Session: *3D Landscapes. Metrics, techniques and applications.*

Title: Computer graphics approaches related to environmental applications. A focus on vegetation representations for 3D Landscapes.

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Introduction

3D Landscape modelling and visualization is a challenging research area mobilizing multidisciplinary approaches since 30 years [Zube 1987], [Edelin 1989], [Orland 1992]; taking benefits of technologic progresses in computer sciences, spatialized data availability, landscape biophysics and societal dynamics understanding, and user/planer feedbacks. A research agenda on digital landscape modeling and visualization was proposed by S.E. Ervin in 2001 [Ervin 2001], understanding the landscape from a combination of six components: landform, vegetation, water, (infra)structures, animals and people, and atmosphere from which interrelated questions are issued such as physical laws and systems, sheer size, level of details, dynamics… among others.

Nowadays, while 3D landscape planning and representation tools get more and more often mobilized in planning projects (landscape architecture, environmental planning, energy structures aesthetic impact,…) with an increasing (photo)realism, major questions raised by Ervin remain open. As underlined by Portman and al [Portman 2015], virtual reality faces challenges in landscape architecture and environmental planning. Current technics luck user interactions models and functional realistic models, including or not their dynamics: those are still multidisciplinary research challenges. 3D landscape visualization challenges, requirements, feedback and relevancy are regularly observed by the community: one could cite [MacEachren 2001] for research challenges in geovisualization, while Paar et al. [Paar 2006] relates 3D visualization software applications and requirements for environmental planning. Lovet et al evaluates 3D visualization options and practical issues [Lovet 2015] while [Downs 2015] explores bias between architectural synthetic project views and post project real views.

In the world of computer graphics, natural phenomena and more precisely natural environment modelling and visualization is a hot topic of Computer Graphics since its early age [Fournier 1982] [Aono 1984] [Reeves 1985], due to the complex, heterogeneous, multi scaled and dynamic phenomena involved in the various components building landscapes. The topic covers modelling and visualisation of terrain, hydraulic components, plants, sky and clouds up to atmospheric or artificial conditions (explosions, fire, fog, rain, smoke, snow…). Boosted by the entertainment market –mostly movies and games, a wide range of techniques and approaches were developed since the early 80’s. A review such as [Wolff 1993] update would be a tremendous work. However, to make simple, natural phenomena can be represented by figurative techniques, simply featuring the visual aspects, for instance using a single photography. Reversely, an exhaustive model –usually procedural- can be used to build a complex object, on the basis of biophysical laws –or not. Such procedural approaches share often the following characteristics:

- They rely on stochastic aspects, allowing variability in representations.
- Natural objects have a procedural definition; i.e. a component (fire, tree, terrain) is built from smaller components and rules. Conversely, the smaller components (phytomers, particles, terrain patches…) arrangements are constrained by biophysical rules or laws.
- Natural representations show "Level of detail". Natural objects show a flexible geometrical complexity, in order to adapt their complexity to the viewing distance. In many cases, the representation model (used only for visualisation) is issued from the object model, simplified.

In practice, the distinction between figurative techniques and procedural model is fuzzy and even complementary. As recent examples, one could cite automated terrain colour texture generation from terrain models [Lee 2017]; or reversely; 3D plant models reconstructions issued from photos, the main branches, trunk and crown shape features are extracted from a photo, while the smaller branches and foliage are procedurally generated from a priori rules [Bradley 2013] [Argudo 2016].

The proposed talk focuses on the vegetation component representation in 3D landscapes, illustrated by our experience within projects with industrial partners related to site restorations, pathway banks or road slide ecological communities studies and visualization. It also refers to the plant modelling research area, we did contribute to, since the mid 80's [de Reffye 1988], up to now on functional plant models [Kang 2016]. The key point refers to the (vegetation) dynamics. S.L. Ervin [Ervin 2001] makes a clear distinction between dynamics types in the landscape as follows: movement through the landscape, movement of the landscape, interaction with the landscape. We keep here this distinction.

The contribution organizes as follow: -at first the individual plant level is considered; then the community level is discussed, both in a context of movement through the landscape. Some trends related to the landscapes dynamics are finally discussed.

Plant individuals and plant communities (interactive walk through landscapes with)

Vegetation representation shows interest in numerous planning studies. The applications we experimented were mainly based on LandSim3D tool [Bionatics], but not restricted to, in the frame of: - planning (mainly urban planning), - project aesthetics impact studies related to infrastructures implementations (transportation, energy), or related to land use development (agriculture, tourism) under various regulation scenarios; - area / regional promotion; - virtual visit to limit impacts of real visits (in protected areas).

