

# Collaborative and Competitive Decision Making (CCDM)

## ■ CCDM Motivation

- From AI Toy Examples to a Theory of Complex Systems
- Multi-Agent Interactions and Emergent Behaviour
- Experiments in Artificial Worlds

## ■ CCDM Research in the CMIS Applied Artificial Intelligence Project

- CCDM Team and Our Collaborators
- Research Areas
- The RoboCup Initiative
- Experimental Prototype Design and Development

## ■ Potential Applications

- Simulation of Complex Systems
- Industrial Robotics
- Communication Technology

By Mikhail Prokopenko,  
Applied Artificial Intelligence  
Project, CMIS, December, 98

## From AI Toy Examples to a Theory of Complex Systems

*Complex Systems* (John L. Casti):

- **involve a medium-sized number of agents**  
(drivers, traders, molecules...);
- **the agents are generally both intelligent and adaptive**  
(they *make decisions* in accordance with various rules and are ready to modify their rules of action on the basis of new information);
- **there are no centralised controllers**  
(no dictators);
- **agents make their decisions and update their action rules on the basis of *local*, rather than global, information**  
(no single agent has access to what everyone else is doing - autonomy)

## Multi-Agent Interactions and Emergent Behaviour

### Emergence:

an overall system behaviour that comes out of the interaction of many participants - behaviour that cannot be predicted or even envisioned from a knowledge of what each component does in isolation.

- Two molecules of hydrogen and one of oxygen (both quite flammable and reactive gases), result, when combined, in an inflammable liquid (*emergent* properties);
- The so-called circuit-breaker rules prohibiting certain types of trades when the DJ index has risen or declined more than 50 points from its previous close have a settling (*emergent*) effect on over-exited markets;

## Multi-Agent Interactions and Emergent Behaviour

- The Central Limit Theorem: if individual random factors are numerous, mutually independent, and the effect of each such factor on a process (function) is very slight, then this function will be a normally distributed random variable: a simple behaviour *emerges* out of the interaction of a large number of complex agents;
- Straightforward interactions among relatively simple individual agents may result in a rich and varied emergent structure, having a level of complexity far greater than any one of its components: ant colonies, etc.

## Experiments in Artificial Worlds

- The problem with complex systems is that we cannot do the kinds of experiments needed to create a reliable model and theory of their operation.
- But now we can actually construct artificial surrogates for these complex, real-world processes and carry out the repeatable, controllable, scientific EXPERIMENTS needed in order to obtain viable theories of complex systems.

## Intelligent Trading Agents

### An artificial world:

- a fixed amount of stock in a single company;
- a number of traders that can trade shares of this stock at each time period;
- a simulator setting the stock price by observing market supply and demand and matching orders to buy and sell;
- an outside investment in which traders can place money at a varying rate of interest;
- a dividend stream for the stock that follows a random pattern.

## Intelligent Trading Agents

### Traders

- summarise recent market activity by descriptors A, B, C, etc.;
- employ decision making rules, e.g. “if market fulfils conditions A, B, C then buy”, etc.;
- re-evaluate decision making rules;
- re-combine successful rules.

## Intelligent Trading Agents

- What emerges after many time periods of simulation is a kind of “ecology” of predictors, with different traders employing different decision making rules.
- The population of predictors in the artificial market continually evolves, showing no evidence of settling down to a single best predictor for all occasions. The optimal way to proceed at any time depends critically on what everyone else is doing at that time.

## CCDM Team

- Ryszard Kowalczyk
- Maria Lee
- Ian Mathieson
- Mikhail Prokopenko
- Wai Yat Wong
- Dong Mei Zhang

and

- Marc Butler (Macquarie University)

