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Agent Based Modelling of Caribou Environmental Interactions in the Canadian Arctic

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Abstract: Agent or individual based modelling (IBM) is recognized as an important tool in biological modelling for simulating animal behaviour and interactions with the environment at the level of the individual while maintaining a collective perspective. The method allows rules to be programmed for the interactions between like and unlike species, responses to geographic factors and impacts from human activities. By emphasizing the development of appropriate rules for the individual, one can avoid imposing ad hoc assumptions concerning the population as a whole and instead allow emergent phenomena to unfold at the larger scale. Here we report on preliminary results using IBM to simulate the movement and population changes of an idealized caribou herd in a Northern Canadian Arctic setting. A wolf population is included in the simulation to study how the predator-prey relations impact the fluctuations in total population. The simulations use GIS data to account for a varying landscape including topography, water bodies and vegetation. The challenges of developing the software components will be discussed including the relative merits of using C# and NetLogo as programming languages. Future inclusion of Inuit hunter agents will be discussed.

Keywords: individual-based; modelling; agent; caribou; NetLogo

1. INTRODUCTION

Multi-agent or individual based modelling (IBM) simulates complex systems by applying rules for the interaction of agents or individuals with each other and with the environment. It is well-suited for applications where variation in the individuals' attributes is required to better understand the behaviour of the population as a whole. It captures the richness associated with individual members evolving according to their own unique experiences and interactions, instead of imposing an average effect uniformly to the entire population or sub-population.

In an agent approach the programmer inputs rules of interaction at the level of the individual. This more closely simulates the way natural systems develop or evolve in time. Instead of imposing preconceived notions directly on the population at large, the programmer designs empirically-based rules for the individual and then allows the interactions to determine the consequences for the whole population. This is referred to as emergent phenomena which are common place for complex or nonlinear systems, including those in biology.

The IBM approach in computational ecology and biology is a well-established discipline (Grimm and Railsback, 2005). Early successes include simulating the social hierarchy of the green woodhoopoe (Neuert et al., 1995), the Beech forest model that reproduced spatial patterns (Neuert, 1999) and individual fish behaviour using a stream trout model (Railsback et al., 1999). Recent work has closely critiqued and improved the agent based approach in behavioural ecology (Lehmann, 2009). The method is well suited to predator-prey simulations where interactions at the individual level such as predation and reproduction determine the population periodicities and spatial pattern formations in large-scale populations (Wilson, 1996; Gui-Quan et al., 2008). The limitations of the classical Lotka-Volterra predator-prey model have been demonstrated using IBM comparisons (Donalson and Nisbet, 1999; Law et al., 2003).

Predator-prey interactions take place in a heterogeneous landscape with varying topography, vegetation, water supply and climate. These environmental factors can be included as parameters in the behavioural rules for the individual animals resulting in an important source of variability that needs to be captured in ecological simulations. Rohner and Demarchi (2000) developed an IBM as a tool for comparing forest policy options in which individual caribou were simulated in a GIS application. Metsaranta (2008) used an IBM to show that caribou's preference for home ranges in mature coniferous forests appears driven by a refuge need from predation.

The current work has a long-term goal to better understand how changes in caribou movements and numbers may impact the Inuit peoples in the Canadian Arctic. Wild caribou is an important food and income source for the indigenous Peoples living in parts of Nunavut, Northern Quebec, Northwest Territories and Yukon. Environmental change forced by global warming and local human activities have the potential to disrupt the caribou herds. Berman et al. (2004) assessed various scenarios associated with economic and climate change by using an agent-based model of individuals and households in a hypothetical community in Old Crow, Yukon. The model appears to be able to project changes in economic, demographic and hunting conditions that is consistent with observed trends.

Predicting changes in the herd characteristics is challenging for a number of reasons. The predation from wolves and bears involve complex interaction biology, the strategies of the Inuit hunt can vary between settlements and even individuals, the landscape and food supply for the caribou have large geographic variations, and changes in weather patterns associated with global warming are already being observed. We are beginning a research project to test the IBM approach as a tool to simulate complex processes that have strong individual variability in a heterogeneous landscape.

