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Multi-Agents in a Virtual Regional Landscape

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Abstract**—The Virtual Region More was a research project to investigate how to utilize visualization and simulation methods as planning tools for research and teaching in the More region on the west coast of Norway. The project was developed using a bottom-up process to integrate multi-agents in large 3D terrain models. The Virtual Region More became an arena for testing agent models in shipping, fish farming, ecosystems, virus swarms and energy production.**

The most important result of the project was recognizing that simulating multi-agent systems in position-dependent landscapes leads to complex landscape-dependent systems. Multi-agents in large landscapes need generic methods to modulate generic agents. Generic multi-agents in large 3D landscapes need a system view to represent multi-agents in organizations, where agents are controlled by cost functions.

INTRODUCTION

INDUSTRIAL production has become more client-oriented, which has led to products that are more adapted to local conditions. This development is a challenge for local industry planning and public administration. Solutions adapted to place-bound environments thus have shifted from estimate-based to individual-based models.

Engineering skills are undergoing major changes in marketing, technology and methodology. Previously, standardization and mass production for a stable market influenced engineering. Recently, product development and manufacturing has become more order-based and customized. This has led to product development being more adapted to individual needs, organizations, environments or climates.

Simulation and visualization is a promising method to study the complex relationships that normally act as uncertainties. This project has sought to resolve this problem using individual-based models represented as 3D visual agents in 3D visual landscapes. The Virtual Region More is a strategic university project, founded by the Norwegian Research Council.

The goal was to develop the following:

1. A 3D virtual information world, The Virtual Region More.
2. Adaptive learning models for simulation and visualization.
3. Distributed real-time processes for simulation, visualization and interactive collaboration.

The Virtual Region More (VRM) is a region on the west coast of Norway. The basic idea of a Virtual Region More uses 3D-based maps of this arena for analysis, planning and simulation. The region has industrial clusters related to the maritime industry, fishing industry, fish farming, offshore industry and energy production.

Traditional simulation is based on the system dynamics approach. The system approach is based on a sum of delays in masses and events. If this delay is known, a user can estimate something about the future. When simulation models are individual objects, each object has an individual behavior. Models are then transformed from a deterministic to a non-deterministic simulation approach. Position-dependent simulation models thus challenge traditional simulation methods and open a new set of possibilities. Early virtual world concepts are based on computer games and were developed by the gaming industry [28] [27]. Other examples of virtual world concepts include 3D modeling of complex environments [25] and virtual worlds for estimating urban growth [1][4].

Introducing a game engine for simulating and visualizing a virtual word also introduced a need for simulations based on individual models. During recent years, interest in individual modeling has recently increased. Individual models have been useful for modeling economic systems, urban systems and ecosystems. The concept of individual modeling has grown to flocking agents and large crowds [20] [21][22][24].

The Virtual Region More was based on the idea of making a research tool; however, realizing this idea was clearly going to meet some challenges.

1. 3D landscapes: Terrain models from land and sea had different formats and standards. The challenge was to transform these into a common 3D representation based on GPS positions.
2. 3D integration and simulation: 3D technology was primarily aimed at animation. The challenge was to take the technological leap from a few animated objects into large 3D models and simulating hundreds of objects.
3. Computing power: Simulation and visualization make great demands on computing power. The question was how to get enough computing power to handle hundreds of simulation processes.
4. Individual models: Individual models increase the simulation approach from a set of stationary objects to a sum of 3-body problems. Such systems have

complex dynamic behavior. The research question was how to manage complex dynamic systems.
5. Climate models: The climate influences industrial and ecological processes at the Region More. The research question was how to represent climate dynamics in VRM.

The basic idea for VRM was to simulate industrial and ecological systems simultaneously. Simulating individual models, e.g., ships, fish and viruses, required a new concept based on self-adaptive generic agent models. The solution was to introduce generic multi-agents.

