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Beyond Morphogenesis

Enhancing synthetic trees through death, decay and the Weasel Test

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Abstract. Artificial Life and Computer Graphics merge prominently in the production of virtual trees. This paper highlights several issues seldom raised by procedurally generated, synthetic landscape imagery that result in a perceived lack of authenticity or drama. Some of the concerns discussed include a need for models of decay and an understanding of the tree's role in the environment and within human culture. These issues fall beyond current simulations, yet it is suggested that simple ad hoc techniques might be employed to overcome such gaps in current research. The intention here is to suggest ways to enhance the realism and drama of procedural landscapes. The paper also offers the subjective *Weasel Test* as a means to gauge the success of our models of natural phenomena.

1.0 Introduction and motivation

HAMLET	Do you see yonder cloud that's almost in shape of a camel?
POLONIUS	By the mass, and 'tis like a camel, indeed.
HAMLET	Methinks it is like a weasel.
POLONIUS	It is backed like a weasel.
HAMLET	Or like a whale?
POLONIUS	Very like a whale.

(*Hamlet*, Shakespeare)

Since what might well be the first artistic computer graphic representation of a tree by Milojevic in 1968 [1, p. 67] simulation authors have faced the challenge of representing plants and their morphogenesis. Little attention has been focused during this period on models of death, disease and decay. We also note the need for tools allowing us to easily and automatically build virtual trees rich enough that an observer may imagine a twisted face or clutching fingers amongst their structures. Hence this paper proposes a *Weasel Test* as one means of gauging the sophistication of our model trees. The test might just as well be applied to our synthetic clouds, rocks or models of other natural phenomena.

Even a superficial study of European and Asian landscape art reveals that the physical phenomena of death and decay as well as the perceptual phenomena of interpretation, play a significant and visible role in the artistic representation of foliage and landscape. Yet, with few exceptions, they do not play an equivalent role in digitally synthesized landscapes, especially those constructed procedurally. Whilst as Artificial Life researchers we tend to focus on the constructive aspects of biology, we might also consider a view incorporating negative or disruptive processes as appear frequently in art. In the absence of this breadth, conceptual models of biology are simplistic and detrimentally bias the possibilities for Artificial Life. Without decay for example, researchers take an absurd view of biology, overlooking one of its most significant processes. Without an understanding of the human relationship to trees many of our artworks will not be true to experience.

Although there are countless papers published on synthesis in the Artificial Life literature, this being a focus of the field, the author is not aware of any that concentrate specifically on decomposition. This problem is apparent in models presented as pinups for Artificial Life research. For example, "death" in many agent-based simulations involves instantaneous removal of the agent from the virtual world. A dead agent is assumed to be irrelevant to most simulations. Procedurally generated landscapes are overly green with vegetation, giving the appearance of toy train sets decorated with plastic plants. Where are the virtual swamps and bogs, amongst the richest sources of life on our planet? Of course they are exceedingly complex to model with our limited resources. Yet until recently, even disease was not a topic studied by Artificial Life researchers [2] so it is not necessarily complexity that is constraining us. Our closed view of what is interesting or relevant is at least partly to blame.

Decay is an essential tendency of organic matter. It may be that the form of constructive processes is a direct consequence of the actions of their destructive counterparts. This seems to be the case for example where disease may act to build spatially and genetically diverse populations. If the major problems in Artificial Life include emergence and open-ended evolution then perhaps we ought to be involved in a struggle against convergence and disintegration of our software models. Ambrose Bierce's definition of life, "a spiritual pickle preserving the body from decay", seems particularly apt [3], yet how many software models explicitly tackle this phenomenon? Our lack of appreciation for decay is apparent in our ongoing waste management problem: we are great at building non-biodegradable artifacts, but what a mess this has made!

Incorporating the effects of death and decay into architectural renderings or landscape garden proposals may be counter-productive although many contemporary architects have creatively utilized weathering in their inorganic constructions. Still these applications will benefit little from the ideas presented here since many of us would regard decay and disorder in our built environments as unsightly. Instead, those producing images for animation, fine art, film or for demonstrating the realism of the models produced by their software, will find some ideas to advance their results. As indicated above, it is also hoped that by examining processes of death and decay, Artificial Life researchers may gain new understanding of the processes that make life unique.