In this presentation we report on a preliminary project to evaluate the tools that might be used to accomplish the longer-term objectives. The simulated system is simplified to a single predator and single prey, namely wolves and caribou, interacting in a tundra landscape typical of Northern Canada. The software must allow easy design of agent objects that can interact with a GIS (Geographic Information System) database. It must be able to handle many thousands, preferably hundreds of thousands of individuals, moving in a landscape 1000 km or more in horizontal extent. A time step of less than one hour is preferable to handle the movement of hunting wolves and migratory caribou. Total simulation time should ideally extend for one year to encompass an entire annual cycle with seasonal variations included. All these requirements put an enormous demand on the speed and memory of the software and hardware components.

2. METHODS

In this work two software languages will be considered: C# and NetLogo. C# is a modified version of C++ which is distributed by Microsoft as part of their .NET framework of languages. Its advantages include that it is type-safe and automatically deals with garbage collection when an object is deleted. C# design of the classes needed for predator-prey simulations gives the programmer total control of a fully object-oriented language yielding fast code when using good programming practices. The disadvantage of C# is that its target platforms must be Windows based, a reason why many developers opt for a JAVA based environment. Although one can use traditional Windows system graphics it is preferable to attach the Microsoft XNA library which is designed for fast graphics and animation. Both C# and XNA program design can be done within the Microsoft Visual Studio IDE. All these software components have free versions that are downloadable from the web.

NetLogo (Wilensky, 1999) is a multi-agent programming platform developed by the Center for Connected Learning at North-Western University in Illinois that can be downloaded for free. It is a closed source, multi-platform, JAVA based high level programming language that comes packaged with its own IDE and graphing capabilities. A great advantage of NetLogo is its ease in learning and intuitive use of commands. Novice programmers can get fairly sophisticated code up and running in a day. Some compromises in speed and versatility can be expected.

Between the extremes of building applications from scratch using C# and the pre-designed interface and data structures of NetLogo are a range of multi-agent libraries and IDEs that are typically JAVA based. These include MASON, RePAST, SWARM and many others, some of which are free to download and some proprietary. Some might find these alternative products a better compromise between software development and program execution times, but we will not be examining them.

A simple simulation, using a single predator type (wolf) with a single prey type (caribou), is coded in both C# and NetLogo. The animals move pseudo-randomly with no herd or pack behaviour. Caribou health is maintained by consuming fixed vegetation and they reproduce at a fixed rate. Wolf health is maintained by consuming caribou and they reproduce at the time and location of the caribou predation. Predation occurs when a wolf and caribou happen to be co-located in the same grid box.

For the purposes of evaluating the performance of similar codes in C# and NetLogo the predator-prey simulation is a modification of the Wolf Sheep Predation sample model included in the NetLogo library (Wilensky, 1997; 1999). A uniform domain of 701 x 481 grid points with wrap-around boundaries is used. Initially 500 caribou and 250 wolves are positioned randomly with a random direction vector for movement. Caribou move 0.1 grid length per time step with a random directional change of up to 45 degrees while wolves move 1 grid length per time step with a directional change of up to 20 degrees. Animal age is predetermined randomly with caribou living for a maximum of 1000 time steps (ticks) and wolves 600 time steps. A caribou's life is ended if it is collocated on the same grid box as a wolf. At this predation event the wolf gives birth to one new wolf. Caribou births occur with a probability of 0.3 % per caribou per time step.

