Untitled: A DirectX Game

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Untitled is [...].

2 User Controls

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The following is a technical discussion of the key features of *Untitled*, with a focus on advanced procedural generation. Mathematical models and code snippets are kept to a minimum, edited for clarity rather than accuracy to the original application.

3.1 Noise

3.2 Procedural Terrain

Given its grounding in nuclear semiotics, this game's terrain is of course intended to evoke a sense of "shunned land" (Trauth et al. 1993). In generating the jutting thorns and blocks so essential to the post-nuclear setting, though, there comes a problem - concavity. Height maps are perfectly adequate for creating rolling hills and valleys, but the fact that each (x, z)-coordinate can correspond to only one y-value prevents any features that ominously overhang *Untitled*'s barren earth (see Figure 1).

Figure 1: Two sketches of *Untitled*'s thorny terrain; though the former can be generated by a height map, the latter is concave.

Consider the two dimensional analogue here: how might one construct the bounding curve of a (potentially concave, or even disconnected) area? [1]

$$f(x, y) = \min\left((x-0.5)^2 + (y-0.5)^2, 4\left((x-0.25)^2 + (y-0.75)^2\right)\right),$$

describing two overlapping circles.

Figure 2: Bounding curves of $f(x, y) = 0.16$, at increasing levels of granularity.

[Linear interpolation]

Figure 3: Bounding curves of $f(x, y) = 0.16$, before and after linear intepolation.

In much the same way, *Untitled* uses *marching cubes* to generate the bounding surfaces of its 3D volumes. Outside of the expected changes - scalar fields now operate on domain $[0, 1]^3$, vertices now have $2^8 = 256$ possible configurations along the edges of each marching cube - this is actually a rather straightforward generalisation.

[These are just the broad strokes; nuance to, say, weighing vertex normals correctly]. Definitive... Paul Bourke's *Polygonising a Scalar Field* (1994) remains the definitive source on the matter.

3.2.1 Case Study: Hexes

Having . 3D fields are inherently , yet these are essential to carving out *Untitled*'s landscape.

Even a blank hex tile comes with som nuance. [Use of noise...]

[Bounding hexagonal prism... As much as flat faces are antithetical to marching cubes (if they run parallel to the grid, then... can't interpolate? notice that interpolation doesn't account for the degenerate case where two adjacent gridpoints are equal)...]

[1] This could equally be an $n \times m$ grid; keeping the dimensions the same is just 'neater'.

3.2.2 Case Study: Landmarks

3.3 Procedural Screen Textures

The post-processing in *Untitled* is, in one sense, rather simple. The 'stress vignette,' for instance, calls only two renders-to-texture on every frame: the board itself, and an alpha map of blood vessels that sprout from the edges of the screen. As striking as the final effect is, `vignette_ps.hlsl` is surprisingly straightforward in blending the textures into a single, pulsing eye strain overlay; far more deserving of further discussion is how the blood vessels themselves are generated.

In formal languages, a grammar is a tuple $G = (N, \Sigma, P, \omega_0)$. This contains two disjoint sets of symbols: nonterminals $A, B, \dots \in N$, and terminals $a, b, \dots \in \Sigma$. The production rules in P map nonterminals to strings $\alpha, \beta, \dots \in (N \cup \Sigma)^*$; applied recursively to the axiom $\omega_0 \in (N \cup \Sigma)^*$, these rules can produce increasingly complex *sentences* of terminals and/or nonterminals.[2]

The Chomsky hierarchy (Chomsky 1956) classifies grammars by their production rules:

Type-3. Regular grammars map $A \mapsto a$ or $A \mapsto aB$.

Type-2. Context-free grammars map $A \mapsto \alpha$.

Type-1. Context-sensitive grammars $\alpha A \beta \mapsto \alpha\gamma\beta$.

Type-0. Unrestricted grammars map $\alpha \mapsto \beta$, where α is non-empty.

Note that all Type-3 grammars are also Type-2, all Type-2 grammars also Type-1, and so on.

