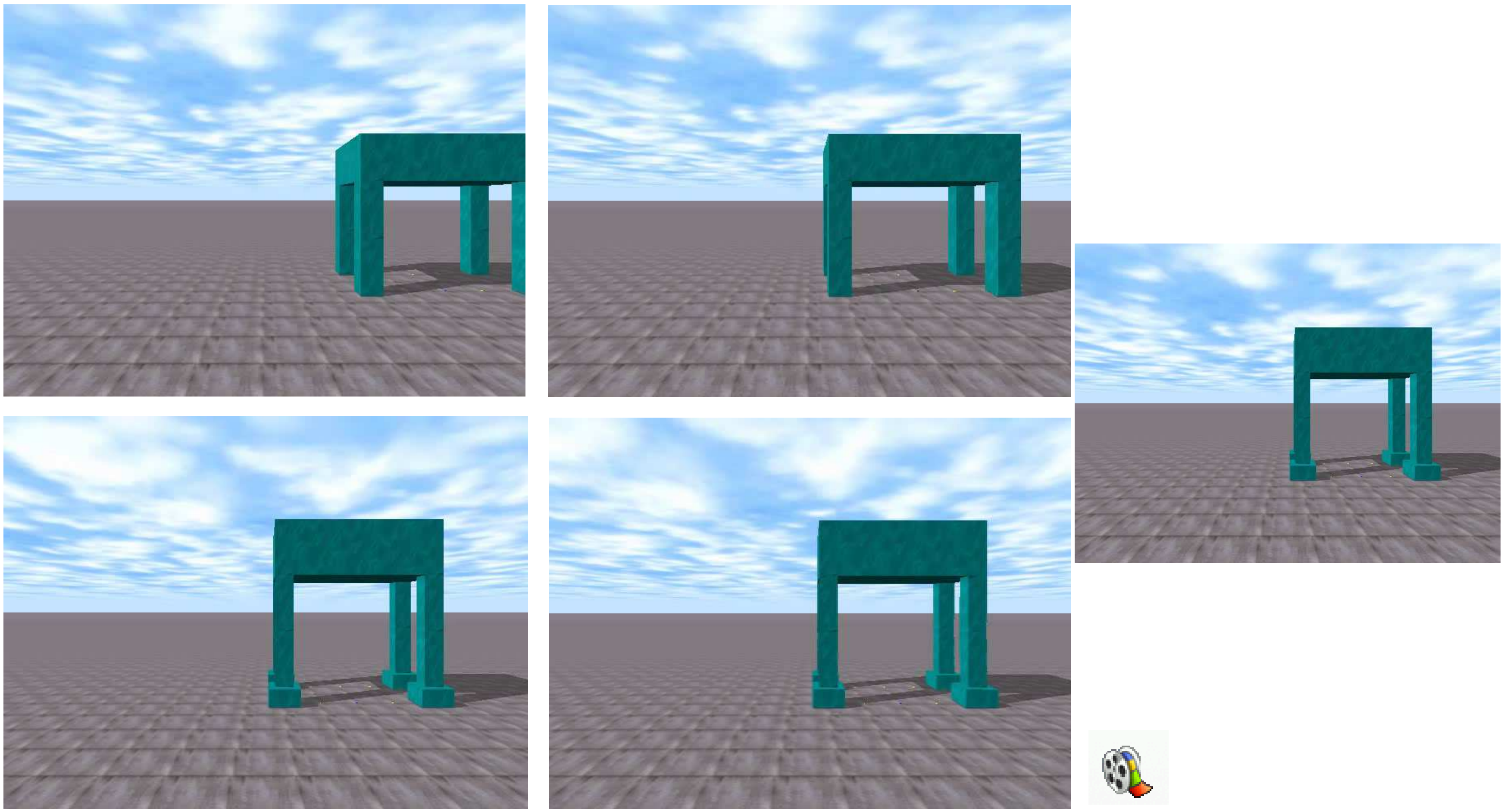
Simulation RESULTS:

