

Humanoid Soccer – A Challenge for AI and Robotics

Sven Behnke

Rheinische Friedrich-Wilhelms-Universität Bonn
Institute of Computer Science
Autonomous Intelligent Systems



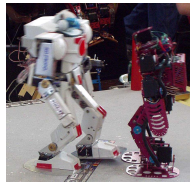
Outline

- Motivation
- Humanoid League
- Team NimbRo
 - Mechatronics
 - Perception
 - Behavior control
 - Learning
- RoboCup results
- Outlook



Robot Competitions

- **Standardized** test environment
- Robot operation
 - Outside the own lab
 - Different environment
 - Predetermined time
- **Direct comparison** of different approaches to mechanical construction, perception, and control
- **Exchange of ideas**
- Some popular competitions
 - FIRA (soccer)
 - Robo-one (marital arts)
 - AAI Robot Competition (conference participation)
 - DARPA Grand/Urban Challenge (autonomous cars)



Robo-one

RoboCup-Initiative

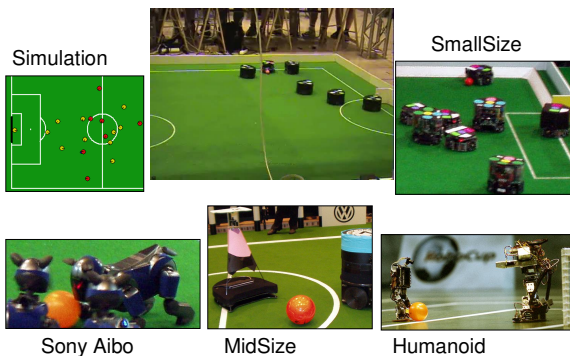


- Since 1997
- Soccer as new challenge problem for AI

	Chess	RoboCup
Environment	static	dynamic
State change	turn taking	real time
Observability	full	incomplete
Sensors	symbolic	signals
Control	centralized	distributed

- Long term goal: Win against FIFA world champion by 2050
- Also: Rescue, Junior, @home
- 2008: Suzhou, 400 teams from 35 countries with ~2.000 participants

RoboCupSoccer Leagues



Outline

- Motivation
- **Humanoid League**
- Team NimbRo
 - Mechatronics
 - Perception
 - Behavior Control
 - Learning
- RoboCup Results
- Outlook



RoboCup Humanoid League

- Since 2002
- Step towards long-term goal: "... humanoid robots that can win ..."
- Size classes
 - KidSize (<60cm)
 - TeenSize (>100cm)
- Competitions
 - 3 vs. 3 (KidSize)
 - Dribble & Kick (TeenSize)
 - Technical challenges



Technical Challenges



Dribbling around poles



Obstacle avoidance



Passing

Humanoide League 2008



32 teams from 13 countries

Autonomous Mobile Robots

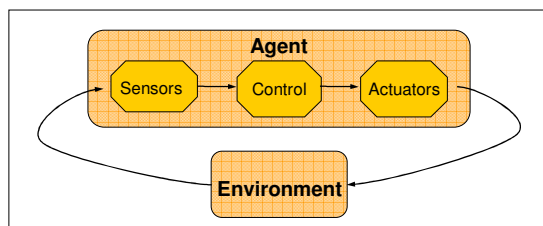


„Fungus Eater“ by Isabelle Follath
Masanao Toda 1962, Rolf Pfeifer 1994

- Complete agent
 - Autonomy
 - Self support
 - Embodiment
 - Situatedness
- Ecological niche
 - Soccer field
 - Game rules

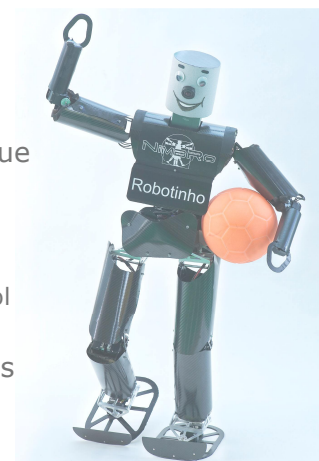
Main Tasks

- Perception of the world
- Behavior control
- Action



Outline

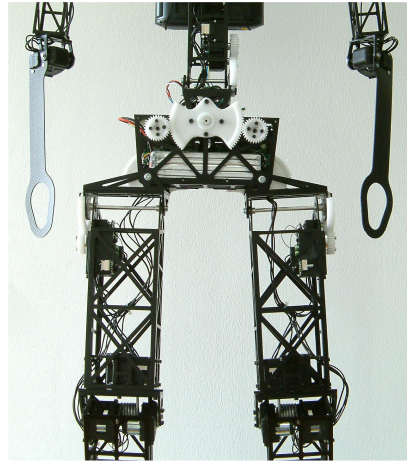
- Motivation
- Humanoid League
- **Team NimbRo**
 - Mechatronics
 - Perception
 - Behavior Control
 - Learning
- RoboCup Results
- Outlook