Suppose, for example, that $N = \{F, G\}$, $\Sigma = \{+, -\}$, $P = \{F \mapsto F + G, G \mapsto F - G\}$, $\omega_0 = F$. Letting ω_n denote the sentences generated by applying the production rules n times, it follows that

$$\begin{aligned}
\omega_1 &= F + G, \\
\omega_2 &= F + G + F - G, \\
\omega_3 &= F + G + F - G + F + G - F - G, \\
\omega_4 &= F + G + F - G + F + G - F - G + F + G + F - G - F + G - F - G, \quad \cdots .
\end{aligned}$$

While these defintions are rather abstract, Lindenmayer (1968) provides a remarkable application. Treating each symbol as an instruction like 'go forward' or 'turn right', *L-systems* visualise sentences via 'turtle graphics'; when those sentences have been generated recursively by a grammar, the line drawings inherit that same self-similar structure. Consider the above, where reading non-terminals F, G as 'draw a line while moving one unit forwards,' and terminals $\pm$ as 'turn $\pm\,\pi/2$ on the spot,' produces the fractal dragon curves in Figure 4.

While L-systems are most common in the modelling of 3D plants and other branching structures (Prusinkiewicz & Lindenmayer 1996), *Untitled* only uses them to generate 2D alpha maps. Moreover, it restricts its attention to L-systems paired with context-free grammars.

3.3.1 Case Study: Runes

Parametric L-systems (Hanan 1992) exist as a generalisation of the above. [theory].

The modules in *Untitled*, then, track three . More than anything, this offers a certain clarity of code - at least from a

[Example: various geometric runes!].

[2] In mathematical literature, $\omega_0 \in N$ (Hopcroft, Motwani & Ullman 2000), but *Untitled* takes an informal approach.

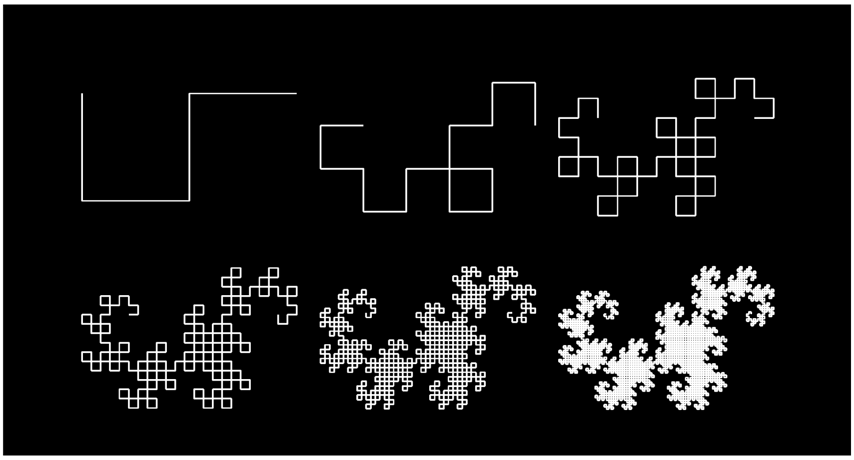

Figure 4: Dragon curves, generated by strings $\omega_2, \omega_4, \cdots, \omega_{12}$.

3.3.2 Case Study: Blood Vessels

Zamir (2001), meanwhile, uses parametric L-systems to visualise the bifurcation of blood vessels. Suppose a branch with length l, width w bifurcates into two branches M and m, such that $l_M \geq l_m$. Defining the *asymmetry ratio* $\alpha = l_m/l_M$, it follows that

$$l_M = \frac{l}{\left(1+\alpha^3\right)^{1/3}}, \quad l_m = \frac{\alpha \cdot l}{\left(1+\alpha^3\right)^{1/3}}, \quad w_M = \frac{w}{\left(1+\alpha^3\right)^{1/3}}, \quad w_m = \frac{\alpha \cdot w}{\left(1+\alpha^3\right)^{1/3}}.$$

Furthermore, the branches diverge from their parent at angles

$$\theta_M = \arccos\left(\frac{\left(1+\alpha^3\right)^{4/3} + 1 - \alpha^4}{2\left(1+\alpha^3\right)^{2/3}}\right), \quad \theta_m = \arccos\left(\frac{\left(1+\alpha^3\right)^{4/3} + \alpha^4 - 1}{2\alpha^2\left(1+\alpha^3\right)^{2/3}}\right).$$

Untitled's framework is therefore capable of reproducing Zamir's results (see Figure 5), using an L-system with the single production rule:

$$\mathbf{C}(l, w, \theta) \mapsto \mathbf{X}(l, w, \theta)[\mathbf{C}(l_M, w_M, \theta + \theta_M)]\mathbf{C}(l_m, w_m, \theta - \theta_m).$$

Figure 5: Zamir's model of arterial branching, with asymmetry ratios $\alpha = 1.0, 0.8, \cdots, 0.2$.