Tetrapod Video - Distance, Gyro



LEGGEN SIMULATOR

Simulation
RESULTS: ***Tetrapod Video - "bloopers"***



5. Applications: VR Simulation Tools

Applications @ Unisinos

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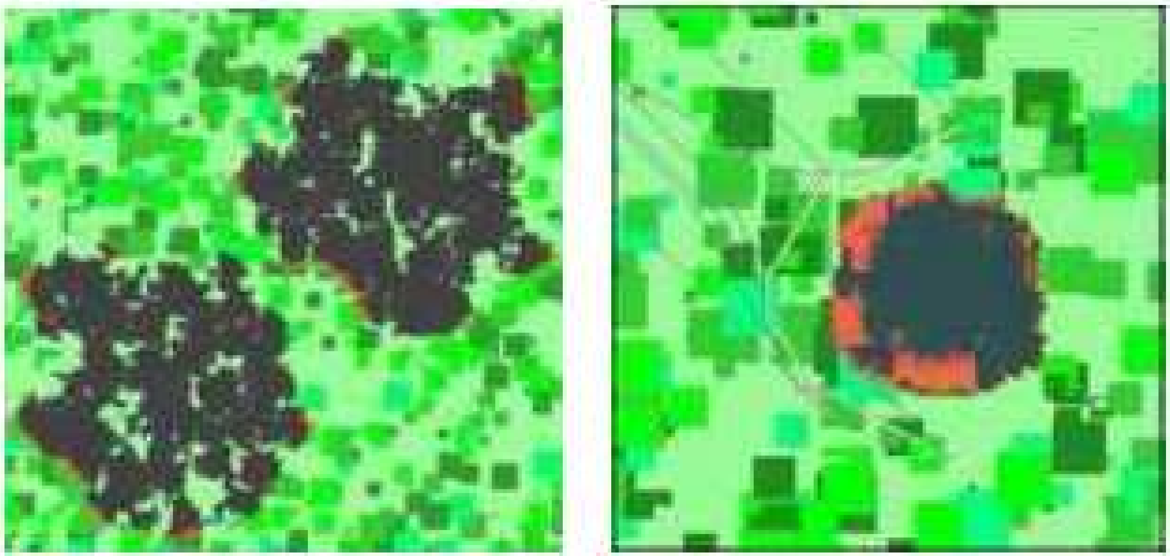
➔ **Robombeiros - Fire Fighting**

Robombeiros - Fire Fighting VR Simulation

Virtual Simulation Environment:

* 2D and 3D Simulation
* Simulation of fire propagation
* Autonomous fire-fighting team
* Define: Strategy, Mission, Execution



Fire Propagation Simulation:

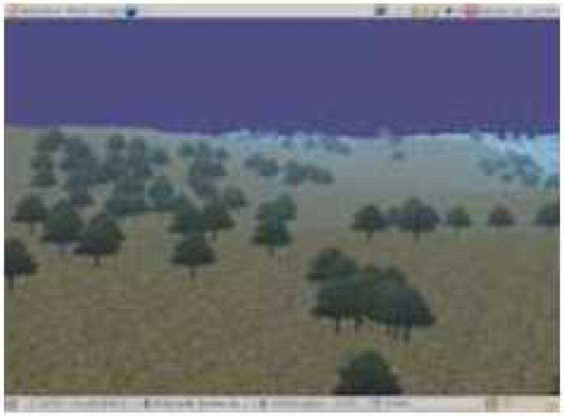
- Direction and Speed of wind
- Vegetation type and coverture density (speed of propagation)
- Terrain

Figure: 2D Simulation using SDL library => http://pessin.googlepages.com/robombeiros

Published at SVR 2007 (Symposium on Virtual and Augmented Reality)
[G. Pessin, F. Osório, S. Musse, V. Nonnenmacher, S. Ferreira]

Robombeiros - Fire Fighting VR Simulation

Virtual Simulation Environment:



3D Visualization:
- Vegetation, Fire
- Autonomous mobile Robots
- Stereo 3D
- Tools: OSG, ODE, Demeter