Another simulation was done to experiment with more realistic environmental conditions using only NetLogo. A digital elevation map downloaded from Geobase (http://www.geobase.ca/geobase/en/index.html) but originating from NRCan's Centre for Topographic Information (Region 116O10 in Northern Yukon) was input using the GIS extension of NetLogo. The domain extended from 138.5 to 139.0 degrees West longitude and 67.50 to 67.75 degrees North latitude using 1202 x 1202 grid points which results in a grid size of around 23 metres. Vegetation growth was simulated by a constant regeneration rate for the whole domain while vegetation loss occurred on patches with caribou. Initially 3000 caribou and 2000 wolves are randomly positioned in the domain, with a maximum life span of 1990 and 600 ticks for caribou and wolves, respectively. Caribou moved 0.24 grid lengths per tick while wolves moved 1 grid length per tick using the same directional randomness as before. Caribou and wolf births and deaths were simulated as before. Caribou were allowed to quickly cross the river while wolves were not. Caribou were prevented from climbing a slope greater than 3 metres in elevation over a 20 metre span, whereas wolf movement was not restricted by topography. Caribou moved faster through terrain with low vegetation density, and both caribou and wolves are prevented from crossing the domain boundaries.

3. RESULTS

Using NetLogo it took just a couple of hours to write the entire program in about 60 lines of code for the software comparison experiment, whereas C# required over 400 lines of code and took a couple of weeks to complete and debug. Although these numbers can vary widely depending on the programmer's experience, there is a substantial savings in development time using NetLogo. C# requires the extra overhead in designing the various classes from scratch, dealing with inputting parameters and outputting the display and results and writing type-safe code. Program execution speeds are compared in Table 1. The comparison tests were performed on an Acer 4810T notebook with a 1.3 GHz Intel U7300 processor using 4 GB of RAM under Windows 7.

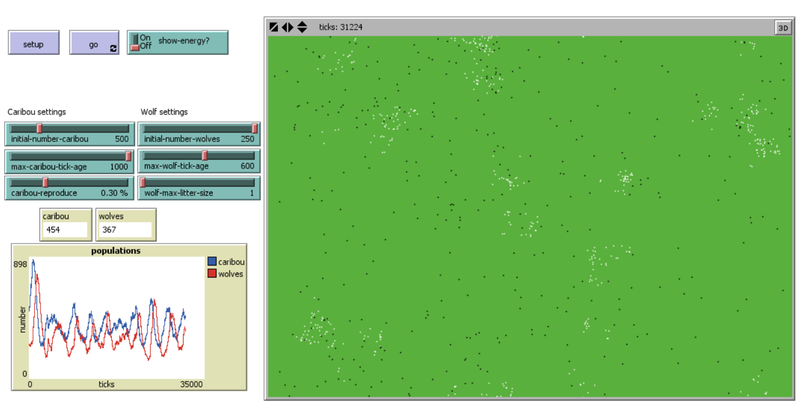
Table 1. Comparison of execution speeds in time steps per minute for the cases with and without display updates every time step.

	NetLogo	C#
Update display each time step	300	3,500
No display	20,000	3,600

The performance bottleneck for NetLogo is in the display update. Fortunately it is easy to modify the frequency of display updates or to turn it off entirely. It is surprising that without display updates NetLogo was over 5 times faster than C#. This likely reflects inefficiencies caused by a non-expert C# programmer and the handling of the XNA time clock in C#. It is remarkable how small the graphics overhead is for C# when using the XNA library.

Figure 1 shows a screenshot during a NetLogo simulation of the caribou-wolf model used in the C# comparison study. The domain in green is populated by individual caribou in white pixels and wolves in black pixels. To the left are slider boxes that allow the numerical parameters of the simulation to be adjusted. In the lower left is a graph showing how the total population of caribou and wolves change with each time step. The phased-shifted periodicities typical of simple predator-prey differential equations are evident. An interesting result with the parameters used is the clustering of caribou in groups while the wolves have sufficient speed to move between the caribou groups during their lifetime. This is an example of an emergent phenomenon that was not imposed in the algorithm. This scenario was run for about an hour of actual time without changes in the basic oscillatory and spatial patterns.