I. Materials and methods

The Virtual Region More was developed using a bottom-up process where prototypes tested different components separately on different technological platforms. Typical 3D tools for 3D modeling were Global Mapper, Google Sketch-Up, Blender, 3D-Studio and Maya. The first 3D model of a city area was modeled using the 3D tool Sketch-Up. The next step was to transfer 3D buildings into Google Earth. The first version of VRM represented a 15x15 km2 region of the Aalesund area on the west coast of Norway. This area was later expanded using a Unity game engine, which provided the ability to include a 3D virtual world that covered an area of approximately 300x300 km2.

Pure simulation models were developed using the same step-by-step process. The first simulation models were implemented by programming a dynamic model. The model analyzed climate indicators, rainfall at the west coast of Norway and the marine ecosystem in the Barents Sea. A neural network was useful to estimate rainfall for power production, genetic algorithms were useful to identify ship model parameters and wavelet spectrum analysis was useful to identify climate periods. The simulation models were later transferred to the game engine, combined with 3D visualization models, and developed as VRM.

A. Data

The data used in VRM project were integrated from a variety of sources. All terrain models were based on publicly available local county maps, terrain models, sea maps, air photos and terrain maps from the Norwegian Mapping Authority. 3D models of buildings were partly developed in the project and partly developed by students who have had training in 3D modeling. 3D models of ships were taken from publicly available 3D model libraries managed by Google Earth.

Simulating the virtual sea route was based on data from the Automatic Identification System (AIS) and zone data from a Global Positioning System (GPS). The data to visualize virtual farming were based on data from the college's own fish farms, external fish farmers and the National Veterinary Institute. Furthermore, an oceanographic flow model from MARINTEK in Trondheim was incorporated.

The ocean temperature and salinity in the Norwegian and Barents Seas were based on data from the Institute of *Fisheries Research Services* in Aberdeen and the Institute of Marine Fisheries and Oceanography (PINRO) in Murmansk. Rainfall quantities were based on data series from the electric power producer. Climate indicators from publicly open data series were downloaded from the Internet.

B. Methods

The large application differences and simultaneous modeling similarities led us to search for a generic method to model VRM as a complex dynamic system.

Position-dependent models were transformed into individual models. Individual models were implemented in a computer as agents. Agents are based on the idea of goal-oriented objects with autonomous responsibility to optimize their own methods and services. The agents were first tested as real-time processes in Matlab and later implemented in the game engine. The agents' object-orientation in the game engine laid the foundation for managing visual agents in groups or herds. Scenes could then be built by groups of ships or fish farms. The next step was to develop concepts and methods for separating agents into groups and theories behind agent learning. Eventually, we standardized agents as generic agents. With generic agents, we can use the same set of concepts and methods to simulate things as different as viruses, ships or fish farms.

Simulating different types of objects in a position-dependent virtual world required simulation models to suit the needs of individual situations. The model's complexity was reduced by introducing generic modeling principles:

1. System modeling: The virtual world was modeled using a system approach.
2. Agents and landscapes: Each model in the virtual world was either an agent or a landscape.
3. Intelligent agents: Learning agents were able to adapt to local landscapes and other agents.
4. Swarm intelligence: Agent groups were managed as swarm intelligence.
5. Abstract landscapes: Position-dependent cost functions were modeled as abstract landscapes.
6. Climate modeling: Climate was modeled as a set of climate oscillators.

The principles listed above yielded a virtual world without any central control mechanism. The landscapes were dynamically influenced by climate dynamics. The climate dynamics were influenced by the tide and astronomic models. Each agent had autonomous dynamics dependent on the current states of the landscapes and other agents.

One issue the system encountered that created a bottleneck access to computing power. The first version of VRM was developed as a simulation in Matlab software, where agents and services communicated using a software bus. This solved some demand for data capacity, but it lacked integration between simulation and visualization. This was eventually resolved by porting the Matlab simulation code to a Unity game engine. Currently, at the termination of the project, work is underway to decentralize computing power from the game engine to parallel computing power connected to the Internet.

II. Results

A. Virtual 3D landscapes

The first prototype was a 3D terrain model of Aalesund, a town on the west coast of Norway, in the middle of the More region. Virtual Aalesund City covered an area of approximately 15 x 15 km2 with a resolution of approximately 1 meter. The terrain was textured using images from aerial photographs for a realistic finish. The model had 3D models of art nouveau buildings in the town center, the main sports stadium and roads to the Aalesund city center.

