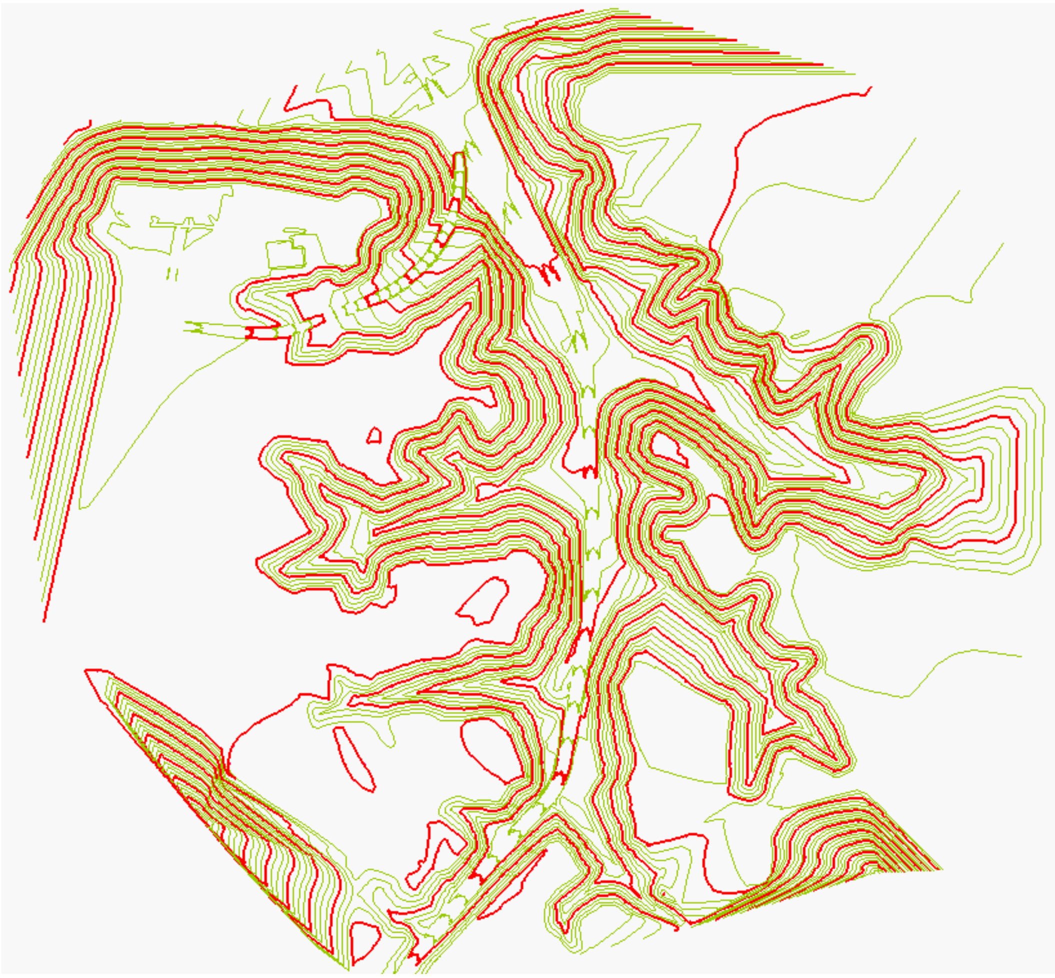
"Traditional" Terrain Modeling

Anyone associated with Civil Engineering recognizes what the screenshot below represents.



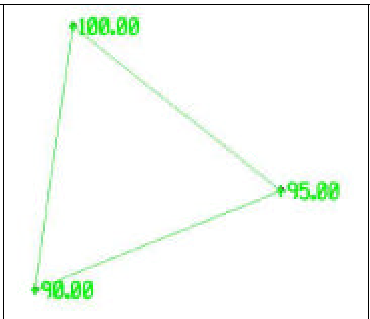
The contour map is perhaps the primary way to represent three-dimensional terrain in two dimensions. A Digital Terrain Model is an electronic representation of a 3D surface, typically existing or proposed terrain. All DTM formats start with a basic unit of a 3D point. A triangle of lines between any three non-collinear 3D points forms a plane. Four points form two triangular planes, etc. Any set of points can form a "mesh of triangles" model of a surface. While sophisticated algorithms such as Finite Element Analysis can be used to model surfaces from points, triangles of 3D points tend to be sufficiently accurate, simpler to verify and faster to process.