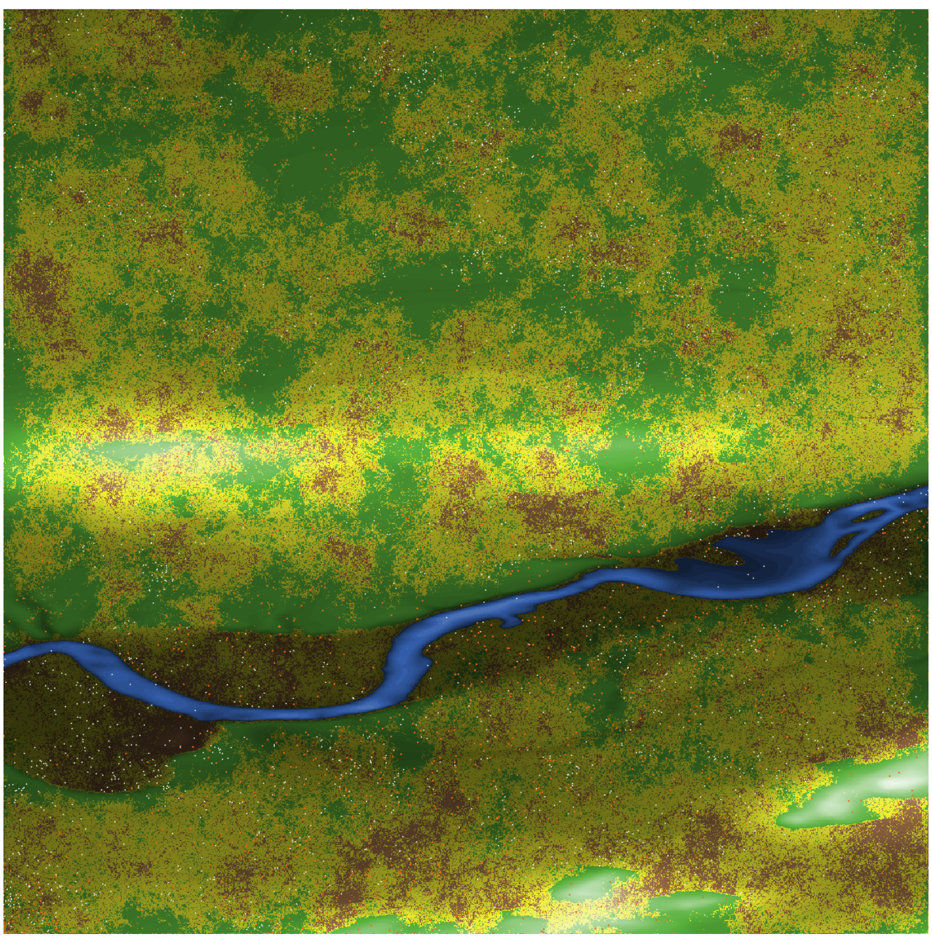
Figure 1. Display from the caribou-wolf simulation using Netlogo.



In Figure 2 a screen shot of the domain is shown from the NetLogo simulation with topography and vegetation included. The elevation is depicted by the brightness with the highest elevation of around 575 m appearing nearly white and the lowest land elevation of around 260 m appearing dark. The river depth is shown in shades of blue with the lighter blues corresponding to deeper water. Vegetation density is tracked by an integer and displayed in 3 categories on the map: brown for the lowest third in vegetation density, yellow for the middle third and green for the highest third. Individual caribou and wolves are plotted as white and orange pixels, respectively. The simulation with elevation and vegetation was performed using a PC tower with an Intel i7-940 processor at 2.93 GHz with 8 GB RAM under 64 bit Windows 7 Pro.

Even though the simulation started with the same vegetation density (middle of the yellow category) for all land grid points, the spatial variability of the caribou's grazing resulted in coherent patterns of enhanced and reduced vegetation. As in the C# comparison simulation the spatial distribution of the caribou and wolves does not appear random with well defined areas completely void of caribou. Regions void of wolves are smaller since wolves move faster than caribou. Also the tendency of caribou to avoid climbing steep terrain results in their paucity in the higher elevations.