Virtual Aalesund City showed that it is possible to develop 3D models of large urban areas. Such models can be used to visualize how urban areas are organized while simultaneously visualizing how these urban areas may change in future plans.

In this project, special art nouveau buildings were selected for convenience. There was in principle no limit to the number of buildings or level of building detail. The fundamental limitation was that this was a static 3D model with no moving objects. There was no room to integrate simulation and visualization on the same technological platform [5].

The Storfjord tube tunnel

The Storfjord tube tunnel was a 3D model of a floating tunnel over the Storfjord, a large fjord on the west coast of Norway. The model of the tube tunnel was developed in collaboration with a Norwegian offshore engineering company and, if built, would be the longest tube tunnel in the world. A car animation was developed to showcase how the tunnel would look both on the outside and what a car driver was expected see when driving through the tunnel. This tube tunnel showed that 3D models are suitable planning tools for mobile traffic planning because they can visualize public encroachment on nature from roads, bridges or tunnels as well as how local conditions are affected.

Compared with the Virtual Aalesund City model, the tube model was more functional than the static 3D objects on a 3D terrain model. It introduced the experience of being on-site in a realistic 3D environment, including animated (moving) 3D objects.

The Virtual Aalesund Region

The Virtual Aalesund City was a static 3D model. The next prototype model was The Virtual Aalesund Region. This model covered an area of 15x15 km2 and was implemented using the game engine. The model's texture was based on aircraft photography and buildings from The Virtual Aalesund City. Introducing a game engine technology platform opened the possibility of introducing moveable objects on 3D terrain models. This model was thus subjected to various tests for different animation concepts.

Autonomous ship agents

Autonomous objects were implemented as agents and agent groups. In this project, we chose to model mobile agents as ships because ships use relatively plain terrain models and a straightforward route. The autonomous ship agents could manage their own travel routes to targets on landscapes. Agents for autonomous ships showed that it was possible to make similar autonomous agents representing cars, people, and fish. The limitation of this model was that the agents had no access to local data. Introducing a genetic algorithm allowed introducing an adaptive optimum control for speed and position [10].

Real time AIS-ships

Introducing Virtual AIS-ships was the first step in introducing position-dependent agents. In cooperation with Norwegian authorities, the project was given access to the GPS coordinates of ships sailing along the Norwegian coast. These data were based on AIS technology, where the ships' positions became available over the Internet in real-time. The on-line access to ship GPS positioning created an opportunity to place the position of actual ships and autonomous ship agents in the same 3D terrain model. It was thus possible to simulate how autonomous ship agents may handle real ship traffic in real-time. The greatest challenge of this model was the relation between AIS vessels' positions and positions on the 3D terrain model. It required a new terrain model in which all position information is a reference to a GPS position.

The Virtual Region More

The Virtual Region More was developed using a 3D terrain model based on place-bound GPS coordinates. The model had a spherical shape and covered an area of 300x300 km^2 with a resolution of 20 cm. The VRM model introduced abstract landscapes with different location-bound information to agents. It also introduced the idea of connecting virtual 3D landscapes and position-dependent information related to cost functions. Based on the abstract 3D landscapes, agents were able to adapt to local conditions in VMR. It was thus possible to solve different types of optimization problems.

B. Simulation models

Astronomy simulator

The Virtual Region More was driven by an astronomical model. This model was based on five basic periodic cycles of the moon's rotation around the earth and the earth's rotation around the sun. This astronomical model formed the basis for a tidal model, sun positioning, and solar time-dependent radiation in relation to the landscape.

Tide simulator

The astronomical model formed the basis for a tide model. The tidal model was based on more than thirty cycles and produced periods from six hours to more than a hundred years. The model was the basis for developing a climate model calculation of rainfall for the electricity market and simulating oceanographic dynamics and ecosystem dynamics.

