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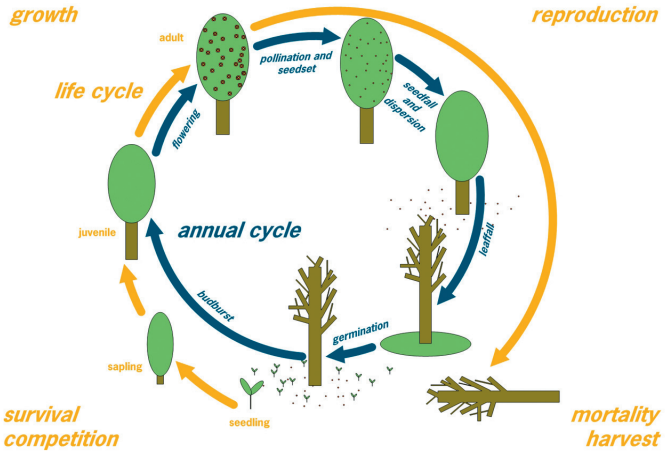
Nested Systems Modeling

A Hierarchical Approach to Individual Based Models

Bert van der Werf

In ecosystems, individual-, small scale spatial- and temporal variations interact with each other. This interaction drives biological diversity at the community level and the flow of resources at the ecosystem level. Individual Based Models (IBMs) are ideally suited for assessing consequences of variations on the characteristics and dynamics of individuals. Subsequently population- or community properties can be derived from individual features.

Cycles are important aspect in biology as well as discrete events. Numerous examples of feedbacks and feed forwards exists. IBMs should be able to follow this closely.



Life cycle and annual cycle of a broadleaved tree species.

In order to simulate IBMs in an easy way a unifying methodology has been developed and implemented. Key characteristics are:

Systems and processes: Systems and processes are regarded as objects defined by state-variables (differential and difference equations). Systems can be regarded as concrete objects or populations of objects over time such as a tree or a forest. Processes are more abstract and are related to concepts.

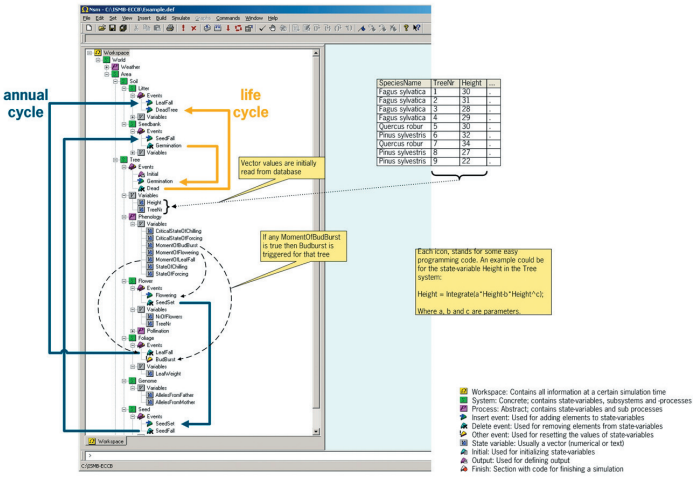
Spatial scale: Hierarchical structuring of systems allows simulation at different spatial scales simultaneously. The *lies-in* relationship often implies a smaller spatial scale for the subsystems, e.g. multiple forests in a landscape.

Time scale: The speed of change depends on the time scale of a system or process. Small time step evaluations of fast processes can exist next to large time step evaluations of slower processes. Assigning different time steps to evaluate the state-variables in different systems can even lead to nested simulations.

Input and output: By defining systems and processes in a hierarchical way it becomes clear that the input of a system or process is the output of a parent system or some summary function of the outputs of (sub) systems and processes.

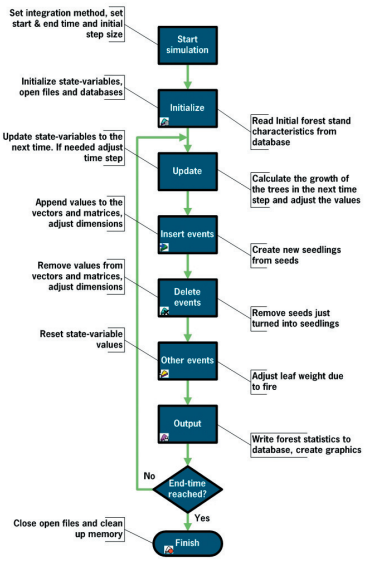
Events: Discrete events often occur in the field. While birth and death can be considered as discrete events, they are usually evaluated at the boundaries of a normal time step. Other events are considered to occur at special moments in time at which the integration should stop, state variables be adjusted and integration restarted. Disturbances like fire, wind-throw, flooding or other calamities are examples of this.

Transformations: During the life cycle of an individual, discrete changes can occur. Systems can change into other systems. Seeds in a seed bank change into plants, pupae transform into adult insects, etc. Transformations are often triggered by discrete events in time.



Screen shot of the NSM application developed for simulating Individual based models. The example shows the annual and life cycle of trees. Critical state of chilling and forcing are determined by heredity. Budburst timing is a function of these states and climate.

Next to structuring the simulated world to keep the model understandable, the order in which programming components are evaluated is equally important. As there is a constant creation and deletion of individuals, a strict programming flow has been implemented. Immediately after the update of the state-variables all new individuals are created. Only after the creation of new ones, removal of individuals are carried out. For example if seeds are removed first then the information to create trees from it is lost, so deletion should be done after creation.



Picture showing the program flow. The left column depicts the use, while the right column gives an example.

Alterra
P.O. Box 47, 6700 AA Wageningen, The Netherlands
Tel: +31 317 47 47 00 - Fax: +31 317 41 90 00
E-mail: bert.vanderwerf@wur.nl
Tel: +31 317 47 79 75
www.alterra.wur.nl

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