In most of 3D landscape viewers and editors, the vegetation component is clearly described at two scales: the individual plant level, and the community plant level, as reminded in Deussen and Lintermann's book "Digital design of nature" [Deussen 2006]. Authors also present an interesting overview of various technics related to both scales description and design.

The Individual plant level

At the individual plant level, the plant representation generation (especially trees) can be seen as a dedicated task or even as an external contribution. Let's consider a typical urban scene with a poplar tree alignment along a street. In such a case, the user just specifies the location of the trees and selects tree representations hopefully close to real poplar trees representations. Using an advanced 3D editing tool, or a single drawing tool he will have to choose tree models among a wide range of 2D/3D available ones [Muhar 2001][Deussen 2006], issued from real photo libraries, or 3D models built from specialized tools ([OnyxTree], [RealNat], …) or available from multimedia object libraries [3ds max]. An alternative is not to refer to a representation itself, but to an abstraction, just specifying that there is a poplar tree at this place, of a given height (or age). Coupled to a plant modeller, the editor stores the plant parameters at the given position. At rendering stage (i.e. visualisation stage), the drawing process checks if the plant representation is available for visualisation, uses it if so, and launches a computation to generate if not (such is the case of LandSim3D).

Using plant representations abstractions show several interests. First, the plant description is light. Second, it offers the visualisation tool the opportunity to select an appropriate representation level, adapted to the distance to the viewer (for instance a small single image far away to a detailed polygon mesh near). Mixt representations, called hybrid models, built from few polygons for the trunk, and a small set of textured images for the foliage are often used, especially in games [Jakulin 2000]; such representations allow wind dynamics simulations [Zhao 2013]. Moreover, given a complex tree 3D structure, the literature proposes efficient ways to simplify it and merge the foliage in order to reduce drastically the geometrical costs without visual change perceptions [Deng 2010], [Zhang 2017]. Third, the representation task can be operated by the GPU, since the plant geometrical instantiation occurs only at visualization stages. Last, but not the least, the growth dynamics can be automated: a single age (year) increment on the full scene will apply on all "procedural trees" without specifying, for the user, a new representation for each species and species location.

Plant communities

Plant communities are key subjects of interest in ecology. Diversity, dominance [Whitaker 1965] resulting from the use of cover and frequency characterizes patterns in plant communities [Kershaw 1957]. The structure of plant communities and its dynamics [Crawley 2009] is also an interesting point to consider, since vegetation typology (herbs, shrubs, trees) and its distribution can be straightforward assigned to visual properties (height).

In 3D landscapes, a plant community description consists in a pattern description. Such patterns are understood as a collection of individuals, in which each individual (each plant) must be possibly identified. In other words, a vegetation pattern must be defined as a list of plants defined by their position (arrangement) and appearance, i.e. their species, their geometrical aspects (status, height). A crop representation (wheat, maize, up to industrial forest stands) defines easy patterns, those complexity are limited due to regular arrangements, a unique species, and limited plant status. Patterns get complex in lower entropized environments, for instance when considering a natural arrangement along a small river, showing heterogeneity of species and wide age distributions. The most common way to define a virtual pattern is a list of plant individuals with their density. Usually, the virtual pattern definitions are under the user control: he defines the list of species and for each, a density, and a visual representation. Playing with representation sizes and densities allows to model and visualize open and closed vegetation covers. Note that it is possible to generate automated virtual patterns from classical ecological cover and frequency if, for each species, all individuals look similar (i.e. individual have nearly the same age and show poor structural plasticity). If not, for each species, a distribution of characteristic individuals must be defined from age distribution or crow shapes clusters.

It is understood that procedural "seeding" or "planting" is prefered in 3D landscapes modelling tools, applying virtual plant community patterns in spatialized areas such as polygons from a land use map or, along a path (for instance the river banks). It is also understood that each individual plant altitude is automatically retrieved from the digital elevation model. Procedural seeding or planting can also be filtered introducing probabilities depending on external local conditions such as terrain altitude [Forester], terrain orientation or slope value (as in Virtual Nature Studio [VNS] or Terragen [Terragen] tools). Another common rule consists in blurring patterns area edges, in order to mimic smooth transitions between various communities. Procedural seeding and planting is efficient on shrub and tree vegetation layers but remains too costly on herb layers, especially at mid and far distances. Ground cover plants are usually modelled by simple textures. In order to minimize period artefacts on large areas, cover texture duplications can combine using complex techniques such as Wang tiles [Cohen 2003].