1.1 Computer graphics and photo-realism

In the production of images of vegetation the usual rendering and modeling problems such as textural accuracy and the complexity and faithfulness of the geometry are significant but will be rectified as hardware continues to improve. These problems are not addressed here. A legitimate criticism of the early computer graphics images produced by ray-tracing was that they fetishized a kind of Ideal Platonic perfection – perfectly spherical, perfectly reflective balls on planar, infinite checkerboards for instance [4, p. 220]. In the digital world we must work hard to overcome monotony. Our procedural trees are still at this early phase of development. Often the problems in our models may be solved using current software — and a lot of extra care. The necessary features are already present in some existing tools for plant modeling but have rarely made their presence felt, largely for practical reasons, occasionally because the tools do not anticipate the necessary modeling tasks.

So what makes a *realistic* tree? Is this the same as a *believable* tree? In this paper we will search for answers to these questions that fall outside the standard scope of Computer Graphics and Artificial Life. The first type of answer to each requires us to view the tree as an organism attempting to survive in its environment. That is, the first takes as its basis the standard ecological view of the tree and models its interactions with its surroundings during development. However, for realistic trees, its shall be argued that the model must extend beyond morphogenesis and treat decay and its effects as important tree-shaping phenomena. The consequences of this are detailed in the following section.

An alternate answer to the questions views the tree as a symbol to be interpreted by a human observer with a rich background knowledge of trees in their many contexts. This approach pays special heed to our relationship with nature. It shall be argued that no viewer can examine an image of a tree without influential, preconceived ideas. These cannot be ignored when the goal of the image-maker is purported to be believability. These ideas are treated briefly in a later section of the paper.

2.0 Natural phenomena

Artificial Life is at least tenuously tied to a study of biology as it exists on earth. To model trees in this light is to examine them *in situ*, as organisms. Whilst a researcher may focus on one or two aspects of a plant's structure, such as the topology of its branches and the position of its leaves, in striving for an authentic visual representation many other aspects also dictate a helpful methodology. We may always investigate these and consciously choose to abstract them from a model. However the question then arises, which aspects of tree development can be omitted safely whilst aiming for photo-realism or believability? Clearly we need not be concerned with faithfully modeling the processes of growth and decay. Still, if the aim is photo-realism a modeler shouldn't ignore at least the visible *effects* of any biological or physical process. Below are a few related natural phenomena that may be incorporated into existing models to significantly enhance the images that result. Many of these additions are simple to incorporate, some have been addressed by researchers.

2.1 Dead wood

A cursory scan of a Western art folio volume [5], reveals that for every image of a healthy tree there is another of an injured or dead one. On close inspection, even the healthy trees depicted may sport damaged limbs and branches devoid of leaves. A wander around even the most carefully tended garden will reveal that rarely does a tree hold no dead wood or leaves — an observation reflected in fine art but noticeably absent from much procedural computer graphics. Certainly a forest is incomplete without fallen trees and branches. It is a sad indictment of our lack of understanding in this regard that many European woods are regularly stripped of their dead wood, much to the detriment of the ecosystems it supports.

The European landscape traditions of the 18th and 19th centuries, often focus on picturesque deciduous gardens in which every tree was expected to be healthy and a picture of grace. (See the works of Constable or the Barbizon painters.) Even in these images a naturalistic style dictated that trees not be *too* perfect. When dealing with nature beyond the garden walls in its romanticized European form, blasted stumps, cracked and fallen limbs and twisted twigs in flourishes of otherwise immaculate foliage, all make frequent appearances.

Branches tossed aside by gales, a trunk splintered by lightning or completely overturned by floodwaters were also recurring subjects. All indicate the tree is an organism situated in an environment that dispassionately opposes its existence. With these elements, a picture may support the authenticity of its subject.

2.2 Dynamism and the life cycle

An obvious application of trees in landscape imagery is to illustrate the current season according to their position in the annual cycle: autumnal leaves, winter's bare branches, spring's budding twigs and blossoming flowers or summer's luscious vegetation. This element at least has been incorporated into some computer-graphics imagery even as far back on the CG timescale as 1986 [6].

In addition, the tree's dynamics might be clearly depicted. There may appear in its image fresh new growth and old weathered foliage, especially in evergreens. New leaves differ in colour and texture from their more mature forms depending on the plant. For example fresh leaves may be bright green or red. Old leaves may be stained, singed, bleached by exposure to the sun or smothered in roadside dust. Trunks too may be scarred and stained by fire, algae or fungi. Models of weathering effects are yet to find their way into general use for plant life although they have indeed made appearances where inorganic materials are considered [7].