Published at SVR 2007 (Symposium on Virtual and Augmented Reality)
[G. Pessin, F. Osório, S. Musse, V. Nonnenmacher, S. Ferreira]

http://pessin.googlepages.com/robombeiros

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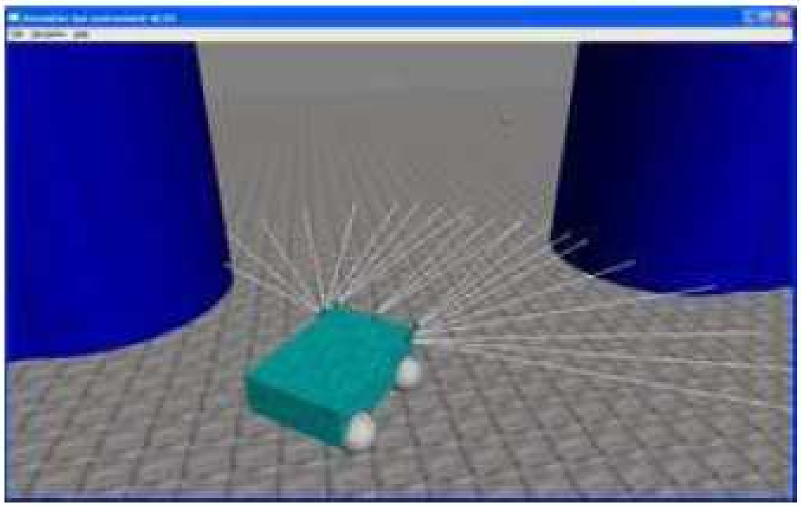