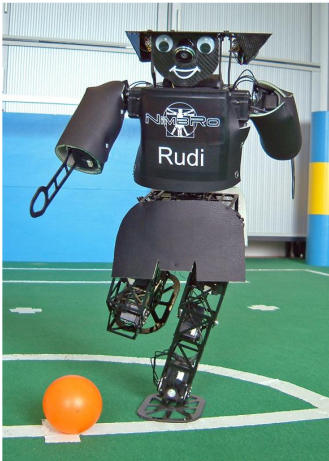
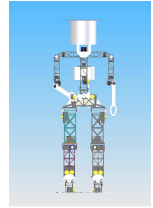
TeenSize 2007: Robotina

- 122cm, 9kg
- 23 DOF
 - 6 per leg
 - 4 per arm
 - 3 in the trunk
- Soft cover
- CardS12X controller
- RS485 bus
- PC, three cameras
- Li-Poly batteries
- Attitude sensor



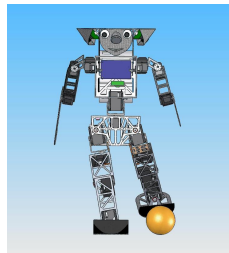
Robotina Mechanics

- Dynamixel actuators
 - Master-Slave
 - Extra gears
- Knee spring
- Lightweight skeleton



NimbRo KidSize 2007

- 60cm, 4kg
- 20 DOF
 - 6 per leg
 - 3 per arm
 - 2 in the trunk



NimbRo KidSize 2008

- 60cm, 3.5kg
- 17 joints
 - 6 per leg
 - 2 per arm
 - 1 in the neck
- PC
- Three cameras
- Attitude sensor

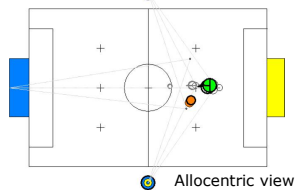
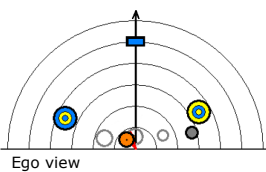
Visual Perception



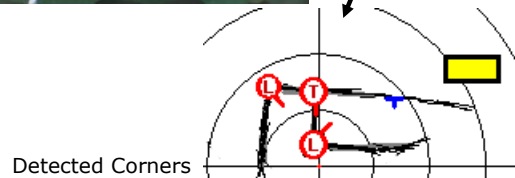
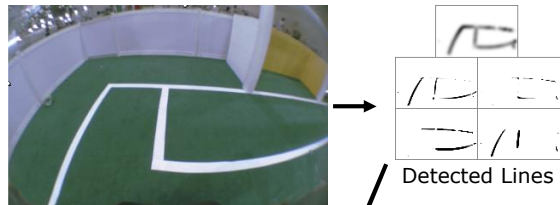
Front left