The life cycle of a tree is often visible in a landscape: young saplings; mature trees; ancient trunks. A natural forest does not usually possess trees of a single age, although a plantation or a wood decimated by fire may be quite uniform in this regard.

2.3 Root systems

Many trees have their roots exposed at least around the base of the trunk. These often leave telltale creases and folds in the trunk even if they themselves are not directly exposed. Some tree models have incorporated this [8] and researchers have certainly looked at models of root development [9]. The ground around a tree swells and falls as shallow-rooted trees or those inhabiting regions subject to erosion leave the mark of their subterranean structure on the landscape.

Muscular roots strangle boulders and probe the soil for energy. They may grasp firmly at a cliff face or spread broadly through the litter of a forest floor in a sinewy mat. Aerial and buttress roots form spectacular architecture in swamps and rainforests. Visible roots invest a tree with power and energy. Roots are a tree's means of support and the conduit through which nutrients flow, they are certainly worthy of inclusion in our images. With some adaptation Greene's *voxel automata* [10] might be a suitable method [Fig 2a].

2.4 Decay

A limb partially submerged in a pond or swamp does not sit like Narcissus admiring its own ray-traced reflection, it decays and collapses. Mosses, fungi, water-plants and algae grow vigorously on its decomposing surface. Such considerations add significant complexity to a model's geometry, nevertheless, we mustn't unthinkingly stop modeling once a tree reaches its prime.

Leaves are not raked away by a busy gardener the second they have fallen from a limb. Leaf litter and decaying fruit may cover the ground, cones lie in a dense bed of needles beneath conifers. In a field or a waterside view, the blades of grass and rushes do not all bend smoothly or sit upright. Some will be broken and kinked, yellowed or withered.

Trees suffer at the hands of humans. A giant stump dries and cracks, erodes and rots, before crumbling into a termite-ridden pile of debris. A truncated limb or trained branch will often appear alongside a clearing, in a park, beside a footpath or overhead wire. Japanese trees are pruned particularly heavily (see for instance Hiroshige [11]). A tree may swell around an injury and bleed sap. The exposed surface shows rings that may permit decay to enter the timber or the amputation may encourage fresh growth. Mechanisms have been proposed to prune and train virtual trees [12], yet even the relatively simple truncation of a targeted branch is sufficient to extend the utility of procedural and interactive plant modeling tools for computer artists.

Decay of a tree in its entirety may be difficult to model. Decay of a leaf or flower is not difficult to approximate visually. An image sequence like the many produced by Prusinkiewicz (cited throughout this paper) and his co-authors depicting the successive stages of development of a leaf or flower ought not stop when the organ is in its prime. Models need to be considered to show the decay of these growths, the dispersal of their seeds and their final fall to the ground. The images produced by Prusinkiewicz's group over the years have shown extraordinary progress in plant modeling and a clear appreciation and love for plants. Still, their realism could be amplified by considering the effects of decay.

2.5 Disease and parasites

Trees suffer under disease and parasites. Their leaves may be spotted by fungi, smothered by strangler figs and mistletoe, marked or decimated by insects and their larvae. Hanan in particular has examined the interactions between insects and L-system plant models [9]. Still, a full-blown simulation is not required for many artistic applications. In addition to insects, larger animals such as owls, possums and squirrels have visible effects on trees. They may clear hollows, strip bark and build nests. The tree is not an island, other organisms depend on it for their survival as it may depend on them. These features assist in the production of images that highlight the tree's participation in an ecosystem.

The features of natural landscapes listed above are sometimes easily incorporated into existing software at a superficial level, others will require further advances in technique or hardware. Nevertheless, stochastic mechanisms are sufficient for occasionally eating segments from large, visible leaves, for tearing or severing a tree limb mid-stem. Occasionally a leaf may be discoloured and hung vertically. Textures may incorporate the effects of disease or destruction also and these may occasionally be switched in to replace their healthy equivalents. These details will allow artists to bring digital images into line with the more evocative landscapes depicted in Western art of the last few centuries.

3.0 The tree and its cultural significance

It is useful at this stage to consider the tree beyond visual likeness, in light of its relationship with humans. This perspective is essential even if an image is to be held up as an example of photo-realism. A Christmas pine, a hangman's elm and a lover's oak are more than a set of connected branches. This section explains why such connotations must be considered.

