# Dunes and Sandwaves
with Terragen 2

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PART ONE

Creating a dune profile

First I want to thank David Burnett for his work upon the linear dunes. My early experiments were made with his very instructive tutorial.

Here is the side view of a typical dune. The wind is coming from the left, and pushes the sand to the right (this is called « saltation »). At a certain point, the sand falls on the other side (slip face, or collapsing face). Initially the opposite side has a rounded profile (F2a), so the sand formation looks like a sand dome. But as the dune rises, the slope increases and the sand collapses under its own weight. It stops collapsing when the slip face reaches the angle of repose, about 34 degrees for dry sand. At this moment the sand formation is a real dune with a crest profile (F2b).
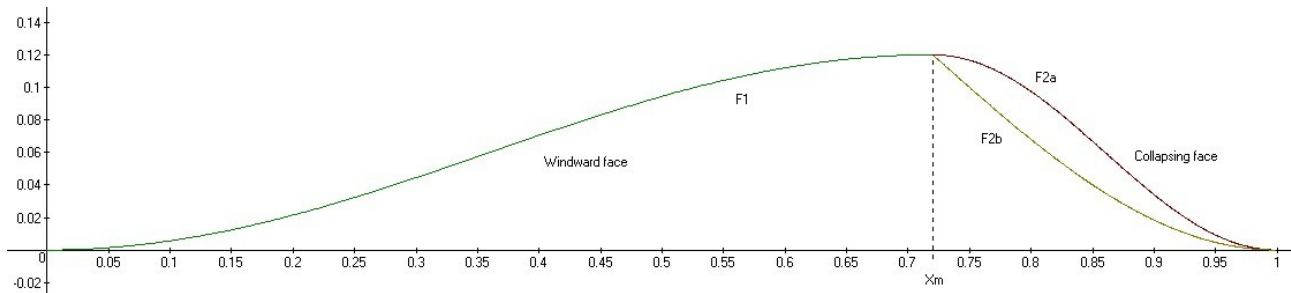
Both sides of the dune are generated with trigonometric functions. These functions require a variable (X) between 0 and 1, as you can see above. As we want to generate some fields of dunes, this interval needs to be repeated ; for this we will use a modulo function.

The avalanche point of the dune corresponds to the value of X named Xm. So in most cases, Xm will be set between 0,5 and 0,95. Values out of this range will give inappropriate or strange results.

For this first example, in a matter of simplification, Xm is also the top of the dune. It means that, at this position, the top is flat (horizontal). We will see later that with real dunes, it's not always true, and we will improve the function. But for the moment, it's enough to begin with.

In the example above, Xm is set to 0,72. This value gives nice proportions to the dune.

I don't want to go too far in the mathematical demonstrations, so I just give the formula for each part of the structure :

- windward side (F1) : $\dfrac{1}{2} \cdot \left[1 - \cos(\pi \cdot \dfrac{X}{X_m}) \right]$ (for X between 0 and Xm)

- slip side, sand dome (F2a) : $\dfrac{1}{2} \cdot \left[1 - \cos(\pi \cdot \dfrac{X-1}{X_m-1}) \right]$ (for X between Xm and 1)

- slip side, dune (F2b) : $\left[1 - \cos(\dfrac{\pi}{2} \cdot \dfrac{X-1}{X_m-1}) \right]$ (for X between Xm and 1)

These three functions have similarities, so it's possible to create one unique function with two additional variables p (profile) and s (side) :