Figure 2. A screenshot of the domain after 593,307 time steps into the simulation with elevation and dynamic vegetation included.



4. SUMMARY

We compared the performance of NetLogo and C#/XNA in developing and running a simple caribou-wolf interaction in a spatial domain. NetLogo was easy and intuitive to use which greatly reduced development time compared to C#. Surprisingly the execution speed of NetLogo outperformed C# when display updates were turned off. With display updates turned on every time step NetLogo was much slower than C#. Based on these limited tests we conclude that NetLogo is an efficient tool to use in a research mode for predator-prey type modelling. Memory limits should only be dictated by the available RAM in the hardware configuration.

Preliminary simulations were successful at including topography from a real elevation dataset and dynamic vegetation. Future work needs to explore the sensitivity of results to initial conditions, topographic features and the details of the dynamic vegetation processes. NetLogo is also capable of importing vector GIS data (SHAPE files) although a full-fledged GIS application is usually needed to prepare arbitrary GIS files for input into NetLogo. Future model development will include the role of the Inuit with their interactions with the caribou, and the impact of climate change on the behaviour of the caribou and the condition of the environment. NetLogo appears to be well-suited for these ambitious tasks.

REFERENCES

Berman, M., C. Nicolson, G. Kofinas, J. Tetlichi and S. Martin, Adaptation and sustainability in a small Arctic community: Results of an agent-based simulation model, *Arctic, 57*(4), 401-414, 2004.

Donalson, D.D. and R.M. Nisbet, Population dynamics and spatial scales: Effects of system size on population persistence, *Ecology, 80*, 1537-1551, 1999.

Grimm, V. and S. F. Railsback, Individual-based Modeling and Ecology, Princeton U.P., Princeton, N.J., 428 pp., 2005.

Gui-Quan, S., J. Zhen, L. Quan-Xing and L. Li, Pattern formation induced by cross-diffusion in a predator-prey system, *Chinese Physics B, 17*(11), 3936-3941, 2008.

Law, R., D.J. Murrell and U. Dieckmann, Population growth in space and time: Spatial logistic equations, *Ecology, 84*, 252-262, 2003.

Lehmann, H., On the applicability of agent based modeling in behaviour ecology, Ph.D. thesis, University of Bath, 235 pp., 2009.

Metsaranta, J.M., Assessing factors influencing the space use of a woodland caribou *Rangifer tarandus caribou* population using an individual-based model, *Wildlife Biology, 14*(4), 478-488, 2008.

Neuret, C., Die dynamic raumlicker Strukturen in naturnahem Buckenwaldern Mitteleuropas. Ph.D. diss., University of Marburg, Germany, 1999.

Nueret, C., M. A. Du Plessis, V. Grimm and C. Wissel,. Welchhe okologischen Faktoren bestimmen die Grupppengrosse bei Phoeniculus purpureus in Sudafrika. Ein indivduenbasiertes Modell, *Verhandlungen der Gesellschaft fur Okologie, 24*, 145-149, 1995.

Railsback, S. F., R. H. Lamberson, B. C. Harvey and W. E. Duffy, Movement rules for individual-based models of stream fish, *Ecological Modelling, 123*, 73-89, 1999.

Rohner, C. And D. A. Demarchi, Cumulative effects and mountain caribou in west-central Alberta: An individual-based and spatially explicit population model for conservation planning, Report to West-Central Alberta Caribou Standing Committee, July 28, 2000.

Wilensky, U., NetLogo Wolf Sheep Predation model. http://ccl.northwestern.edu/netlogo/models/WolfSheepPredation. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL., 1997.

Wilensky, U., NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL. , 1999.

Wilson, W.G., Lotka's game in predator-prey theory: Linking populations to individuals, Theor. Popul. Biol., 50, 368-393, 1996.