Figure 1 (a) The Serpent Woman and the Snake Vine, *Machacuy Huasca*. Yolanda Panduro Baneo, Eden Project, Cornwall UK. The plant is used as an anti-venom, here depicted with its spirit by the Peruvian shamanic artist. (b) A Eucalyptus typical of the Australian bush. Wilson's Promontory, Australia.

For convincing or artistic imagery a thorough *understanding* of trees beyond visual and botanical likeness is desirable. We may claim that a photograph does not require such depth of understanding to do its work, yet even the camera and print introduce distortions that need to be understood. The camera does not neutrally capture reality as we humans perceive it. It confuses many things: compressing space; distorting or removing colours and luminosity; eliminating stereo effects. Most importantly, the camera is selective in what it portrays. Effective photographers know and utilize their understanding of the camera, film, print and slide. It is our brains and bodies that construct our image of the world and that of images, not a mechanical or digital device. Without taking this into consideration we will fail to produce satisfactory visual representations of trees.

3.1 The tree as symbol

Trees are extremely widespread objects of worship and symbols for nature, life, growth, fertility, wisdom and history. They are well known in Judeo-Christian culture in this guise as the Garden of Eden's *Trees of Life* and *Knowledge*. Groves of specific trees were associated with ancient Greek gods, for instance Zeus was associated with oaks and Apollo with the laurel[1]. Australian aborigines treat every component of the landscape with spiritual significance, trees included. Other cultures who possess a close affinity with nature do likewise [Fig. 1a].

The significance of the tree continues to this day in many religions including Christianity, Judaism and Islam. Especially important in these religions are the date-palm, pomegranate and the grape-vine since these provide food and drink. Trees also appear in Buddhist traditions (the Bhodi tree) and are of particular importance in Shinto beliefs (the Sakaki or any particularly large, ancient tree) where they remain sacred to this day. Even science has tree myths, for example that of Newton and the famous apple tree. In short, trees are important practically, spiritually or symbolically to humans of nearly all cultures. The researcher ought not be surprised if when trees appear in art their presence indicates more than a purely aesthetic decision on the part of the artist.

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[1] For example, the image *Young Woman (Laura)* (c. 1506), in the Kunsthistorisches Museum, Vienna by Renaissance artist Giorgione shows a girl and laurel branch. The Laurel's appearance may have been intended to represent the fidelity and chastity that Apollo promised Daphne who was changed into a Laurel.

Trees have also come to symbolize particular countries or landscapes: Cedars with Lebanon, the Sequoia and the Joshua Tree with California, the Maple with Canada. Australia has its Eucalypts [Fig. 1b], New Zealand its massive Kauri, Madagascar the Baobabs, Europe has Oaks and Elms. A specific tree species can't help but conjure up a locality in the mind of a viewer.

How does this bear on the software developer? At a superficial level, the trees that must be modeled will need to encompass those specific to various locations. More significantly, software developers will need to consider the meanings of the trees required for a particular image. In particular, artists may be interested not only in bland office adornments, but in those that have a unique character that somehow typifies or exemplifies the tree's relationship with humans. This character often takes the form of a requirement for *exceptional* trees[2].

3.2 Exceptional trees

A tree stump is not merely a cylindrical segment truncated at the base. We might say that "it is the corpse of a powerful but mortal creature that has been mercilessly decapitated by the greed of humankind". Without this Western, environmentalist's emotional attachment to the stump, or some alternative but equally human perspective, we will not approach a believable image of a tree. The realism considered in this instance is not only about what is visible but what is *known* and *felt* about trees. Whilst it may be argued that a photo-realistic image of a tree need not consider its symbolic value, nor its relationship with humans, this flies in the face of what any photographer knows : the subject cannot be divorced from the act of its observation and interpretation. It is quite irrelevant that the image is intended to be faithful to a mechanical snapshot, it remains open to interpretation. Humans will *always* carry a culturally-specific and biologically-based relationship to the tree that effects their interpretation of its image.