Front center

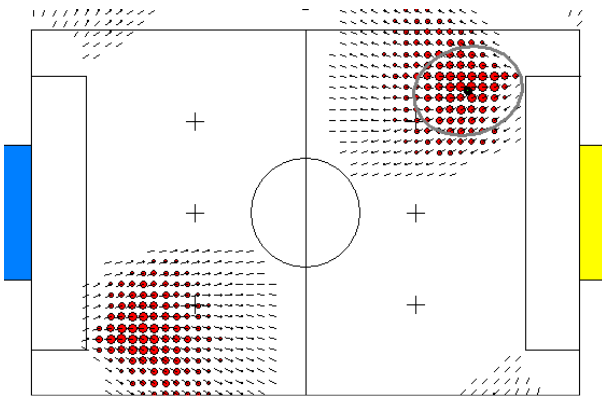
Front right



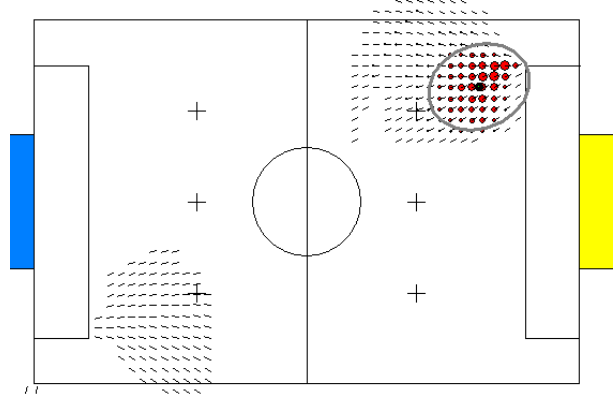
Corner Detection



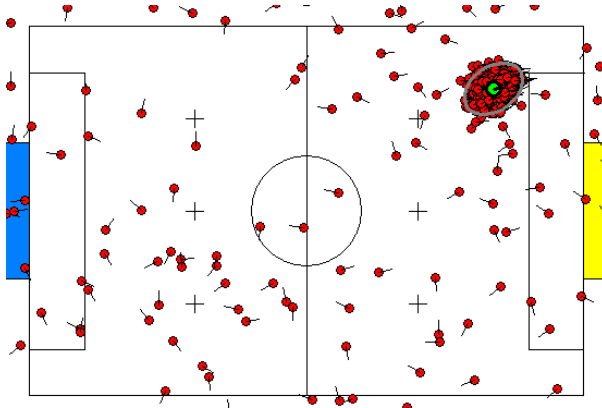
Corner-based Localizaton



Corner Observations + Goal



Particle Filter Localization

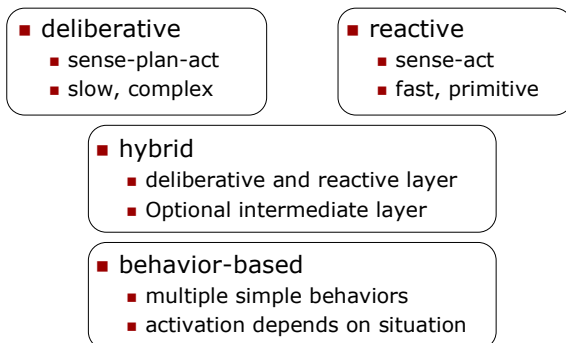


Outline

- Motivation
- Humanoid League
- Team NimbRo
 - Mechatronics
 - Perception
 - **Behavior Control**
 - Learning
- RoboCup Results
- Outlook

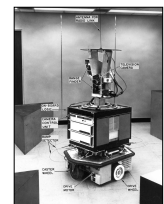
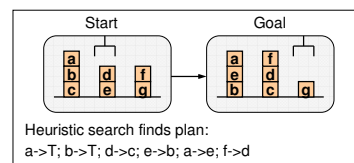


Behavior control architectures



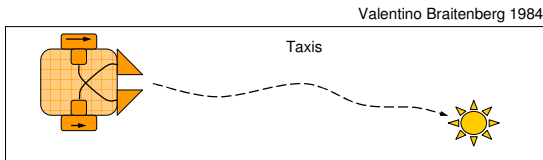
Deliberative Behavior Control

- Construction of a complete world model
- Planning from start to goal
- Plan execution
- Examples: blocks world, Shakey



Reactive Behavior Control

- No world model
- No plan
- Direct coupling from sensors to actuators
- Example: Braitenberg vehicles

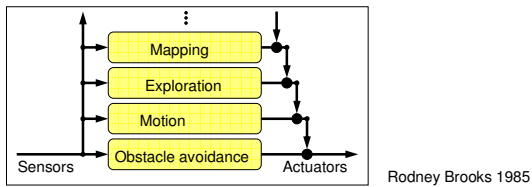


Hybrid Behavior Control

- Attempt to unify best of both worlds
- Example: three layer architecture (Erann Gat 1998: Alfred)
 - Reactive layer (Controller)
 - No state, fast, sensor-driven
 - Intermediate layer (Sequencer)
 - Representation of the past
 - Abstraction
 - Error recognition, alternative behaviors
 - Deliberative Layer (Planner)
 - Representation of the future
 - slow, goal-driven

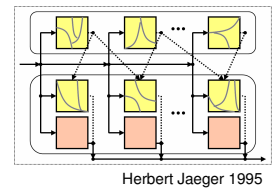
Subsumption Architecture

- Behavior-based, FSMs, messages
- Levels of competencies
- Increasing complexity
- Subsumption: Overriding lower level
- Incremental design