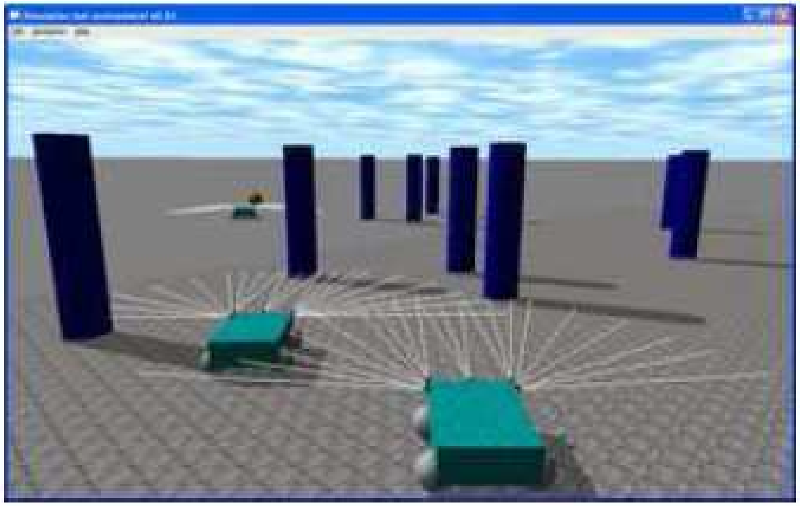

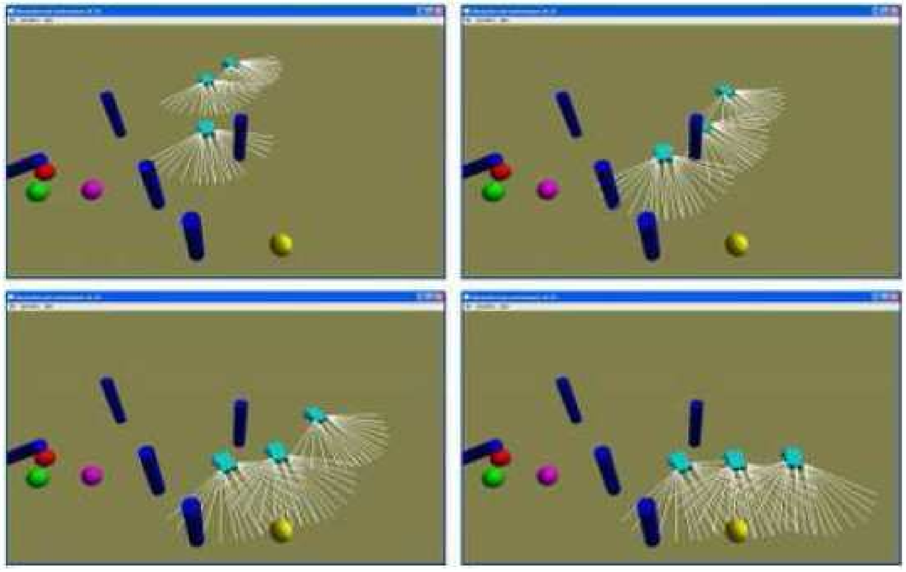

3D Simulation:
- Fire propagation
- Physics
- Robot Control

http://pessin.googlepages.com/robombeiros

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6. **Conclusions and New Trends**

New Trends

A 3D Fax Machine based on Claytronics

Padmanabhan Pillai, Jason Campbell
Intel Research Pittsburgh
Pittsburgh, PA 15213

Gautam Kedia, Shishir Moudgal, Kaushik Sheth
Carnegie Mellon University
Pittsburgh, PA 15213

Abstract—This paper presents a novel application of modular robotic technology. Many researchers expect manufacturing technology will allow robot modules to be built at smaller and smaller scales, but movement and actuation are increasingly difficult as dimensions shrink. We describe an application — a 3D fax machine — which exploits inter-module communication and computation without requiring self-reconfiguration. As a result, this application may be feasible sooner than applications which depend upon modules being able to move themselves.

In our new approach to 3D faxing, a large number of sub-millimeter robot modules form an intelligent "clay" which can be reshaped via the external application of mechanical forces. This clay can act as a novel input device, using intermodule localization techniques to acquire the shape of a 3D object by casting. We describe software for such digital clay. We also describe how, when equipped with simple inter-module latches, such clay can be used as a 3D output device. Finally, we evaluate results from simulations which test how well our approach can replicate particular objects.

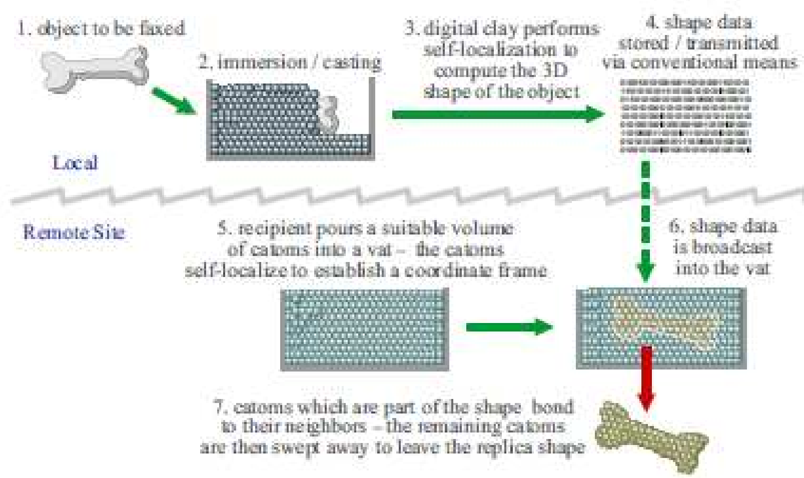


Fig. 1. An overview of the 3D fax scenario

Claytronics - Nanotech
http://www.cs.cmu.edu/~claytronics/

[Published at IROS2006]
IEEE Intelligent Robot and Systems Conference

Conclusions and New Trends

Virtual Reality Environments:

Geometric + Kinematic + Physical + Behavioural + Cognitive

=

Realistic VR Environments

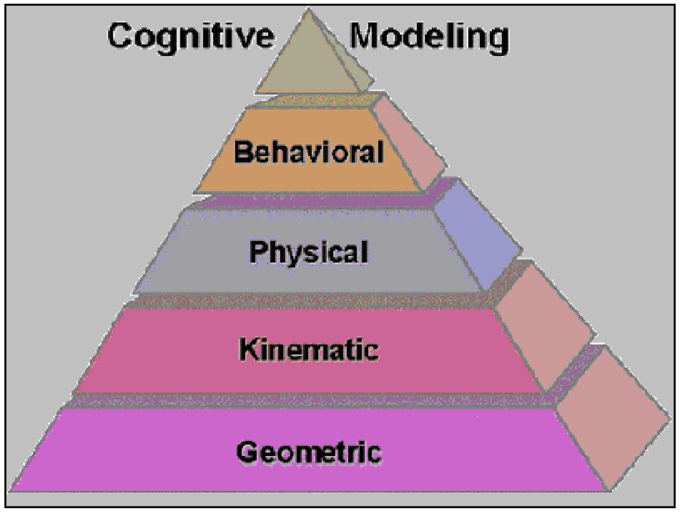
New Trends:

- **VR + Physics**
- **Artificial Intelligence**
- **AR - Augmented Reality**
- **Haptic Interfaces**

Autonomy **IVRE**
Intelligent Virtual Reality Environments

Simulation **VR PBSim**
VR Physical and Behavioral Simulation

More Real **VR++**



CERMA 2007

IEEE computer society
CERMA 2007

UNISINOS

CONTACT INFORMATION

UNISINOS University - Brazil

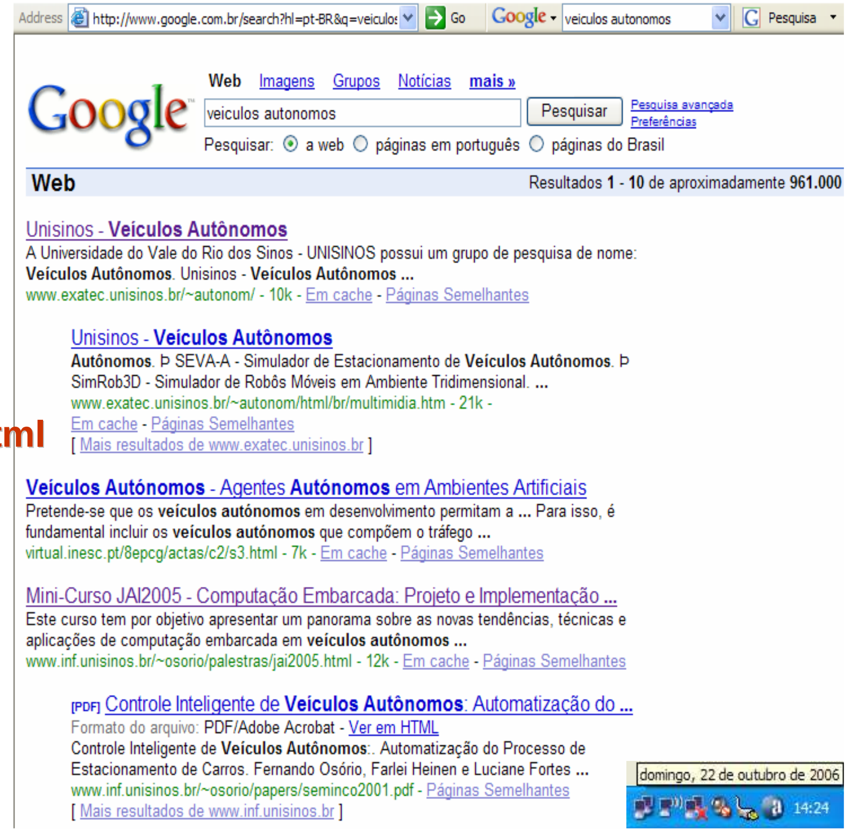
Applied Computing Research Post-grad Program - PIPCA
Autonomous Vehicles Research Group - GPVA

Web: Google - veiculos autonomos

GPVA Web Page:
http://www.eletrica.unisinos.br/~autonom

Contact - Web Page:
http://inf.unisinos.br/~osorio/

This conference - Web Page:
http://inf.unisinos.br/~osorio/palestras/cerma07.html



Contact:
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E-Mail: fosorio@unisinos.br