DTM Point Types and Triangulation

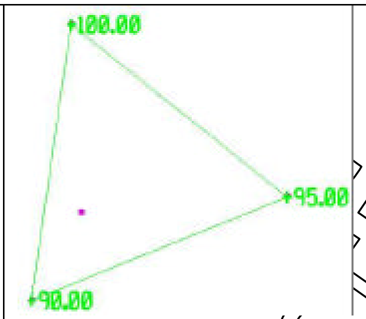
Random Points
Ultimately all surface information consists of horizontal and vertical information, the smallest unit of this is the point.

Triangles
Given three 3D points in space, we can assume a linear relationship between these points. A 3D triangle makes up a plane. Given any horizontal position within the plane, we can calculate an elevation for that point.

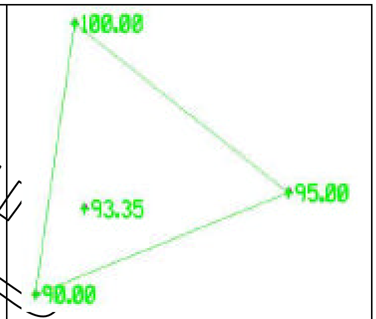
Three points in space



Linearly connected into a triangle



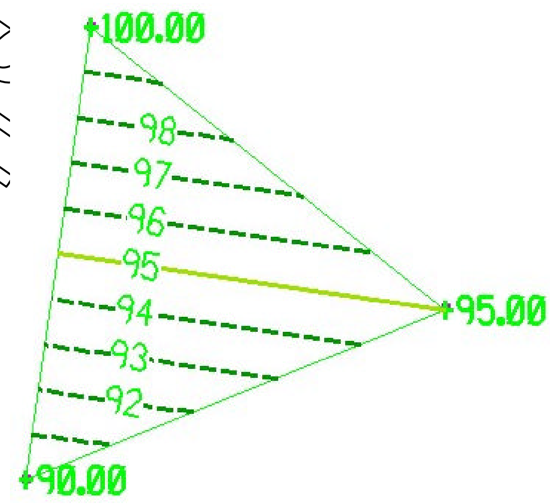
Any point in the triangle



Has a calculated elevation

This is the fundamental theory of the DTM, and the triangle is primary unit of the Terrain model from which everything else is derived.

Contours represent lines of identical elevations in a surface. Given a triangle we can generate contours.



An obvious property of this triangle is its slope direction, which is perpendicular to the contours, in this case identical to the direction from the 100 ft point and the 90 ft point. This is known as the triangle Aspect. The slope of the triangle is the rise/run along the Aspect, in this case it is 11.25%.

InRoads has a full suite of surface visualization tools for such things as triangles, contours, Aspects, Slope Vectors, etc.

A single triangle is a valid, but limited, surface. Given four points we have two contiguous triangles and so on. The InRoads Terrain Model is simply a mesh of triangles.

Each vertex of every triangle represents a survey point. Placing a tentative point at the vertex echoes the x, y, z coordinates.