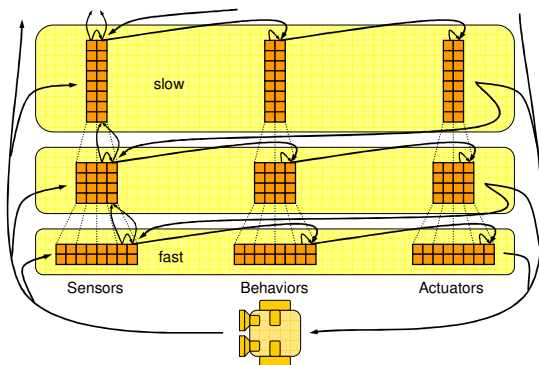


Dual Dynamics

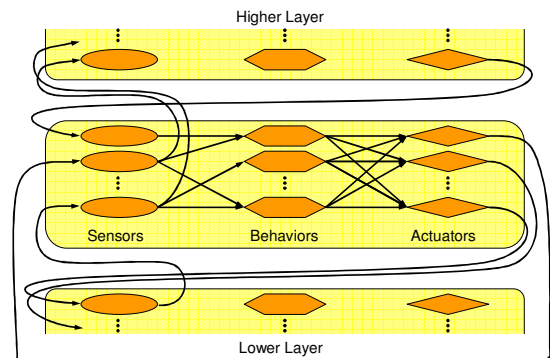
- Behavior-based
- Dynamical systems
- Two control levels
 - basic
 - complex
- Basis behaviors have two modules:
 - Activation dynamics: Should I do something now?
 - Target dynamics: What shall I do?
- Complex behaviors have activation dynamics only
- Bifurcations, modes, multi-functionality



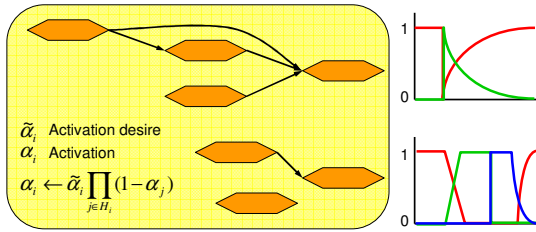
Hierarchy of Reactive Behaviors



Structure of a Layer

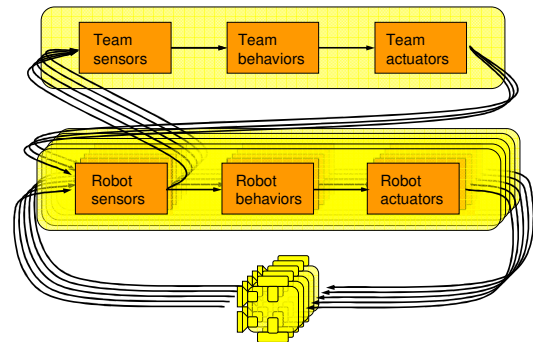


Behavior Inhibition

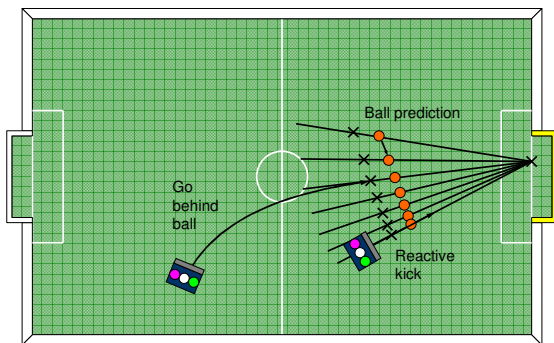


- Multiple behaviors can be active simultaneously
- Acyclic inhibition graph
- Multiplicative inhibition
- Actuator dynamics: weighted mean of change requests