## Our Collaborators

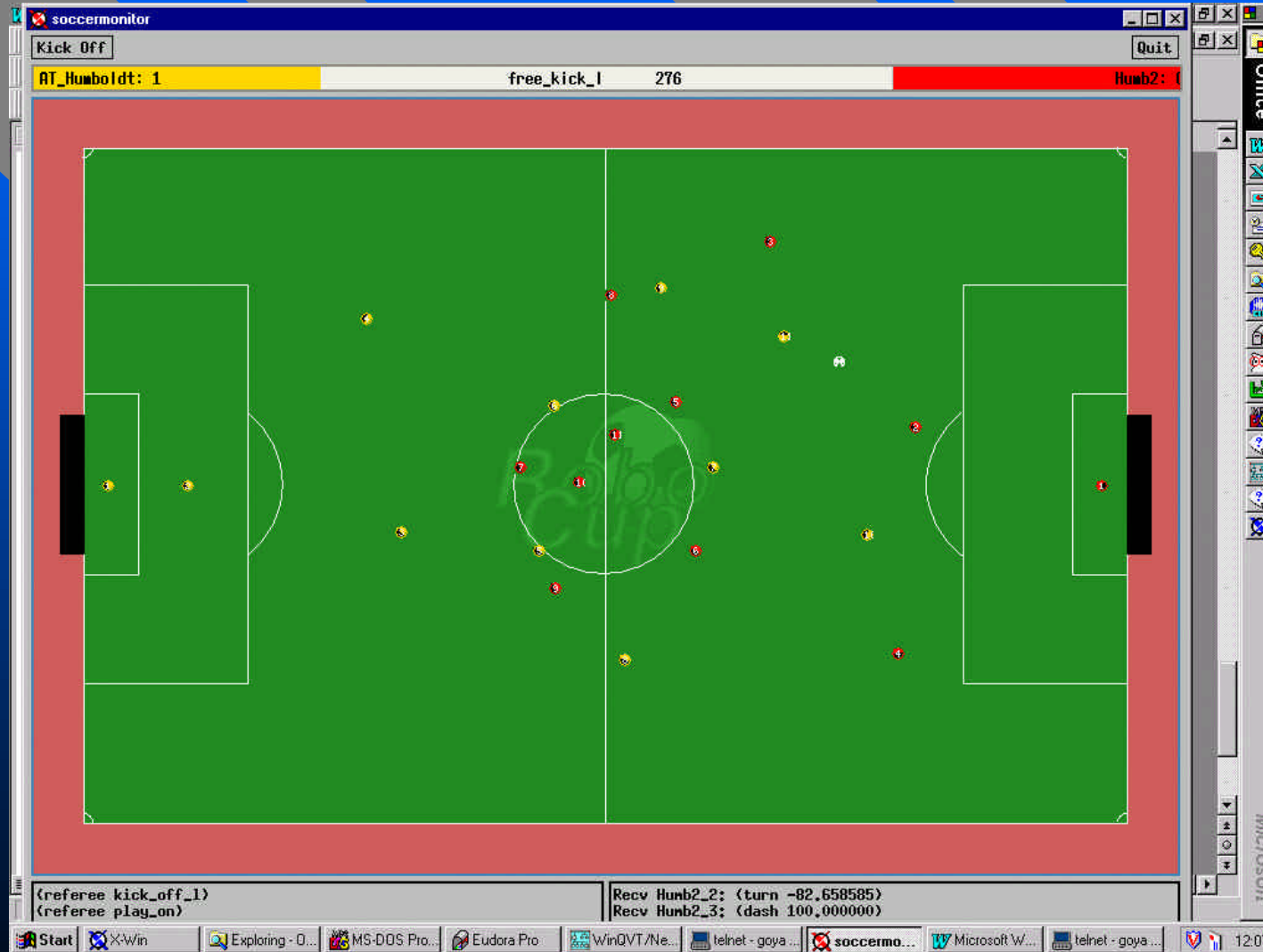
- *University of Wollongong (UW),* *Dr. Aditya Ghose*  
"Cooperative Problem Solving in Multi-Agent Systems"  
(a grant has been awarded by the UW Research Office)
- *University of La Reunion, France,* *Dr. Pierre Marcenac*  
"Strategy-oriented Learning in Multi-Agent Systems"  
(a PhD scholarship is under consideration)
- *RMIT University* *Dr. Lin Padgham*
- *University of New South Wales* *Dr. Norman Foo,*
- *Macquarie University* *Dr. Maurice Pagnucco,*
- *University of Western Sydney* *Dr. Yan Zhang*

## The RoboCup Initiative

- The Robot World Cup Initiative (RoboCup) is an international research initiative.
- It provides a standard problem where wide range of technologies can be integrated and examined.