Triangulation

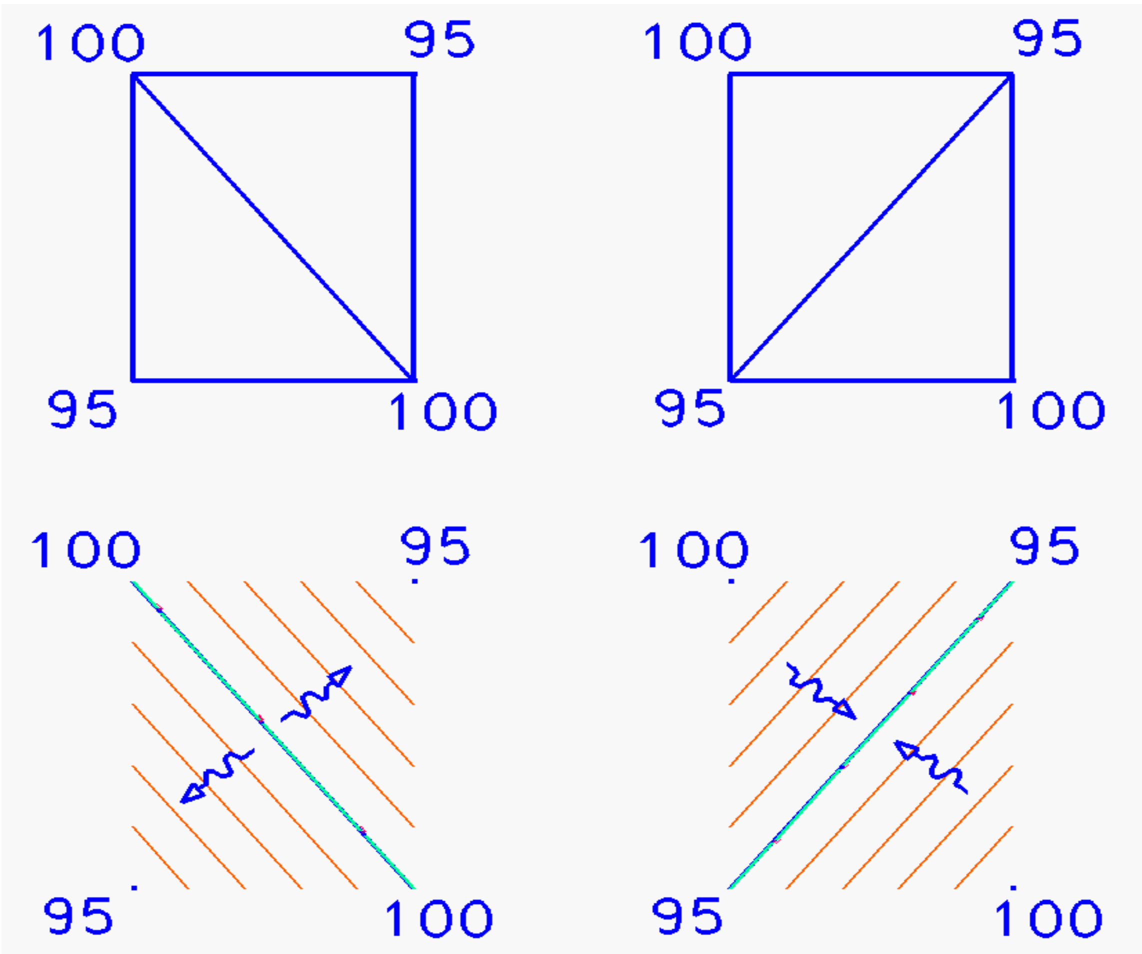
Creating triangles from points is known as Triangulation. Note: Triangulation and Displaying Triangles are two very different things. Triangulation is the creation of triangles from data in the DTM , forming the mathematical model of the surface. Displaying Triangles does no math and no modeling, it simply displays any previously Triangulated triangles in the DTM.

The process of Triangulation for any DTM with more than 3 points is, without help, guesswork. InRoads tries to guess well, using Delauney's Criteria to create triangles that tend to be short as opposed to elongated. Regardless of the algorithm, triangulating is guessing. Given four points there are two different ways to create two triangles amongst them. Which is correct? Which most accurately models the “real world?”

Why Points Alone Are Not Enough

Let's assume that we have four survey shots at four corners of a square. Let's further assume that the upper left and lower right corners have elevations of 100 and the upper right and lower left corners have elevations of 95. There are two combinations of triangles that can be "drawn" between the points. The common triangle boundary can run along either diagonal, that connecting the 95 elevations or connecting the 100 elevations. The model will either be of a 100' elevation crestline or a 95' elevation trough. Which is correct? The following diagram shows the two options.