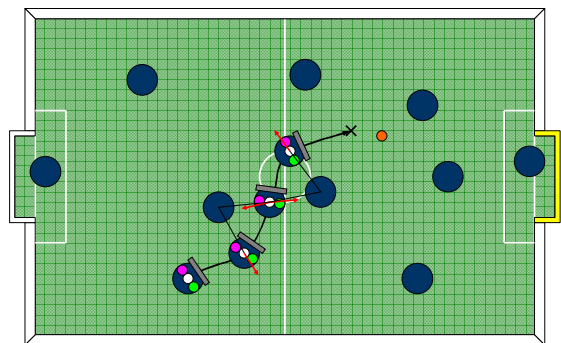
Team Levels



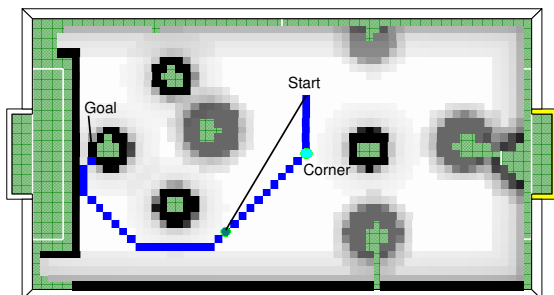
Kicking moving balls



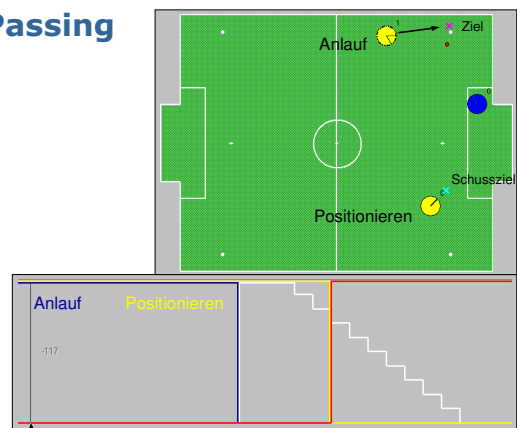
Avoiding Multiple Obstacles



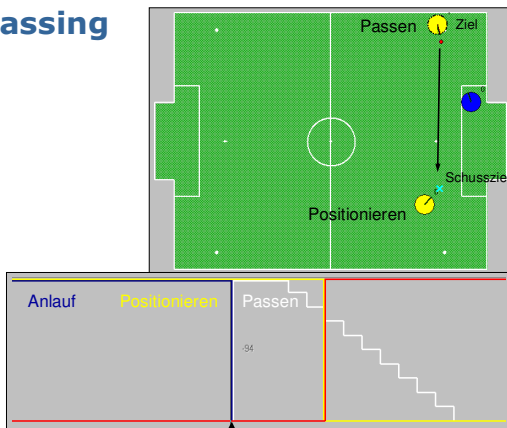
Path Planning



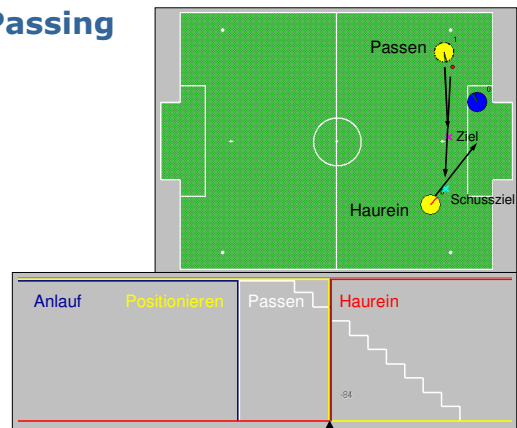
Passing



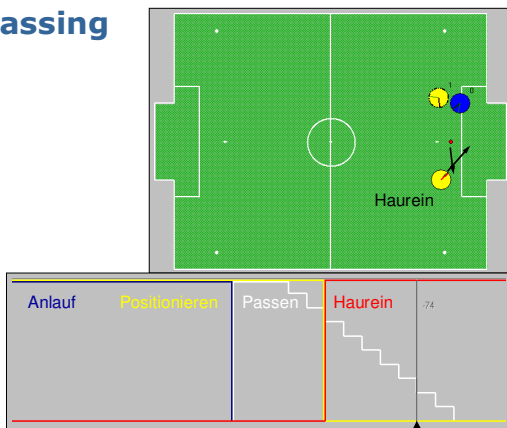
Passing



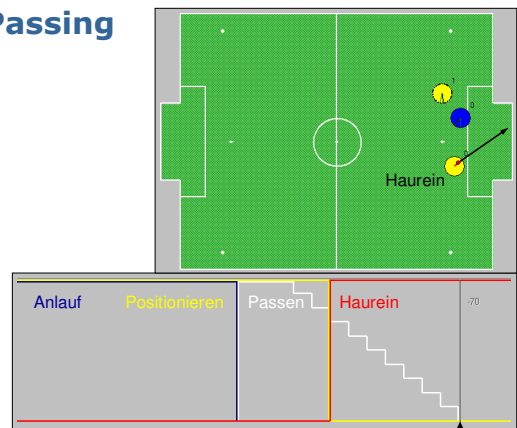
Passing



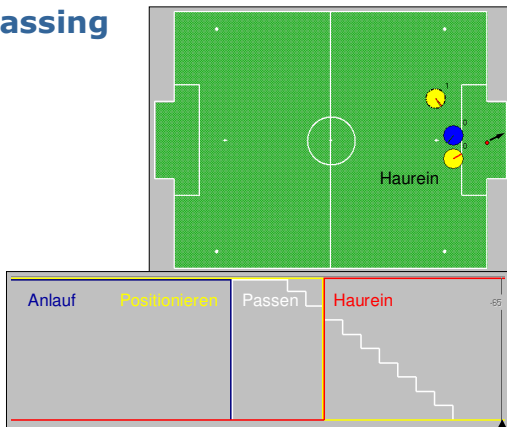
Passing



Passing



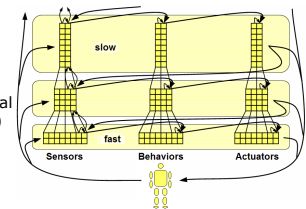
Passing



Behavior Control

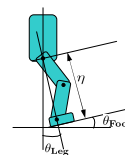
■ Hierarchy of reactive behaviors

- Time hierarchy (kHz, 83Hz, 41.5Hz)
- **Agent hierarchy** (individual joint, body part, robot, team)
- Complexity reduction through interaction constraints



■ Leg interface:

- Leg angle
- Foot angle
- Leg extension



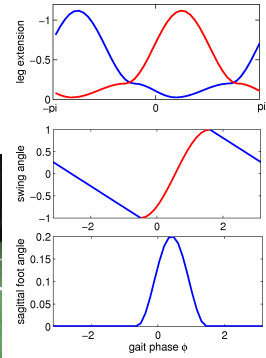
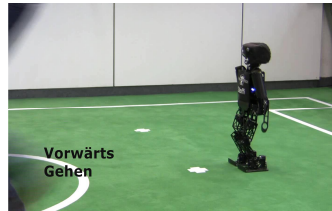
Dynamic Walking

- Starting from static stability
 - Zero-Moment-Point
 - Center of Pressure
- Starting from limit-cycle stability