# Simulation League



# Robot League



## **Results: Experimental Prototype Design and Development**

### **Designing and Modelling Situated Agents Systematically: *Cyberoos'98***

- **a hierarchical logic-based framework for intelligent agent architectures;**
- **an ontology of synthetic worlds and situated agents;**
- **an approach to formalising interactivity in dynamic multi-agent systems;**
- **a mapping from logic theories of actions to reactive agent architectures;**
- **implementation of the Cyberoos'98 – a soccer team of heterogeneous software agents.**

## **Applications: Simulation of Complex Systems**

- **RoboCup Rescue:**
  - environmental simulation for planning (bush-fire, floods, etc.);
- **people movement simulation (Olympic Games, transport junctions, etc.)**
- **stock market simulation, share trading and portfolio selection (fund management);**
- **resource management and information tasks automation (network management, travel planning, etc.)**

## **Applications: Intdustrial Robotics** **(petroleum, mining, forestry, agriculture, construction, etc.)**

- **material transportation in building sites, forests, farms, docks and warehouses;**
- **special-purpose machines, such as harvesters, rock-drills, construction machines, and cleaning machines for large areas;**
- **surveillance of outdoor sites and in hazardous environments, such as chemical and nuclear plants;**
- **control and operation of large hydraulic and cable machinery;**
- **seabed surveying equipment for diving operations;**
- **regular hydrographic surveys to study silt build up in tidal estuaries;**

# Self Guided Transport Vehicle

INTELLIGENT SYSTEMS FOR  
MOBILE MACHINERY

RSI Technologies Ltd.  
#3-203 Harbour Road  
Victoria, BC, V9A 3S2,  
Canada



# Remote Controlled Materials Handling System

INTELLIGENT SYSTEMS FOR  
MOBILE MACHINERY

RSI Technologies Ltd.  
#3-203 Harbour Road  
Victoria, BC, V9A 3S2,  
Canada



## Remote Excavator

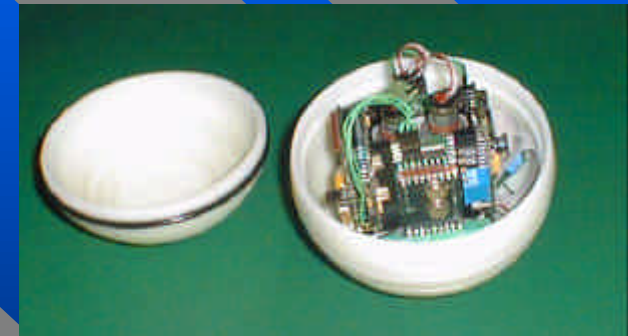
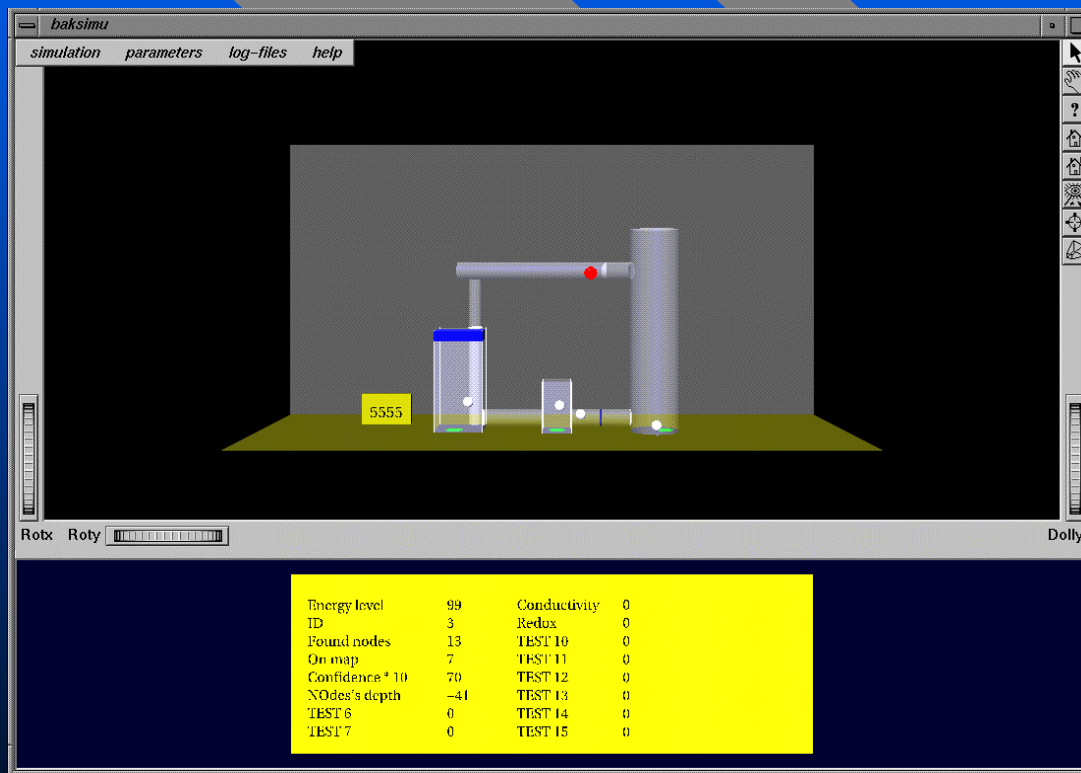
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Canada