−   p will value 0 for a sand dome profile and 1 for a dune profile. This value will be selected by the user.
−   s will value 0 for x between 0 and Xm, and 1 for x between Xm and 1. This value will be automatically calculated.
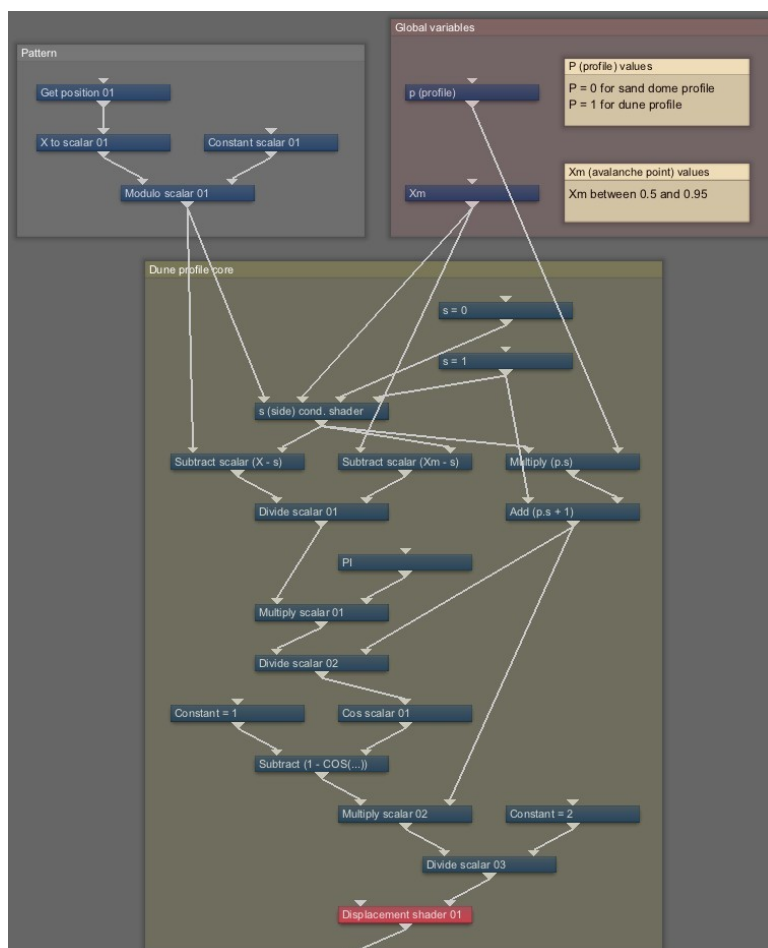
This gives, with s only :

−   sand dome profile (F2a) : $\dfrac{1}{2} \cdot \left[1 - \cos(\pi \cdot \dfrac{X - s}{X_m - s}) \right]$

−   dune profile (F2b) : $\dfrac{s + 1}{2} \cdot \left[1 - \cos(\dfrac{\pi}{s + 1} \cdot \dfrac{X - s}{X_m - s}) \right]$

And then, using p and s :

−   unique profile : $\dfrac{p \cdot s + 1}{2} \cdot \left[1 - \cos(\dfrac{\pi}{p \cdot s + 1} \cdot \dfrac{X - s}{X_m - s}) \right]$

This is the formula we are going to use in Terragen. It will be the core of the dune creation process.

Here is the node tree for this formula, and the associated .tgc files : [dune-core-1a (.tgd + .tdc)]


The tree is composed of three parts :

−   The « pattern » group used to generate repetitive values of x between 0 and 1.
−   The « global variables » group contains the parameters for the dune's shape. You can modify the values.
−   The « dune profile core » group contains the main formula. Just notice that the « s » variable is calculated with a conditional shader, and uses the X and Xm values. At the end of the process you've got a displacement shader to visualize the dunes. Il can be used on a surface layer.
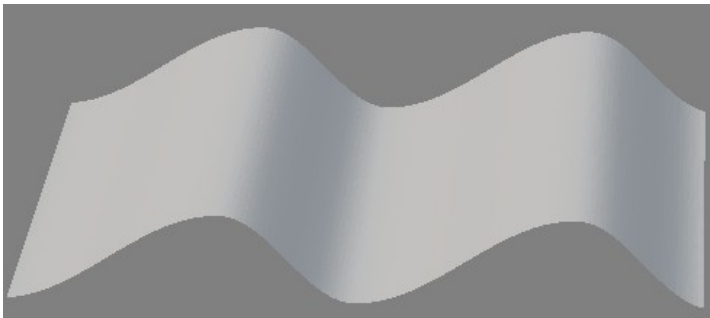
Each of these groups will be improved later.