 - Passive Dynamic Walking
 - Elegant
 - Energy efficient
 - Also with actuation
 - Inverted pendulum
- Both modes necessary

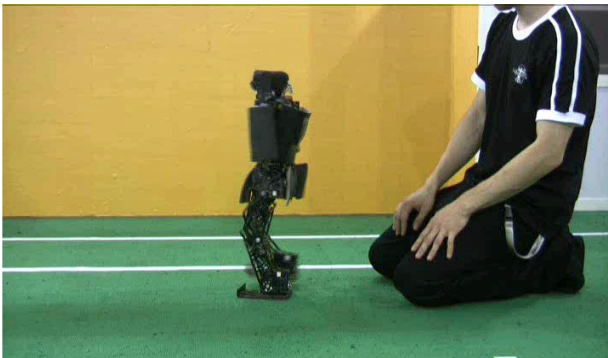


Omnidirectional Walking

- Combination of:
 - Forward/backward walking
 - Lateral walking
 - Rotation around vertical axis
- Key ingredients:
 - Rhythmic weight shifting
 - Leg shortening
 - Swing in walking direction

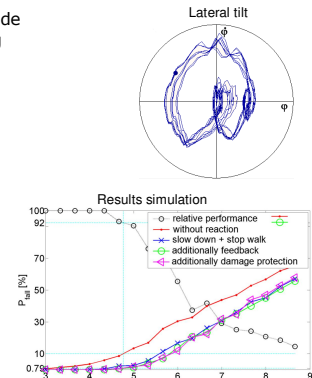
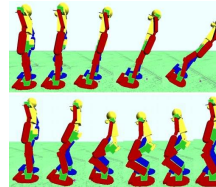


Dynamic Walking Stabilization



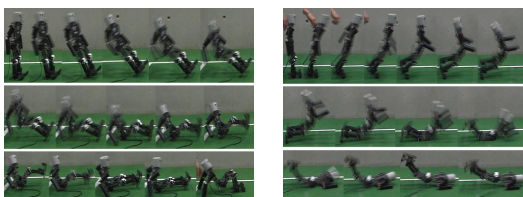
Fall Avoidance

- Learn model of trunk attitude during undisturbed walking
- Aggregate deviations to instability measure
- Stabilizing reflexes
 - Slow down
 - Stop walking
 - Leap step



Controlled Fall

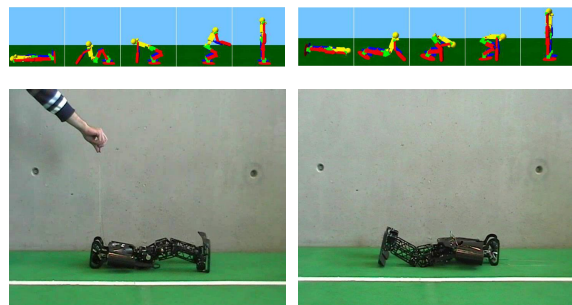
- Falls cannot be avoided completely
- Timely recognition by instability measure
- Landing at cushioned primary contact points
 - Knee (forward fall)
 - Lower back (backward fall)
- Arms as secondary contact points
- Relaxation of joints