Liu et al. (2010) expand on this by introducing a stochastic component - that is to say, they allow [a more random structure]. *Untitled* incorporates such randomness into its own rules for blood vessels:

$$\begin{aligned}
\mathbf{C}(l, w, \theta) &\underset{0.4}{\longmapsto} \mathbf{X}(l, w, \theta)[\mathbf{L}(l_M, w_M, \theta + \theta_M)]\mathbf{R}(l_m, w_m, \theta - \theta_m) \\
\mathbf{C}(l, w, \theta) &\underset{0.4}{\longmapsto} \mathbf{X}(l, w, \theta)[\mathbf{L}(l_m, w_m, \theta + \theta_m)]\mathbf{R}(l_M, w_M, \theta - \theta_M) \\
\mathbf{C}(l, w, \theta) &\underset{0.2}{\longmapsto} \mathbf{X}(l, w, \theta)\mathbf{C}(l, w, \theta) \\
\\
\mathbf{L}(l, w, \theta) &\underset{1.0}{\longmapsto} \mathbf{X}(l, w, \theta)\mathbf{C}(l_M, w_M, \theta - \theta_M) \\
\\
\mathbf{R}(l, w, \theta) &\underset{1.0}{\longmapsto} \mathbf{X}(l, w, \theta)\mathbf{C}(l_M, w_M, \theta + \theta_M)
\end{aligned}$$

These describe a capillary with a 40% chance of bifurcating with branch M tacking clockwise, a 40% chance of bifurcating with M tacking anticlockwise, and a 20% chance of extending forwards without any branching. The determinstic production rules on **L**, **R** provide course correction, guaranteeing the [...]; further informal tweaks can be found in the `LBloodVessel` class, all intended to get the final look of the L-systems 'right' (see Figure [reference]).

[Figure of blood vessels in isolation]

[Discussion of animation (and the shortcomings thereof)...]

[Figure of final render]

3.4 Procedural Narrative

Untitled was originally conceived as a showcase of procedural text generation, an application of [authored X] towards interactive fiction.

3.4.1 Grammars

Given their origin in linguistics, it is perhaps unsurprising that grammars (see Section 3.3) are of use in the field of procedural narrative - *Tracery* (Compton et al. 2015) being the prime example. From a mathematical perspective, this is a stochastic, context-free grammar, with uniformly-distributed production rules for each non-terminal; it iterates a given axiom until all non-terminals (demarcated by `#HASHTAG#` delimiters) have been replaced. To bemoan the generator as better suited to Twitter bots than immersive storytelling is to misunderstand its design. Compton et al. present a lightweight tool that is left *deliberately* narrow, intended for ease-of-use amongst even the most fledgling authors.

More substantial works, then, adapt *Tracery*'s grammar-based approach to their own specifications. In *The Annals of the Parrigues*, Short sets out the need for a consistent generator, one that "defines any facts about the world that aren't already defined at the moment of generation" (2015, p. 83). *Voyageur* (Dias 2018) integrates several weightings into distribution of production rules (Dias 2019). While [this project], this project wears its influences on its sleeve - *Untitled* uses an implementation of *Tracery* with a couple of custom modifications...

Recency [Or 'dryness'].
$p^{n/(N-1)}$, such that (all other weightings being equal), the most recently used rule (with $n = N - 1$) will be p times as likely as the least recent ($n = 0$).

Note that [joint recency!].

3.4.2 Content Selection Architectures

Storylets (Kreminski & Wardrip-Fruin 2018) are [definition].

[Though conceptually no different, ... , our 'narrative stack'...]

4 Code Organisation

4.1 Post-Processing

4.2 GUI

[Include HDRR/bloom here...]

5 Evaluation

5.1 Features

[Start with marching cubes: successful, but more to do...]

[L-systems: far more robust...]

To the extent that *Untitled* has any single 'special feature', though, it would surely be its approach to procedural storytelling. [...]

5.2 Code Organisation

[Position weakness of the storytelling as an *organisational* matter...]

[Discuss the broader merits of Section 4, ultimately landing on the value of *internal consistency*.]

6 Conclusions

[Coheres in a way that my CMP502 project absolutely didn't...]

Of course, there is a distinction to be drawn between *Untitled*'s functionality as an interactive experience and as a game. [Perils of interactive narrative].

[What/how would I go about cannibalising this? Screen shader first/hexes... narrative much more an early experiment in structuring content selection architectures/context-sensitive grammars...]

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