# Team of small robots OR one large robot ?

## Underwater Robot Society for Environmental Monitoring and Process Control



Intelligent SUBMAR Society Oy

Toimitusjohtaja Antti Hakala

Käyntiosoite:

Itälahdenkatu 18 C, 00210

Helsinki, Finland

## **Applications: Communication Technology**

- **environmental monitoring and border patrol in demanding environments, such as ports, harbours, along river banks, and near sources of high radio frequency that may interfere with satellite signals;**
- **land/marine car navigation and vessel tracking;**
- **hydrographic and dynamic positioning navigation systems;**
- **ground and aerial surveillance and structure deformation monitoring;**
- **airborne applications: target acquisition, target designation, and minefield and surface ordnance survey;**
- **civilian and police applications such as day/night traffic surveillance.**

# Unmanned Aerial Vehicle



Shiebel Corporation

# Simulation League



## Two problems

- How to represent what persists through an action:

**the Frame Problem**

- How to represent action effects efficiently - without describing all indirect effects:

**the Ramification Problem**

## Logic of Continuous Change

- $H(t,f:v)$  the fluent  $f$  has the value  $v$  at time  $t$ ;
- $X(t,f)$  fluent  $f$  is exempt from the minimisation of discontinuities;
- $G(s, a)$  the action  $a$  is invoked at time  $s$ ;
- $A(s, a)$  the action  $a$  is applicable at time  $s$ ;
- $D_s([s,t], a)$  the action  $a$  is *successfully executed* over the time interval  $[s,t]$ ;
- $D_f([s,t], a)$  the action  $a$  *fails* over the time interval  $[s,t]$ ;
- $D_c([s,t], a)$  the action  $a$  is *being executed* during the time interval  $[s,t]$ .

## Axioms

*Interaction description:*

$$\lambda_i \dot{\cup} D_c([s,t], a) \dot{\cup} \emptyset D_f([s,t], a) \textcircled{R} G(t, b)$$

where each  $\lambda_i$  represents an interaction condition, and  $b$  is another action invoked by occurrences of  $\lambda_i$  during the execution of the action  $a$ .

For example,

$$\begin{aligned} & \mathbf{H}(t, \text{see\_opponent}(\mathbf{x}): z) \dot{\cup} \mathbf{H}(t, \text{near}(\mathbf{x}): z) \dot{\cup} \mathbf{H}(t, \text{see\_partner}(\mathbf{x}): y) \dot{\cup} \\ & D_c([s,t], \mathbf{DRIBBLE}(\mathbf{x}, d)) \dot{\cup} \emptyset D_f([s,t], \mathbf{DRIBBLE}(\mathbf{x}, d)) \textcircled{R} \\ & G(t, \mathbf{PASS}(\mathbf{x}, y, \mathit{distance}(\mathbf{x}, y))) \end{aligned}$$

# RoboCup Simulation

## ■ Soccer Server

- Client/server system
- Communicating with 22 player clients

## ■ Clients

- Receive sensory data (visual, auditory, internal)
- Send commands run, turn, kick...
- Process fragmented, localised and imprecise information about the field
- Only have a short time to respond
- Must make autonomous decisions but act in collaboration with members of their own team

## Simulator Agent

$\langle W, P, A, E, C, \text{view}, \text{projection}, \text{send}, \text{receive}, \text{do} \rangle$

$W$  is a set of all external states

$P$  is a set of all possible partitions of  $W$

$A$  is a set of situated agents

$E$  is a set of effectors

$C$  is a communication channel type

*view:*  $A \rightarrow P$

*projection:*  $W \times A \rightarrow 2^W$

$\forall w \in W, \forall a \in A, \text{projection}(w, a) \in \text{view}(a)$

*send:*  $A \times 2^W \rightarrow C$

*receive:*  $A \times C \rightarrow E$

*do:*  $E \times W \rightarrow W$

# Simulator Agent