Here are two examples of what you can obtain :

– With Xm = 0,72 and p = 1
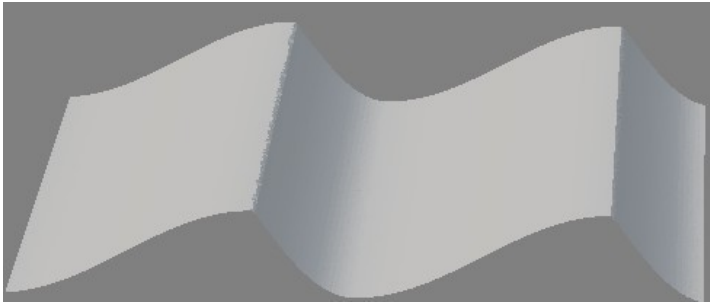

– With Xm = 0,62 and p = 0

These profiles can be used for big dunes and for sand ripples : it's just a matter of scale.

Introducing some variations

Of course, with this set of nodes, we can generate linear dunes only. It's time to add some more controls.
– First we may need to rotate the dunes. It can be done with a « Rotate y vector » just after the « Get position ».
– If we need to move the dunes forward or backward, we need a « Shift » variable (in the « Global variable » group) which is added to the X value. The « Shift » default value is 0.
– To control the global scale (side length, or L) of the dunes, we use a « divide scalar » before the modulo operator. This scalar is connected to the « Global scale » constant in the « global variables » group. Later we will see that this same constant is needed to calculate the dune's proper height.
– The modulo calculation leads to the creation of dunes that are perfectly contiguous. This means that each dune begins where the previous one ends. In some cases we'll need to let a free space between two dunes, so we add a « Gap » constant in the « Global variables » group, which value will be the size of the medium space between each line of dunes. In that case a clamp scalar is also required. The « Gap » default value is 0. Here is an example of a render with Global scale = 100 and Gap = 50 :
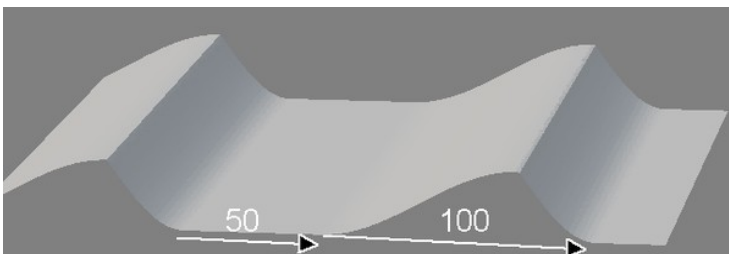
– To break the linearity of the dunes, we also add the result of a « Perlin 3D scalar » before the modulo operator. This « Perlin 3D scalar » and its own parameters belong to a sub-group named « Perturbation 01 ».

At this point, here are the .tgc files : [dune-core-1b (.tgd + .tgc)]

As the « Perturbation 01 » group does not facilitate the reading of the whole process, we replace it with a Power Fractal Shader which gives in the same time some other possible settings.

Maximum slope, maximum height

For the moment, the height (H) of the dune is determined by the disp. multiplier in the displacement shader at the end of the calculation process (at the bottom of the « dune profile core » group). But a multiplier that is too high could lead to a slope that would be steeper than allowed. Remember that the angle of repose for dry sand is about 34° and should not exceed this value. To avoid this situation, it is possible to calculate the max height of the dune, using the derivatives of the F2a and F2b functions. With the derivatives, the max slope will be noted σ (sigma) and σ = tan (angle of repose) ≈ 0,67

We will use the unique profile : $\dfrac{p \cdot s + 1}{2} \cdot \left[1 - \cos(\dfrac{\pi}{p \cdot s + 1} \cdot \dfrac{X - s}{X_m - s}) \right]$

We can see that the max slope is reached in a dune profile (p = 1) on the slip side (s = 1) for X = Xm.