Once more, procedural plant seeding and planting abstraction makes 3D landscape edition and visualisation efficient, as implemented in LandSim3D [Bionatics]. In such cases, a viewer controller parametrizes the virtual plant communities' generation for each pattern description. On far distances, only the tree layers can be considered, rendered with low details techniques. Reversely, on close ground areas, ground cover textures merge or replace ortho-photos, and shrubs as well as trees are 3D generated if their position lies in the viewing frustum. In fact, the full landscape is never instanced, only the visible parts of it are, with decreasing details according to the distance to the viewer, reducing drastically the virtual natural scene geometrical complexity. As a result, the combination of procedural plant community definitions with individual plant level of details representations brakes down the visualisation volume complexity problem, allowing real time 3D landscape walkthrough. The view parametrizations (pedestrian, bird, camera, simulated drone…) and trajectories can be defined according to specific constraints or defined on the fly from the mouse or from a kinetic device with user moves [Jiang 2013].

Can we thus consider that the vegetation component is satisfactory in 3D landscapes visualisations? If we do consider the vegetation as a background the answer could be yes, but if the vegetation component representation should stand for a plausible real representation the answer is clearly no. The fact is that the single plant representations as well as the communities' patterns are not depending on local environmental conditions, except if the user takes care of the vegetation plasticity and diversity, by defining vegetation site indexes, tree status clusters and so on… Higher level of physiological, ecological, and bio-physical rules and laws should be taken in to account to catch the vegetation plasticity and diversity, considering plant growth (structure establishment and production) and communities' patterns (including successions) as resulting from a full dynamic system. Such models typically lie in the "movements in the landscape" dynamics (see reference to Ervin upper).

Movements in 3D landscapes

Large scale inner landscape dynamics simulation (vegetation growth, land use, urbanization) is currently poorly involved in realistic 3D landscape visualization. The classical 3D scene definition refers to exhaustive multi layered spatial data (GIS, inventories) or explicit user controlled definitions, those do seldom include evolutions. And this is unfortunately what the society is asking for. 3D landscape dynamics is thus mainly defined from the user expertise from evolution scenario given at specific time gaps, such as 5 years later, 10 years later… However, in the literature, there are some pioneer interesting works on the vegetation dynamics visualisation in 3D landscapes, based on plant growth simulations.

As a first approximation, most of 3D plant modellers mimics plant structure establishment during time. But few of them have been proved faithful to botanical plant architecture concepts [Barthélémy 2007]; among them, those developed for agronomy/forestry applications are suitable but show usually heavy parametrization, often hidden to the user. Such is the case of Amap structural plant growth simulator [Jaeger 1992]; in its distributed version, the user has no control on the plant species characters; he defines only the plant species, its age, the season and a random seed. Embedded in the LandSim3D scene editor, wide vegetation covers with its growing dynamics can then be simulated and visualized thanks to a wide library of plant species (nearly 600). However, plant structure plasticity remains poor in the whole scene: no local condition affects the growth simulation.

A fast way to introduce such plasticity is to parametrize the procedural generators (trees and community patterns) according to local constraints. "Realistic modeling and rendering of plant ecosystems" [Deussen 1998] is a pioneer tentative proposed by computer graphics researchers using a twostep process. First a plant community is randomly seeded over a noisy surface (terrain); seeds develop with a high mortality due to competition for space and water (simply evaluated from the terrain local curvature). Second, the survival bush and tree seedlings are replaced by structural plant growth model simulations with a competition factor controlling the ramification rate and axis lengths. The result is quite impressive despite the fact that many biological assumptions are wrong compared to physiological knowledge on real plants.

Another interesting pioneer work rose from the artificial intelligence community. In "An Artificial Life-Based Vegetation Modelling Approach for Biodiversity Research" [Ch'ng 2009], the author proposes a modelling approach for biodiversity research based on the emergence phenomenon for predicting vegetation distribution patterns in a multi-variable ecosystem. This "Artificial Lifebased" vegetation grows, competes, adapts, reproduces and conquers plots of landscape in order to survive their generation. The plant representation is synthetic, reflecting leaf area and wood volume quantities.

One could argue that such approaches are empirical, ignoring basis of ecology, plant ecophysiology and plant architecture. However, their underlying simulation principles and architecture are still of interest, they illustrate complex systems simulations.

