Untitled: A DirectX Game

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May 16, 2023

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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 [reference]).

[Hand-drawn figure, demonstrating the shortcomings of thorns].

Marching cubes are therefore central to this modelling process. The concept here is best introduced in two dimensions.

In much the same way, [3D generalisation].

[These are just the broad strokes; nuance to, say, weighing vertex normals correctly]. Definitive... Paul Bourke's *Polygonising a Scalar Field* (1994)... [mention marching tetrahedra? While X, marching cubes have been perfectly adequate for the purposes set out below...].

3.2.1 Case Study: Hexes

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 final, 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.[1]

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

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

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

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. In the above example, interpreting 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 1.

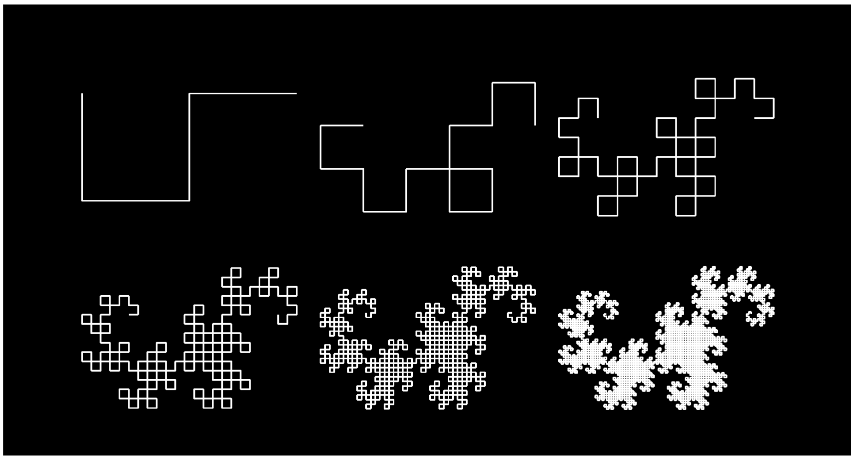

Figure 1: Dragon curves, generated by strings $\omega_2, \omega_4, \cdots, \omega_{12}$.

While *Untitled* only needs them to generate 2D alpha maps, note that L-systems are most common in the modelling of 3D plants and other branching structures (Prusinkiewicz & Lindenmayer 1996). Furthermore, this report will restrict 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!].

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

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

Figure 2: Zamir's model of arterial branching, with asymmetry ratios $\alpha = 1.0, 0.8, \cdots, 0.2$.

Untitled's framework is therefore capable of reproducing Zamir's results (see Figure 2), using an L-system with the single production rule:

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

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

5.2 Code Organisation

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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