Here is the simplified function before calculating the derivative : $\left[1 - \cos(\dfrac{\pi}{2} \cdot \dfrac{X - 1}{X_m - 1}) \right]$

The derivative is : $\dfrac{\pi}{2} \cdot \dfrac{1}{X_m - 1} \cdot \left[\sin(\dfrac{\pi}{2} \cdot \dfrac{X - 1}{X_m - 1}) \right]$

With the global scale (L) and height (H) parameters, it leads to : $\dfrac{H}{L} \cdot \dfrac{\pi}{2} \cdot \dfrac{1}{X_m - 1} \cdot \left[\sin(\dfrac{\pi}{2} \cdot \dfrac{X - 1}{X_m - 1}) \right]$

H will be determined by the result of the following equation : $\dfrac{H}{L} \cdot \dfrac{\pi}{2} \cdot \dfrac{1}{X_m - 1} \cdot \left[\sin(\dfrac{\pi}{2} \cdot \dfrac{X - 1}{X_m - 1}) \right] = -\sigma = -0,67$

As X = Xm and sin (PI/2) = 1, we finally obtain : $H = \dfrac{2\sigma L}{\pi} \cdot (1 - X_m)$

Note : there is also a max slope value for the sand dome profile for **X = (Xm+1)/2**, but it leads to the same result.

The new group « Height calculation » replaces the fixed value of the displacement multiplier by the formula above. The displacement multiplier is now equal to 1. See the files : [dune-core-1c (.tgd + .tgc)]

Note : due to the perturbation shader in the « pattern » group (before the modulo), the final slope seems more or less steep from place to place, but it's not too much annoying.

Now we've got some sinuous infinite lines of dunes, and we need to break all of that !

A field of dunes - First try

The idea is quite simple : we are going to generate two sets of dunes (with some variations between the two) then combine them to create some discontinuity. There are many methods to do that, here is a first one.

First we create a « Set of dunes » group that includes all of the previous groups. With that new group, it will be easier to duplicate the whole process.

Both sets of dunes have a global size = 100 and a gap = 50, but the second set has a shift = 75, so the second lines of dunes form in the spaces between the lines of the first set.

Each set is connected to a displacement shader and a surface layer, using a power fractal shader (and a color adjustment shader) as a mask for the first one, and the complement color of this PF shader for the second one. So the second lines of dunes forms where the first ones are not.

Please note that a <u>flat</u> surface layer is required for each set of dunes. If you connect the displacement shaders to a surface that previously includes some reliefs, it will distort the dunes. If you need to combine the dunes with an existing terrain, you will have to do it <u>after</u> the dunes generation (with a « merge shader » for example).

The results are in the files [dunes-field-1a (.tgd + .tgc)].

A field of dunes – Second try

Here is another example combining three sets of dunes with different sizes.

We use the following parameters :

For the three sets : Profile = 1 ; Xm = 0,72 ; Angle of repose = 34°.
- First set (the biggest dunes) : L (size) = 200 ; shift = 100 ; gap = 100 ; Perturbation shader scales = 200 / 300 / 100
- Second set (medium dunes) : L (size) = 80 ; shift = 70 ; gap = 0 ; Perturbation shader scales = 50 / 100 / 50
- Third set (little dunes) : L (size) = 10 ; shift = 0 ; gap = 0 ; Perturbation shader scales = 16 / 24 / 12

Each set is connected to a displacement shader and a surface layer (as before), but this time we use a different method to blend the dunes. We use PF shaders as masks for the three sets, and we play with the « limit max altitude » parameter (in the surface layers) for the second and the third sets.

