Intelligent Simulation of Coastal Ecosystems

Seminário de Sistemas Inteligentes, Interacção e Multimédia
SSIM 2010

António Pereira - amcp@fe.up.pt
Luís Paulo Reis - lpreis@fe.up.pt
Pedro Duarte (CIAGEB-UFP) – pduarte@ufp.edu.pt
Presentation Outline

• Motivation & Description
• Main objectives
• Technology Description
• Experiences
• EcoSimNet Development Status
• Conclusions & Future Work
Motivation

• Extraordinary times:
  – Population quintupled in less than one hundred years
  – Technologies are thousands of times more powerful than any our grandparents had
  – Ecology in our planet are changing in ways unimaginable a decade ago
Motivation

• Opportunities and threats:
  – We possess the knowledge, the technologies, and the values that can produce a future:
    • overcoming the misuse and over-use of natural resources and ecosystems
    • distributing equally natural assets that are root of many conflicts
  – Qualitative improvement must replace quantitative growth – goal of sustainable development
  – Individual and collective choices will determine, in the next decades, whether the reshape of the planet lead us to a disaster or a positive future.
Motivation

• Coastal ecosystems:
  – 60% of human population lives within 60 km from the coast -on the ribbon of land bordering oceans, seas and great lakes (Watson, 1996)
  – 14 from 17 largest megacities are located along coasts (Olsen, 2009)
  – Relevant numbers in Portugal: 80% of population lives within 50 km from coastal boundaries (INE, 2008)
**Motivation**

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(INE, 2008)
Motivation

• Human activities concentrated along coasts:
  – Industry
  – Transportation and trade
  – Energy processing
  – Tourism
  – Recreation
  – Communications and services

• Disproportionate share of global consumption of manmade and natural resources

• Generation of wastes

• Challenge of the twenty-first century:
  – How does humanity balance the management of its activities and the impacts produced on coastal ecosystems?
Motivation

• Realistic simulation of ecological models
  – Difficult task
    • Mixing complex biological, chemical and physical processes
    • Combining different time and space scales
  – Slowness associated to each simulation
• Integrate human factor/decisions in the simulation
• Provide flexible services to help sustainable management of aquatic ecosystems
  – Custom solutions for “any” aquatic ecosystem
Description

• Simulate the ecological aspects and assess the consequences of projects and interventions in aquatic ecosystems:
  – Coastal areas, lagoons, dams, estuaries, lakes ...

• Integrate a decision support system:
  – Find optimal solutions to environmental problems using intelligent search methods
Objectives

1. Build a simulator for realistic simulations:
   a) Able to include / remove sub-processes of simulation
   b) Flexible enough to simulate distinct ecosystems without change the core modules
   c) Able to integrate simulation modules from other teams / provide simulation modules to other teams

2. Integrate intelligent agents to generate and optimize simulated scenarios

3. Integrate opposite interests in management decisions

4. Develop a user-friendly framework, easy to use and expand by users with small or no expertise in ecological processes
Concretization

• Develop a user-friendly modular simulation software
• Build Intelligent Agents to generate different simulation scenarios
• Develop a language for inter-applications communications
• Integrate opposite interests in management decisions
Generic Network Infrastructure

Motivation | Objectives | Technology | Experiences | Development Status | Conclusions
Technology Description

• EcoDynamo
  – Realistic simulator for aquatic ecosystems
• Intelligent Agents
  – Human rationality in the scenarios generation and decisions
  – Calibration of the simulation model (machine learning)
• Decision Support System
  – Helps user to find optimal solutions for environmental management problems
• ECOLANG
  – Communication language for ecological systems simulation
• EcoSimNet
  – Multi-Agent platform that integrates all the previous
  – Enables parallel simulations - clusters
EcoDynamo Internal Structure
Aquatic Coastal Modelling
EcoDynamo – simulated processes

• Aquatic systems:
  – Flow and circulation patterns
  – Mixing and dispersion of mass and heat
  – Water temperature
  – Settling of planktonic organisms and suspended matter
  – Insulation
  – Light penetration
  – Bivalves growth
  – Zooplankton and phytoplankton biomass
### EcoDynamo – Objects and corresponding variables

<table>
<thead>
<tr>
<th>Object name</th>
<th>Object outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind object</td>
<td>Wind speed</td>
</tr>
<tr>
<td>Air temperature object</td>
<td>Air temperature</td>
</tr>
<tr>
<td>Water temperature object</td>
<td>Radiative fluxes and balance between water and atmosphere and water temperature</td>
</tr>
<tr>
<td>Light intensity object</td>
<td>Total and photosynthetically active radiation (PAR)</td>
</tr>
<tr>
<td>Tide object</td>
<td>Tidal height</td>
</tr>
<tr>
<td>Hydrodynamic 2D object</td>
<td>Sea level, current speed and direction</td>
</tr>
<tr>
<td>Sediment biogeochemistry object</td>
<td>Inorganic nitrogen, phosphorus and oxygen, sediment adsorbed inorganic phosphorus, organic phosphorus, nitrogen and carbon</td>
</tr>
<tr>
<td>Dissolved substances object</td>
<td>Ammonia, nitrate and nitrite, inorganic phosphorus and oxygen</td>
</tr>
<tr>
<td>Suspended matter object</td>
<td>TPM, POM, POC, PON, POP and extinction coefficient</td>
</tr>
<tr>
<td>Phytoplankton object</td>
<td>Phytoplankton biomass, productivity and cell nutrient quotas</td>
</tr>
<tr>
<td>Enteromorpha sp. and Ulva sp.</td>
<td>Macroalgal biomass, productivity and cell nutrient quotas</td>
</tr>
<tr>
<td>Zostera noltii</td>
<td>Macrophyte biomass and numbers, cell nutrient quotas and demographic fluxes</td>
</tr>
<tr>
<td>Clams (Ruditapes decussatus) object</td>
<td>Clam size, biomass, density, filtration, feeding, assimilation and scope for growth</td>
</tr>
</tbody>
</table>
EcoDynamo – Inheritance diagram for TEcoDynClass
EcoDynamo - grid morphology
Intelligent Agent Model
Intelligent Agents
Aquaculture Optimization