Non-domesticated trees, like us, struggle for survival in harsh environments. Garden trees are lovingly tended by an expert, or left to dereliction. Trees have quirks and remarkable features, their branches may be knotted or grafted to one another. Trees may bow to one side, highlighting a long-standing battle against the wind and salt spray or sufferance under a mass of snow. A tree may strive for the upper reaches of the forest canopy in a race for light. Limbs or roots may fabricate hidden spaces in which sprites reside. The texture of bark may give the appearance of eyes and faces, tree limbs evoke grasping arms. The trunks of some trees resemble swollen bellies. Twigs and thorns bring to mind clutching, hostile fingers[3]. Trees may be mighty (see Bloomenthal's *Mighty Maple* [13]), fragile, windswept or decrepit and many things besides. These curiously anthropomorphic traits of trees are part of what fascinates even non-botanists. It is therefore of no surprise that artists have often depicted or photographed exceptional trees. These exceptional trees rarely make an appearance in procedural computer graphics or artificial plant simulations. Without them, the images and simulations we produce remain bland and unconvincing – not necessarily because they are incorrect in some technical aspects (although this may also be the case), but because we are unable to recognize in them the evocative traits of the organisms we find in real forests, landscape paintings or literature and cinema. We

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2 Of course artists may be interested in bland trees too — there is little need to discuss methods for creating them.

3 The illustrator Arthur Rackham had an exceptional feel for trees. His images span the gamut from tree-monsters such as *The Hawthorne Tree* (1922) to more naturalistic trees, *Soldiers Caught in Brambles* (1907), that nevertheless evoke the unique anthropomorphic character of his subjects in these ways.

lack the ability to search them and spot a weasel in the shape of their branches, roots, trunks or bark.

3.3 The human response to the landscape

Appleton [14] examines landscape painting, attributing to elements of its subject appropriate responses in humans. If we accept that we cannot divorce ourselves from our biological origins and responses, such considerations will assist us to create believable and evocative images.

In short, the three concepts he raises are as follows: *Prospect*, a tree standing tall on a hilltop or against an open sky offers a potential view over the horizon or obstacles. This issue may be addressed in image synthesis by paying heed to the positioning of trees with respect to the viewer and allowing open space for a view; *Refuge*, the forest glade, the nook within branches and the hollow trunk provide humans with shelter. Refuge may be implied by a medium density of vegetation in a scene: moderately packed trees or single plants with many leaves and branches; *Threat*, the tangle of brambles, a spiny cactus, clutching, strangling or writhing vines provide a dangerous obstacle. A feeling of threat may be conveyed by careful selection of plant types and character or a high density of vegetation in keeping with the desired outcome.

If we take these ideas as the focus of our work, we stand a good chance of giving our trees that extra spark they require. There is no "magic bullet", experimentation and understanding are required. Landscape art and the spaces that inspire it provide ample scope for exploration.

3.4 The Weasel Test

From an early age children's literature exposes us to the magical, metaphorical and anthropomorphic possibilities provided by trees. Examples include: Blyton's *Magic Faraway Tree*; Dr. Seuss' *Truffala* trees; Tolkien's *Ents*; Jack's *Beanstalk* and in Australia at least, Gibbs' evil *Banksia* men (see image at left of a Banksia and its seed pod).

As we begin to appreciate art, we find that the galleries and literature of the world are similarly rich in fantastic and peculiar trees. Yet the trees we generate using our software often lack character and fall short as symbols. The trees we see about us in the real world and in the arts typically provide wonderful targets for our imagination, we readily see "weasels" hidden in the forms of their branches. Computer animators, architects and illustrators must work hard to overcome the deficits in our software in order to present equivalent synthetic targets.

Character in our tree models may be created by chance. Whilst the stochastic events occurring within computer software are not those that occur in the development of a real tree, we might nevertheless look to the possibilities open to us in interpreting the results of our simulations. Currently when we produce our tree models stochastically, our images have the really odd traits weeded out of them — like we weed out the strange and magnificent shapes of the vegetables bound for the dinner table before they enter the market [Fig 2b]. Why not remove this constraint from the images we manufacture of artificial trees?

Some depictions of trees by new-media artists have successfully developed character through animation. Bill

Viola's evocative interactive installation, *Tree of Knowledge* (1997) is such a success. McCormack's *Turbulence* (1994) includes many frightening, thrashing, unruly trees, as does Sims' *Panspermia* (1990). Of the still images that are noteworthy, Ned Green's *Winter* (1989) [Fig. 2a] brings to mind the obsessively decorated *Root Room* of Peake's *Gormenghast* trilogy [15, pp. 251-253]. Prophet takes a picturesque English landscape to match her synthetic trees in *The Landscape Room* (2001). In this case a lack of exceptional virtual trees is entirely in keeping with the well-manicured setting.