Climate simulator

The More Region is located on the west coast of Norway, an area where climate change influences nature, economy and settlements. Climate change is thus central to the framework for dynamic landscapes in VRM.

Given the long time series involved in climate change, a project was initiated to develop climate simulations. This work was based on basic research, partly in collaboration with the FRS in Aberdeen (North Atlantic Water), PINRO in Murmansk (sea temperature) and BKK in Bergen (precipitation analysis). The climate simulator was developed based on a wavelet spectrum analysis of a variety of climate indicators. These results were again related to complex astronomical and tidal models [8][11].

Ecosystem dynamics simulation

The fish export from the More Region is approximately USD $2.5 billion a year and thus has a major influence on the region's economy. The dynamics of the fish ecosystem is influenced by climate dynamics. To better understand the ecosystem dynamics, an ecosystem simulator was developed based on the tide simulator, climate simulator, and wavelet spectrum analysis of long data series. This basic research indicated that the stock of North Atlantic cod, Barents Sea capelin and Norwegian spawn spring herring had fluctuations coupled to long tides [6] [7][9][12][13].

Rainfall for the electricity market

Norwegian energy production is based on hydropower. Hydropower for the electricity market is based on inflow from rainfall. This rainfall can vary 30 percent from year to year. Good long-term forecasts therefore hold major importance for industries at the Region More. In collaboration with the power-producing industry, there was a time-series analysis of the supply to the electricity market. The inflow to the electricity market had underlying tidal periods of approximately 9, 18 and 75 years. These periods formed the basis for a model of the expected energy production [3][14].

Smart houses

Within the framework of the VRM project, a typical task for an autonomous agent is determining its optimal locations in complex landscapes given some desired criteria. Smart houses are an example of autonomous agents where agents search for their optimal location. In this example, a random population of visual house agents was able to find optimum positions by optimizing cost functions. Each house agent moved itself to an optimum position, relative to some fixed parameters. Smart houses introduced the framework of abstract 3D landscapes. They thus formed a new basis for modeling a group of generic agents, bounded to place references. Other typical examples of these types of position-dependent agents are landscaping and city planning agents.

Tanker and tug simulator

Ship traffic along the Norwegian coast is exposed to tough weather conditions and the risk of drift grounding accidents. In collaboration with the Norwegian authorities, a project was started to investigate and develop methods to determine the optimal positions for patrolling tug vessels. These tug vessels patrol the coast to reduce the risk of oil tankers and other ships drifting aground. Using a receding horizon genetic algorithm (RHGA) solved the simultaneous problems of coordinated resource group control, task assignment, and multiple target tracking in a dynamic environment [18][19].

Virtual fish farm simulator

Norwegian fish farming exports constitute about USD $4 billion per year. Approximately 50% of these exports come from the Region More. A set of virtual fish farms was developed as an example of a distributed real-time simulation of position-dependent marine industry. Each model was developed using data from Norwegian fish farmers and veterinary authorities for fish. The model aimed to study the complex relationships between different types of agents.

The fish farms were modeled as visual agents. Each agent was placed in the landscape in accordance with real fish breeding facilities and had its own financial management. Each farm agent generated a fish agent population. Each fish agent was a moving agent with biomass and growth model in its local conditions. Each fish agent could produce a virus population that could affect health and mortality in the aquaculture facility. Between the facilities, shipping agents transported fish from aquaculture facilities. A system dynamics analysis showed the relation between production and marked dynamics [15][16][17]. The main result of this model was developing the concept of generic agents. Based on the same agent architecture, we could develop agents representing vessels, fish farming, fish and viruses.

Spread of viruses

The spread of viruses among fish farms is a threat to Norwegian salmon exports. It is unclear how these viruses spread among fish farm plants along the Norwegian coast. Consequently, a project was started to study the distribution pattern of viruses from fish farming. This study was based on swarms of active particle agents connected to an oceanographic current model. The game engine had capacity problems when there were more than a hundred agents. Large swarms of particle agents introduced great demands on computing power.