Motivation | Objectives | Technology | Experiences | Development Status | Conclusions
Intelligent Agents
Parallel Optimization
Calibration Agent

Motivation | Objectives | Technology | Experiences | Development Status | Conclusions
Decision Support System

• Aquatic ecosystems:
  – Biological model
  – Environmental analysis
  – Socio-economic analysis
  – Optimization model / decision
  – Sustainable management
    • Water framework directive vs. aquaculture profit
    • Water framework directive vs. tourism ROI
Decision Support System

• Results generated by the scenarios simulation act as indicators to the managers

• How to weight the indicators values?

• How to compare scenarios with several indicators?

• How to conciliate different (antagonic) stakeholders interests?

• Turn stakeholders part of the decision process to understand the options made
Decision Support System

• Model-Driven DSS
  – Mathematical and analytical models
  – Values of the key variables are repeatedly changed to reflect environmental changes
  – Results provided by the models are evaluated and analyzed by humans
  – After the model validation, small databases are enough
Decision Support System

• Analytical Hierarchy Process (AHP)
  – Multiple quantitative and qualitative opposite criteria
  – Pairwise comparison matrix
  – 1\textsuperscript{st} step: calculates the vector of criteria weights
  – 2\textsuperscript{nd} step: calculates the matrix of scenario scores
  – 3\textsuperscript{rd} step: classifies /ranks the scenarios
ECOLANG

• Describe regional characteristics of the ecological system
• Translate agents’ actions and perceptions
• Enable different levels of communication:
  – Execution (commands over the simulation model)
  – Configuration (select classes, change variables, ...)
  – Definitions (aggregate cells into regions)
  – Statistics (collect results from simulation)
  – Events (spontaneous messages from EcoDynamo)
ECOLANG - Message Structure
ECOLANG Messages – trace
EcoSimNet Architecture
EcoSimNet as a logic HLA
Farmer Agent – optimization process
Farmer Agent – optimization process 2
## Experiences

- **Realistic Simulation of Ecosystems**
  - Simulated results in line with measured variables

- **Flexible Simulation**
  - Integrating objects in simulation
  - Integrating DLLs with “legated” code

- **Culture Optimization**
  - Spatial optimization
  - Carrying capacity

- **Environmental DSS with AHP**
Ria Formosa
Motivation | Objectives | Technology | Experiences | Development Status | Conclusions
Sungo Bay
Velocity (m s$^{-1}$) - Animation over a period of 4 days with a time step of 1 hour

Phytoplankton (mg Chl a m$^{-3}$) - Animation over a period of 1 month with a time step of 1 day
Douro River

Douro Estuary – dispersion of pollutants from discharge points that drain into the river estuary

Red color – high concentrations of pollutants
Dark blue color – low concentrations of pollutants
# Motivation

Mathematical model of Douro estuary – direction and velocity of the stream (arrows)

- Red color – sea water
- Blue color – river water
Aquaculture Optimization

• Sungo Bay – distribute 60 cells with scallops in the delimited regions inner and outer (88 cells each)
Aquaculture Optimization

- Simulation time: 1 year and a half
- Number of scenarios: 20
- CPU time/simulation: 8 hours
- Number of simulators: 4
- CPU characteristics/simulator: Intel Quad Core @2,50GHz, 8GB Ram, Windows 7 64-bit.
Aquaculture Optimization

![Graph showing production indicator over iterations](image)
Aquaculture Optimization

Worst

Best

Delta = 37.8%
Aquaculture Optimization

typical evolution

| Motivation | Objectives | Technology | Experiences | Development Status | Conclusions |
AHP Results

Different PCM’s

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| AHP Scenarios Score

Figure No. 1

AHP Scenarios Score

Criteria values (Normalized)

Score Values

Scenario

1 | Ammonia | Phytoplankton | Clam Production Price | SCORE

1 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0

2 | 0.2 | 0.1 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0

3 | 0.3 | 0.2 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.0 | 0.0

4 | 0.4 | 0.3 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.0

5 | 0.5 | 0.4 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1

6 | 0.6 | 0.5 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2

7 | 0.7 | 0.6 | 1.0 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3
Development Status

• System is ready to use

• Commercial version
  – developments in the configuration database
  – introduction of new Agents
  – improvements in User Interface
Conclusions

- Realistic simulations of biological, chemical and physical processes
- Innovative multi-agent ecological simulation system (EcoSimNet, Ecolang, EcoDynamo, DSS, Agents)
- Agents introducing the human factor/decisions
- Easily expandable and customizable / High level software
- Approach has been tested for:
  - Environmental impact studies (simulating short-term and long-term effects of human actions on the ecosystem)
  - Optimal management of the environmental system (bivalve production optimization)
- Technology enables several types of environmental studies
Future Work

• Calibration Agent
  – Calibrates “any” kind of model

• Intelligent Visualizer
  – Suggests the best visual representation for obtained results

• Enhanced Farmer Agent
  – Explores new kinds of “naif” optimizations
References


