10.1071_ISSN0311-4546EC107p9a

Green fingers . . . who needs 'em?
Wendy Pyper discovers some plants can be grown more efficiently on screen.

Landscape architects

Above: Dr Peter Room makes notes on the structure of a sweetcorn plant.

Top: This model, developed by Dr Prusinkiewicz at the University of Calgary in Canada, can incorporate the plant movement and the effect of insects.

Just as dinosaurs can be brought to life on film, the growth of plants and their responses to different internal and external stimuli can be simulated in computers. To do this, scientists from CSIRO and the University of Queensland have harnessed technology used in the film and engineering industries to measure, in three dimensions, the structural development of plants. These measurements are transformed into models, which can be 'interpreted' by special software to generate virtual plants: mathematical representations of plant structure that can be displayed on computer screens.

'Until recently, the complex shape of a plant could only be measured, rather inefficiently, with a protractor, a piece of string and a ruler,' CSIRO entomologist, Dr Peter Room, says.

'Now we can measure this shape with three-dimensional digitising hardware and use software to analyse these measurements and simulate plant growth.'

Room is director of the Centre for Plant Architecture Informatics (CPAI) at the University of Queensland. He says the technology is revolutionising the way scientists study plant growth and plant interactions with the environment and other organisms. Some expensive field trials, which may take decades to complete, will be replaced by virtual experiments that provide answers in minutes.

'Computer simulations certainly won't replace all field experiments, but they'll speed up the research process and provide us with a lot of ideas that would take much longer to generate in the field,' he says. 'We will still have to go back to the field to test the computer results against reality and ensure we haven't made any false assumptions.'

Seeking elite genes

After eight years of developing tools and techniques, Room and his colleagues are starting to apply their technology.

For example, botanists at the centre are studying the genes that control plant shape. With mathematicians, they plan to conduct virtual experiments to help them

See how they grow

FROM mathematics, beauty grows – or at least virtual plants do. Using a combination of mathematical equations, computer science and biological expertise, scientists at the Centre for Plant Architecture Informatics can model all aspects of the structural development of plants: from spidery rootlets pushing their way through soil, to the opening of a bud.

The models simplify reality, but provide scientists with an animated representation of field measurements that would normally appear as numbers in tables.

To convert these numbers into pictures, scientists at the centre use 'growth rules' expressed in mathematical form. This growth rule notation is called an 'L-System', after its inventor, Professor Aristid Lindenmayer.

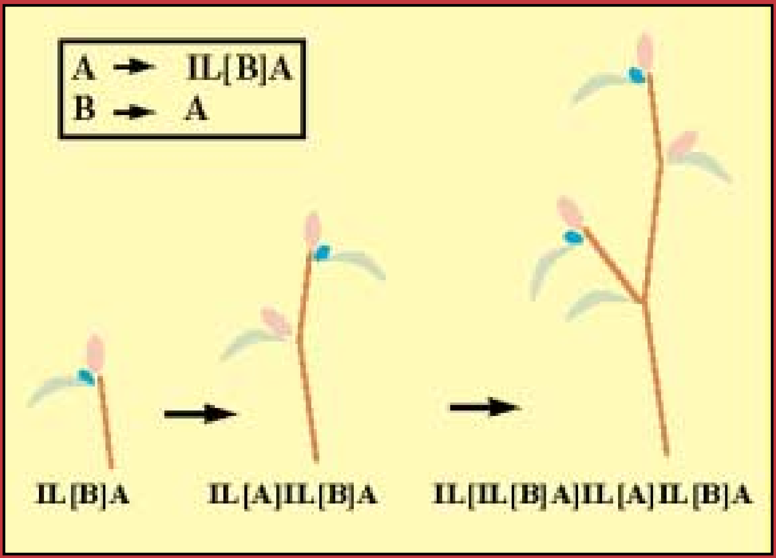
For example, plants are modular and, at their simplest, can be divided into repeating units consisting of a segment of stem, a leaf, an apical (top) bud and an axillary (side branch) bud.

As each apical bud grows to produce another whole unit, its development can be represented by the growth rule, A → IL[B]A, where A = apical bud, I = internode (segment of stem between one leaf and the next), L = leaf, B = axillary bud and [ ] represent the start and end of a branch.

Computer software developed by Professor Przemyslaw Prusinkiewicz at the University of Calgary, 'interprets' such L-Systems graphically. For example , applying the rule A → IL[B]A in a series of 'time steps' (periods of growth) generates a series of growth stages which appear as a growing, virtual plant (see http://www.cpai.uq.edu.au/virtualplants/ipimovies.html for animations).

'The whole plant grows exponentially and we can get a visual impression of what's happening, very quickly,' CSIRO entomologist, Dr Peter Room, says. 'By comparison, if we output this information as a table of numbers and angles, it would be very difficult to understand.'

For a more realistic image, scientists can make a digital scan of a leaf and incorporate it into a simulation. The simulation can focus on a whole plant or on parts of a shoot or root system and may represent a single real plant, the average of several plants or a hypothetical plant. Images may also be viewed from any angle and can be displayed in sequence to give the impression of time-lapse photography.



A simple L-system. Each apical bud (A) becomes an internode (I), a leaf (L) and an axillary bud (B). Axillary buds form branches ([B]) and new apical buds ([A]). Internodes increase in length by 20% at each time step.