Getting-up

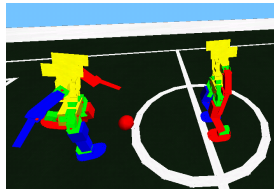
supine

prone



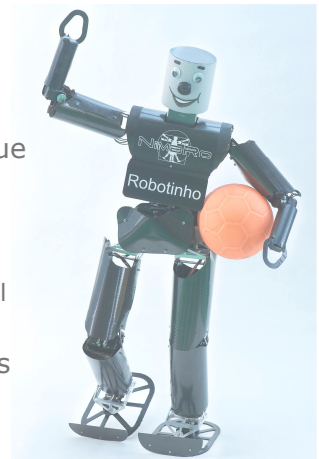
Infrastructure

- WLAN communication (UDP)
 - Start/stop, game state
 - Shared perceptions
 - Logging and visualization
- Simulator
 - Physics based (ODE)
 - Behavior engineering
 - Learning

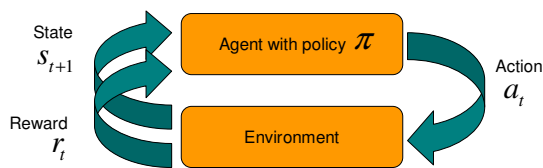


Outline

- Motivation
- Humanoid League
- Team NimbRo
 - Mechatronics
 - Perception
 - Behavior Control
 - Learning**
- RoboCup Results
- Outlook



Stochastic Policy Gradient Ascent



Goal: Learn to chose actions that maximize discounted future reward

- Approach:
- Direct search in policy space
 - Policy depends on parameters θ
 - Estimate gradient of performance w.r.t. θ
 - Update θ in direction of gradient
 - Reach local maximum

Successful Examples



Aibo
Kohl, Stone



RunBot
Geng, Porr, Woergoetter



Toddler
Tedrake, Zhang, Seung

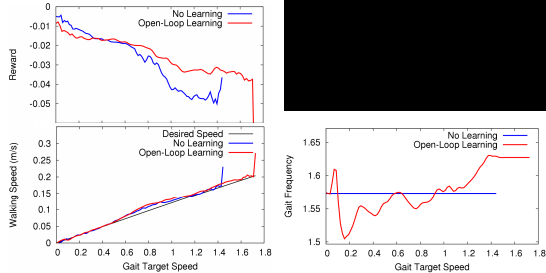
- Feed-forward gait engine
- 12 Parameters

- Neuronal controller
- Sensor-driven
- 2 Parameters

- Ankle roll feedback control
- Model: ramp walk

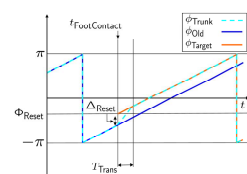
Stochastic Gradient Gait Optimization

- 7 Parameters
- Rewarding
 - Imitation of trunk motion
 - Speed



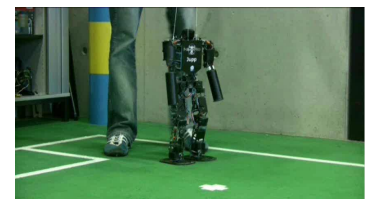
With Gyro Feedback and Phase Reset

- Gyro Feedback stabilizes trunk
- Phase reset yields entrainment

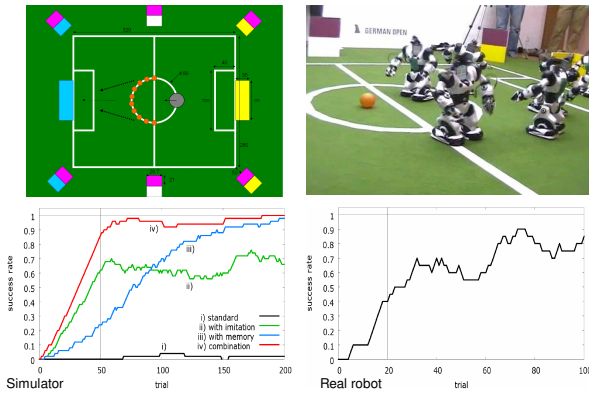


- Policy-Gradient Reinforcement Learning
 - Decreasing step size
 - Sequential sampling