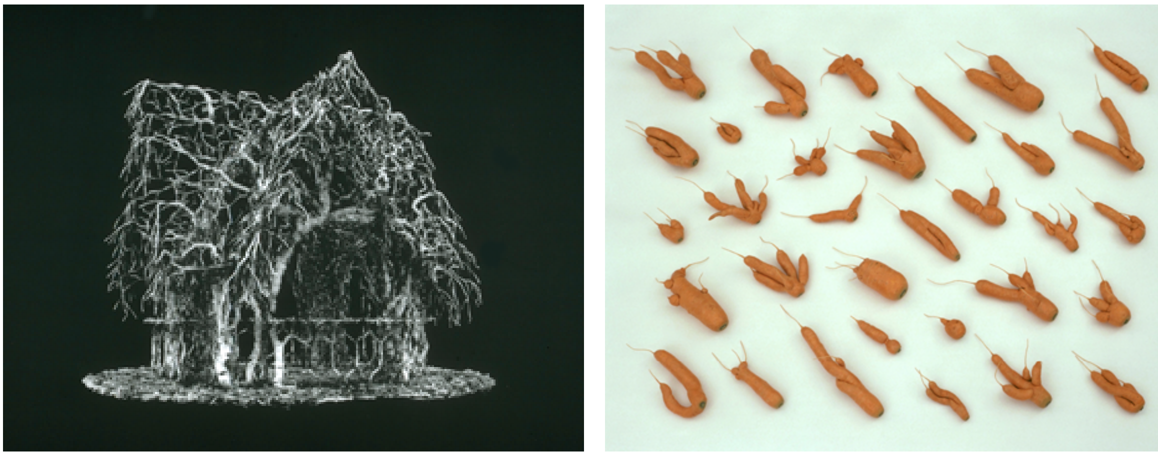

Figure 2. (a) Greene, *Winter* (1989) (b) Verstappen & Driessens, *Morphotheque #9* (1997) collection A.M.&S. Mygind, Copenhagen.

The still images of Gilles Tran lean away from the blandness of many computer generated trees. Tran certainly locates them unusually, growing through the bitumen of a multi-lane highway, in the chassis of an old Citroen or emerging from a cliff in a scene reminiscent of Hiroshige. The trees themselves are less exceptional. Trans' foreground for *The Darkside of the Trees* (2002) shows his attention to detail: the colouration of his leaves varies and he builds a pleasing jumble of dead and living leaves, stems and stalks. Still, as in the images of Deussen et al [16] the flowers are too healthy and well formed even in this otherwise rich, virtual environment.

The online gallery www.onyxtree.com/ includes numerous images of trees and forests, most of which suffer from the problems discussed here. It is interesting to note that whilst their images are less polished than some others on the site, two Swedish animators, Ollson and Ceron, have both placed work online illustrating death and decay in virtual landscapes.

The plant models depicted in Greenworks' X-Frog software catalogue are symptomatic of the standard approach. Of the countless varieties of trees presented none would count as exceptional, nor do they appear to sport dead, broken branches or leaves. Greenworks is not alone in this regard, in fact the author has not come across any advertisement for plant modeling software that displays examples of dead wood. Some X-Frog trees do indeed provide interesting root structures, their catalogue of prehistoric plants for example has some lovely models. Still, X-Frog flowers do not seem to progress past their prime, rot and fall, nor do the trees as a whole. Despite the limitations of the tool, the Greenworks online landscape gallery displays several images that show the artists using the software to be addressing some of the issues raised in this article. A few of the landscapes include leaf litter and dead sticks. Some depict dead trees, although typically in clichéd settings and usually with all branches intact.

4.0 Conclusions

As artists and software developers we must consider trees not merely as collections of branches but as co-habiters and as symbols. Our software must carry with it the implications of our understanding so that those who will use it are provided with tools suitable for their tasks. As researchers in particular, it is lopsided of us to view the morphogenesis of trees whilst ignoring their decomposition. This has significant impact on the images we present as our results. We can fool an untrained observer, but once our audience learns to seek signs of death and decay we will not be able to omit these phenomena from our "photorealistic" imagery.

Eventually the day will come when we can look at a synthesized image of a forest and say of a virtual tree, "Methinks it is like a weasel, or like a whale". On the day our digital landscapes pass this Weasel Test our software will have turned a corner. In the meantime this paper has provided a number of ideas that will assist developers and synthetic-landscape artists to focus their efforts.

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