C. Complex systems theory

Changes in the environment conditions lead to time-variant landscapes. Time-variant landscapes indicate that agents must have adaptive learning methods to accommodate local conditions. The Virtual Region More introduced multi-agents of different types. The simulation of fish farms was based on agents to simulate viruses, fish, fish farms and ship traffic to fish farms. Introducing multi-agents of several types led to the need to reduce modeling agent complexity. This started the development of a concept of generic agents. The generic agents were intelligent and had the ability to monitor their own performance. Intelligent agents monitored their own performance using cost functions. The complex relation between landscape dynamics and agent dynamics was modeled as complex systems.

II. Discussion

A. Virtual 3D landscapes

Virtual 3D terrain models with location bound reference must have a resolution of 1 m or better. They must also be able to cover areas of many square kilometers. The problem was combining large 3D landscapes and achieving high accuracy. This problem was solved using a terrain model, oriented on a sphere in accordance with the curvature fields. All positions were calculated in relation to the GPS positions. Agents were thus positioned with an accuracy of 20 cm. Agent simulation also became less dependent on the accuracy of the landscape database.

B. Learning agents

Agent-based modeling has proven a flexible method to modulate complex systems. The agent capabilities are dependent on the ability to learn [23]. Simulating site-bound activity leads to a need to transfer models based on average estimates for individual-based models and boids [27] [2]. The first simulation modeled agents as simulated ships. We then developed agents for houses, farming, fishing, and viruses. This work gradually led to developing generic agents. Agents with location-bound information must adapt their activity to local variations. Simulation models must have adaptive properties so that they can monitor their own performance.

There were two types of local agent adaptation. One type was based on the agent to determine its optimal location in the landscape, e.g., agent-based houses and fish farms that find optimal locations in the landscape. Another type of customization was agents who seek an optimal adaptation to local conditions. It soon became clear this problem type could be solved using heuristic methods, such as genetic algorithms.

C. Complex systems

Genetic algorithm learning had its limitations. Simulating individual agents was followed by simulating agent groups. We created herds of agents representing viruses, fish, fish farming and ships. Introducing herds of agents meant that the agents had to be adapted to something more than local place-bound information. All agents were more or less influenced by each other, giving a non-deterministic complex system. To understand the dynamic process better, we started to develop agent-based modeling based on complex systems theory.

D. Parallel processing

3D visualization of large landscapes puts heavy demands on computer capacity. It needs large storage capacities of 3D models and computational power. A game engine can produce 3D models with a resolution that changes the visual field. Using a game engine, it was possible to produce 3D models over large areas. Simulating the agent flocks proved to be a larger problem.

The agent-based fish farming simulation showed computer capacity problems when there were more than a thousand agents. This may be sufficient in simple studies. In many cases, however, large areas must be studied simultaneously. Computer capacity is a fundamental limitation, so introducing parallel processing of agents is a necessary method to increase the number of agents and agent flocks [20].

III. Conclusion

The Virtual Region More was developed as a research tool to analyze dynamic changes associated with site-specific information. The research tool was based on a virtual 3D representation of geographic areas and parallel simulation associated with local conditions. The case examples showed that such a research tool may hold interest for research, public management and industrial engineering.

The virtual 3D world was primarily a technological challenge, where using a game engine was the basis for an integrated solution. The most important feature of a virtual 3D world is that it provides information about complex relationships. Introducing abstract 3D landscapes was an important concept to reduce complexity and solve optimization problems. Abstract 3D landscapes produced risk and cost areas that formed the basis for the agent priorities.

Agent-based modeling was a flexible concept for modeling location-bound simulation problems. Genetic algorithms proved to be a good way to train individual agents. Learning agents was a far more complex problem when an agent set was assembled in herds in which all agents affect each other. The solution was a horizontal learning mechanism between agents and letting each agent adapt all activities to cost functions.

Introducing agent-based models on a game engine created the new possibility to manage many parallel simulation models linked to local conditions. A future challenge is to increase the number of agents with greater computing power.

The most important result of the project was recognizing that simulating position-related multi-agents leads to simulating complex systems. It is perhaps in the relationship between visual presentations, multi-agents, artificial intelligence and added cost functions that this research tool will see its future benefits.

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