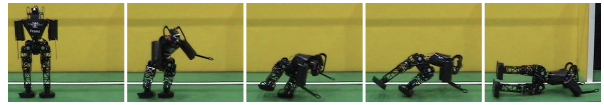
- 60% faster



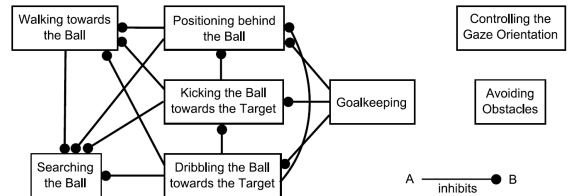
Learning to Score



Diving Motion

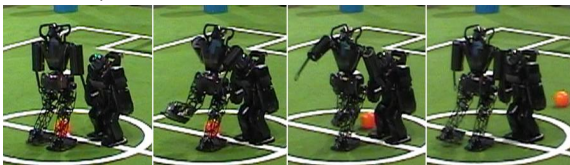
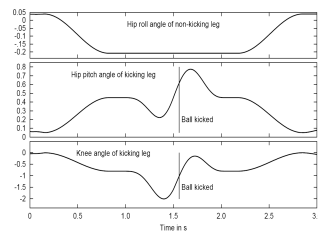


Soccer Behaviors



Kicking

- Shift weight
- Swing back
- Quickly to the front
- Decelerate
- Back to stable stand
- Parameters
 - Kicking strength
 - Direction
 - Ball position



Outline

- Motivation
- Humanoid League
- Team NimbRo
 - Mechatronics
 - Perception
 - Behavior Control
 - Learning
- RoboCup Results**
- Outlook

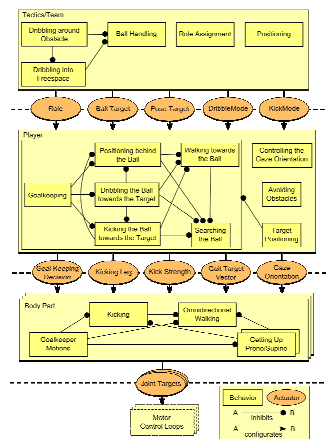


RoboCup 2007 TeenSize Final NimbRo vs. Pal Technology

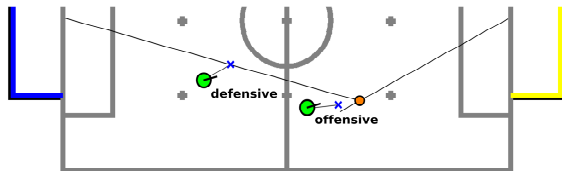


Behavior Hierarchy

- Tactics and Team Behaviors**
 - Role assignment
 - Positioning
 - Ball handling
 - Dribble around obstacles
 - Dribble into free space
- Soccer Behaviors**
 - Searching for the ball
 - Walking towards the ball
 - Positioning behind the ball
 - Kicking ball towards target
 - Dribbling ball towards target
 - Avoiding obstacles
 - Controlling gaze orientation
 - Goalkeeping
- Basic Skills**
 - Omnidirectional walking
 - Kicking
 - Getting-up from the ground
 - Goalkeeper motions



Player Positioning



RoboCup 2008 KidSize Final NimbRo vs. Team Osaka



Outline

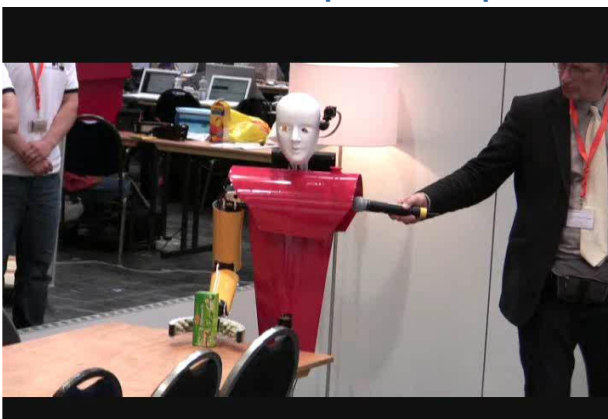
- Motivation
- Humanoid League
- Team NimbRo
 - Mechatronics
 - Perception
 - Behavior Control
 - Learning
- RoboCup Results
- **Outlook**



Communication Robot Robotinho



NimbRo@Home RoboCup German Open 2009



Conclusions

- RoboCup challenging domain for humanoid robotics and AI research
- Soccer games becoming interesting
- Performance still far from perfect
- So far, mostly individual skills
- Team play makes a difference

- Robot competitions foster progress
- Rules must be designed well

- Need for more research
 - Mechatronics
 - Perception
 - Behavior control
- Try to understand human better!

Team NimbRo in Suzhou



**Thank you
for your attention!**

Questions ?