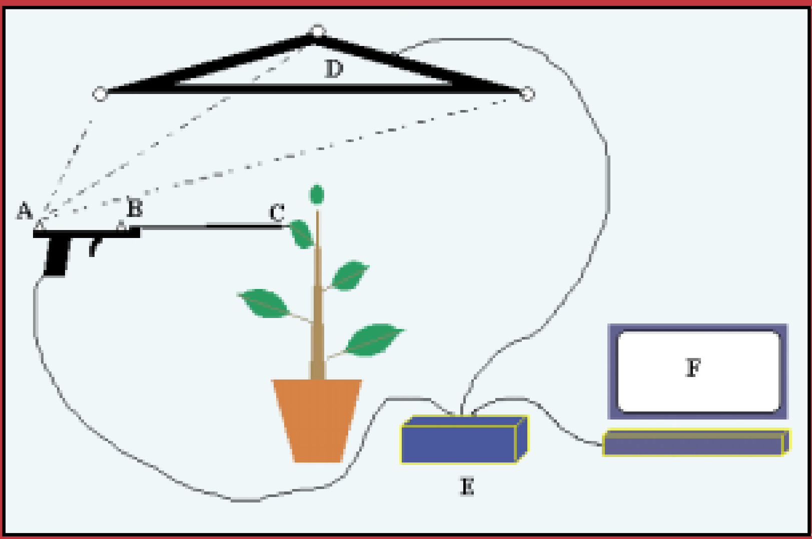
Room says that in time, the simulation process will improve to the extent that fewer real-life experiments will be required. 'We're going though the process that engineers went through when they were developing car crash models,' he says.

'In the early days, car crash models were fairly poor and to improve them, engineers had to crash real cars and compare reality with their simulations. Now car crash models are so good, few real test crashes are needed.

'Similarly, as we get better at simulating plant growth and development, we'll need to do fewer real experiments, though some will always be needed to make sure we don't drift off into a virtual wonderland.'

More about virtual plants

Room P Hanan JS and Prusinkiewicz P (1996) Virtual Plants: new perspectives for ecologists, pathologists and agricultural scientists. Trends in Plant Science Vol. 1, No. 1, 33–38.



Growth rules are worked out by inspecting and measuring real plants. The frequency of measurement and the levels of detail measured and simulated depend on the questions to be answered.
To look at the effect of removing the apical bud on cotton plants for example, Dr Peter Room and his collaborators measured the growth and yield of cotton plants in the field, with and without apical buds. Rather than using a protractor, ruler and string to make these measurements, they used 3-D hardware more commonly used in the film and engineering industries.
The gun of this sonic digitiser fires sound (A and B).
A processor (E) then converts the time taken by sound to travel to three microphones (D), into distance. These distances and the lengths AB and BC are used to calculate 3–D coordinates, which are recorded by a computer (F).

10.1071_ISSN0311-4546EC107p9b

identify genes that increase the efficiency with which plants capture light, water and nutrients. 'They may be able to breed or genetically engineer more efficient plants for farmers,' Room says.

The centre is also examining the effect of 'tipping out' cotton plants (removing the apical bud) on cotton yield.

In the field, cotton plants are grown in rows with furrows on either side. If the apical bud remains undamaged, the plants grow fairly symmetrically and begin to compete with each other for space in the row. But if the apical bud is removed, such as during an insect attack, the plants branch out further over the furrows. Circumstantial evidence from the field suggests this branching actually increases cotton yield, as the plants utilise space and light more efficiently.

After measuring hundreds of tipped (more branched) and untipped (less branched) plants, Room is analysing the data and preparing to simulate the interactions between pest damage and plant growth. If his suspicions are confirmed, insecticide application could be reduced early in the cotton season.

'Farmers have a hard time believing that some insect attack can actually be good for a crop,' Room says. But if a certain level of insect attack early in the season actually increases cotton yield, we'll be able to make better recommendations to farmers about when not to spray for pests.'

Bugs and breakdowns

As well as simulating plant growth and development, software developed by the centre's collaborators at the University of Calgary in Canada can incorporate the movement of insects over a plant, and the movement of metabolites, hormones or systemic pathogens and pesticides within.

Simulating insect movement, for example, can allow scientists to predict the amount of damage a plant will sustain when subjected to insect attack at different stages of development. 'We can also simulate how pesticide is sprayed on to the plants, to see where it is deposited on the leaves and how that interacts with the insects,' Room says.

Room says the software eventually will be able to link physiological processes, such as the response of plants to changes in salinity, pH or temperature, to structural growth and development.

Importantly, the technology developed at the centre is generic and can be applied to any kind of plant, insect, pathogen or other entity present on or inside plants.

It may also be adapted for non-scientific uses. Imagine, for example, a flat screen TV on your bedroom wall, from which you can view the growth of a large, shady tree, a field of flowers or a single rose, depending on your mood.

'Because it's generic, there are enormous artistic and commercial opportunities for this technology,' Room says. 'And in the future, people will have ideas about its application that we've never imagined.'

Top left: Kim Sproutt and Peter Room with sorghum plants used to take digital measurements.

Top: Schematic and realistic images of cotton.

Above: A simulation of root development.

Abstract: Technology for measuring and simulating the structural growth of plants, and the effects of environmental factors and other organisms on them, is allowing scientists to conduct virtual experiments that reduce the need for lengthy and expensive field trials. Simulations rely on mathematical representations of growth rules, called 'L-Systems', which enable structural growth to be calculated and displayed on a computer screen. The field measurements on which the growth rules are based are collected using 3-D digitising hardware, commonly used in the film and engineering industries. As well as having educational and scientific value, the technology has potential uses in art and entertainment.

Keywords: plant growth, computer models, computer simulations, virtual experiments, L-system, insect pests.