Work files : [dunes-field-1b (.tgd + .tgc)].
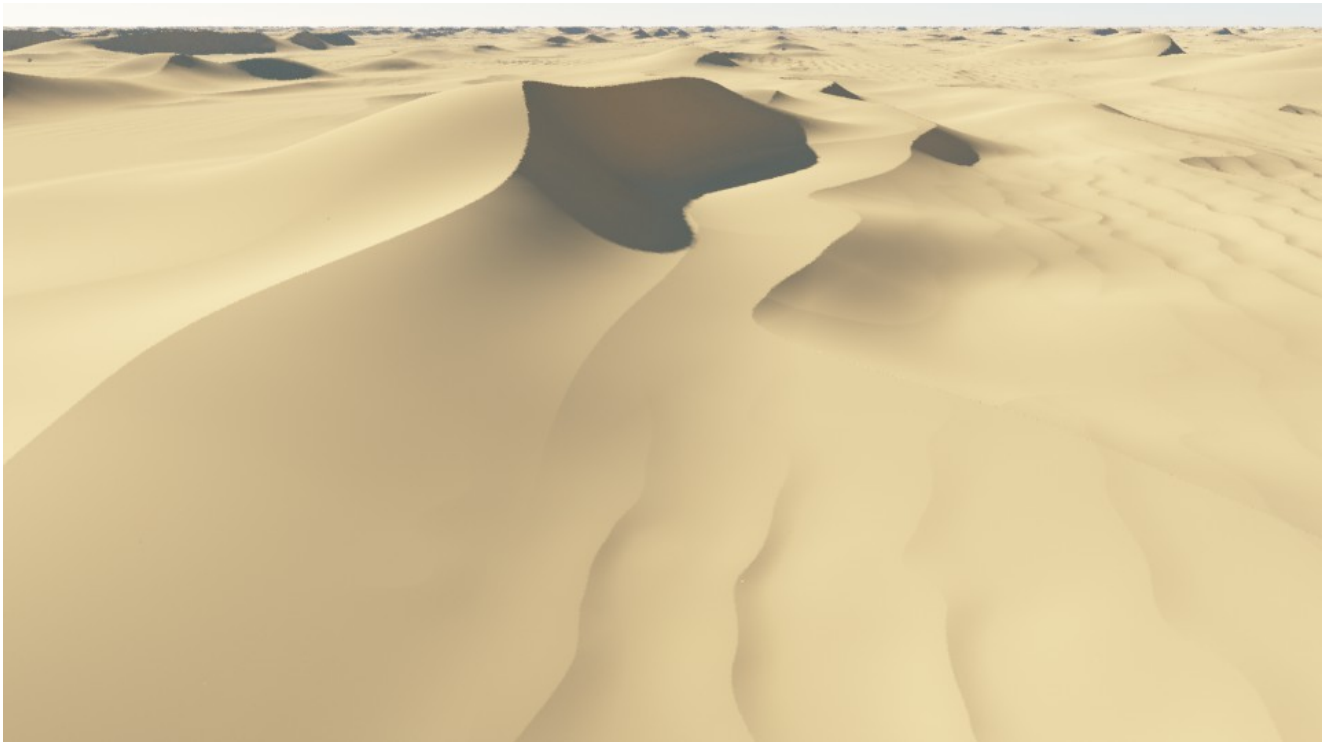
We get a more varied field of dunes, mais there are still some problems :

- There are some faint ridges that are caused by the intersection of the different dunes.
- The little dunes appear in some places where they should not be (on the collapse side of the big ones).
- In certain places the overall shape of the dunes is too much flattened ; in some other places it's too high.

In the next part of this tutorial, we will see another method to combine several sets of dunes.

Dunes for dummies…

You don't understand anything of all this mathematical mess ?
Don't panic ! Just play with the "global variables" groups. All the useful parameters are here, except for the rotation parameter which is in the "pattern" group.

- **Shift :** to move the lines forward or backward.

- **Gap :** the space between each line of dunes.

- **L (global size)** : the main parameter for the size of dunes. It's the side length of the dunes.

- **P (profile) :** 0 for a "sand dome" profile, or 1 for a "dune" profile.

- **Xm :** x position for the top of the dune. This value should be between 0,5 and 0,95.

- **Angle of repose (degrees) :** the angle beyond which the sand collapses. Default value is 34°.
  Don't change it if you don't know how to use it.
  If you want to test other values (that means : for other materials than dry sand), see here :
  http://en.wikipedia.org/wiki/Angle_of_repose

- **Rotate y vector (in the "pattern" group) :** the wind direction.

You can also change the values of the **« Perturbation » shader**, in the « pattern » group, if you want to distort the lines of dunes. Just keep in mind that the values for the « feature », « lead-in » and « smallest » scales in this shader should be in the same order of magnitude as the global scale (L) of the dunes. Some extreme values could lead to strange results. The best thing is to slightly change these values and to see the render...