In agronomy and forestry the past decade show the development of functional structural plant models (FSPM) and its applications [Guo 2011]. Spatialized FSPM, coupled to water diffusion models is an ongoing multidisciplinary research domain. We did some theoretical work in this area considering the GreenLab model [Rostand-Mathieu 2006], spatialized on a raster grid. In our (simplified) functional (bio-physical vegetation oriented) landscapes, the model is simplified (no structure); biomass creation interacts with its environment at local and global scales. Simulation is performed on a daily basis, synchronizing water cycle models (runoff, soil absorption, soil diffusion) with plant growth models under various climatic data (temperature, rain). The model simulates the plant competition for water resource and its spatial heterogeneity [Le Chevalier 2006, 2010]; this bio-physical simulation approach simulates the vegetation evolution and its feedback on the environment. Visualization tools are in this case necessary to understand the dynamics and explore the simulation results. Reversely, simulations output lead to interesting features for realistic landscape visualizations (biomass distribution, fog appearance, rain …) [Jaeger 2012]. The difficult point lies in the models coupling (water, plant) at various time scales (minutes for run-off, days for diffusion, and plant production, thermal time for organogenesis, asynchronic for climatic events…).

Vegetation "movements in the landscape" are also issue from human actions. Landuse changes due to farmers such as crop rotation can be modelled applying stochastic rules from domain specific grammars [Gaucherel 2006]. The evolutions of the landscape are designed from map updates modeled by specific grammars; those grammar productions do simulate the state transfer of each landscape entity component. Such complex dynamic evolutions modelling were simulated and visualized on patchy landscape in Brittany in order to show the evolution of the characteristic local agricultural paths under various regulation policies [Griffon 2010].

The future of 3D landscapes : complex systems or not ?

3D landscape modeler and visualizer tools available on the market are somehow “data integrators” tools (GIS, orthophotos, 3D models, infrastructure and land use maps,..) but they are not simulation platforms in which the technical components do interact and interface in a dynamic manner. In future, should 3D landscapes be considered as complex systems, requiring dedicated methodological and technical environments? This seems to remain an open question to the (multidisciplinary) community [LandMod2010]. 3D (functional) landscape modelling appear as a novel topic of multi-disciplinary researches aiming to define a recognizing ontology and generic approaches to study this complex system. In this context, visualization is a key point, not only as a tool, but also as a experimented field; it is amazing to see raising the notion of “Level of Details, Level of Visions, Point of view, ...” in other disciplines them speaking about landscape modeling.

When modelling a critical point to consider is the data availability. On one side there is luck of data feeding model parameters, but on the other, data acquisitions are getting more and more numerous with a decreasing cost, especially in environment applications. The increasing availability of low cost and free images at higher and higher resolutions also pushes new applications especially in 3D visualisation using 3D reconstruction approaches. It also boosts the potential of augmented reality, as underlined by Taigel [Taigel 2014]. Opposed to classical modelling approaches (statistical, causal), data based modelling approaches (including deep learning) will be more and more used for landscape modelling. The future of 3D Landscape also relates to the future of visualization technics and approaches. Computer graphics on complex heterogeneous systems is a key challenge [Childs 2013][Kumar 2016]. Researches trends show that visualisation could: - be more and more collaborative, - be distributed (and/or web based), - be user “sensitive or adaptive”, - integrate real data and procedural modelling [Smelik 2014], - be of high complexity (multi scaled). The literature also emphasis visualisation efficiency [Gatto 2015] with a clear distinction between images for understanding (realistic behaviour) and images for feeling (photorealistic). It is amazing to note that these trends match the landscape community.

As a conclusion, modelling and visualization of virtual landscape evolutions is seen up to now as a typical complex system application. It is a real challenge to work on, pushed and supported by a high societal demand. Dynamic (Functional) landscape modelling and simulation is clearly a multi-disciplinary task, in which main thread have still to be defined. However, 3D landscape will also be a domain of application and interest for the “Big Data” and its developments. Opposed to modelling and techniques development from human understanding, more and more approaches will be deployed from huge spread data sets for classification, diagnosis, risk analysis among other applications [NR].

Both ways are complementary, and may perhaps reflect diversity of goals for 3D Landscape modelling and visualisation. The domain could be on one hand be considered as component of a scientific topic, acting as a tool to understand the simulated dynamics (and thus simulating realistic behaviour(s)). Or, on the other hand, the domain could be considered as a component of a wider communication topic, acting as a contributor to projective tools aiming to build and share landscape visions between officers and public (and thus more oriented to photo-realism).

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