For a tangible illustration, take a sheet of paper and bend it along the diagonals, one bend with corners folding down, the other with corners folding up. This represents the two ways the surface can be modeled.



Ridge at 100' ?　　　　Ditch at 95' ?

It is impossible to design an algorithm that can tell from those four points what is going on out in the field. The actual terrain might be either. Just as it's impossible for you to tell from the points that a crest or a trough exists in the field, it is impossible for a computer to make this decision accurately. The only way to know how to model this is to know what actually exists in the field. How do you (or the surveyor) force the software to triangulate correctly?

<u>Breaklines</u>

Breaklines are the method that most triangle-based DTM's use to tell the software how to model the surface. A breakline is a way to tell the software to how to triangulate. Breaklines document a linear relationship between points. By definition, triangles cannot cross a breakline. In the example above, if the four points represented a 100' elevation crest, a breakline must be defined between the 100' elevation points to ensure proper triangulation. If the four points represent a 95' elevation ditch, a breakline must be defined between the 95' points.

One of the reasons surveyors use Field Codes to identify field objects is to help software automatically create breaklines between similar Codes. InRoads is particularly well suited to importing the intelligence of the field survey into the DTM for its use throughout the design cycle (see the later discussion on the Engineering Model).

Exterior Points and Interior Points

Left to their own devices all random points and all the points or vertices in all breaklines will “triple up” into triangles. Every triangle implies three linear relationships. Sometimes that linear relationship does not exist. It is important to limit triangulation to only valid relationships. It is important to make sure the “triangle mesh,” that is, the surface” models only valid terrain.

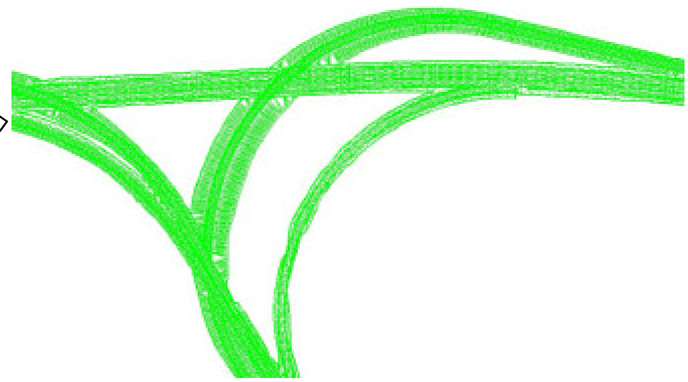
The problem with “bad triangles” is that it implies engineering relationships that do not exist. Typically triangles are not displayed on construction plans, but contours may be. Contours derived from bad triangles do not necessarily look obviously different from good triangles. This opens up exposure to liability.

Exterior and Interior Points are shapes that limit triangulation. A surface can contain a single Exterior shape. No triangles cross the Exterior shape, even if points exist outside of the shape. Interior shapes prevent triangulation inside the interior of their shape. There can be as many interior shapes as necessary.

Exterior Points

The screenshots below show the same proposed surface with and without an Exterior Boundary. Notice the very long, inappropriate triangles. This implies that the existing ground be graded in long skinny planes, which might upset the homes and businesses under the triangles.

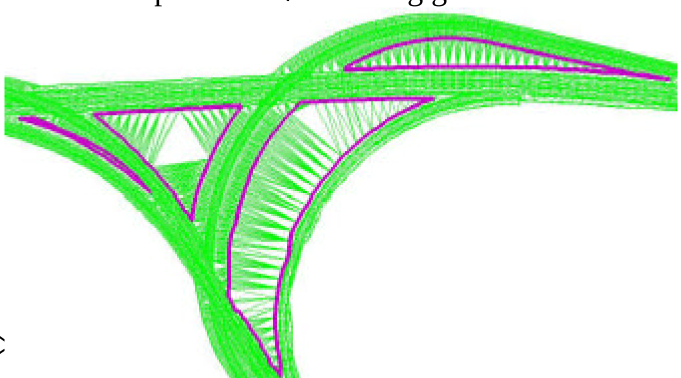
Surface without Exterior boundary

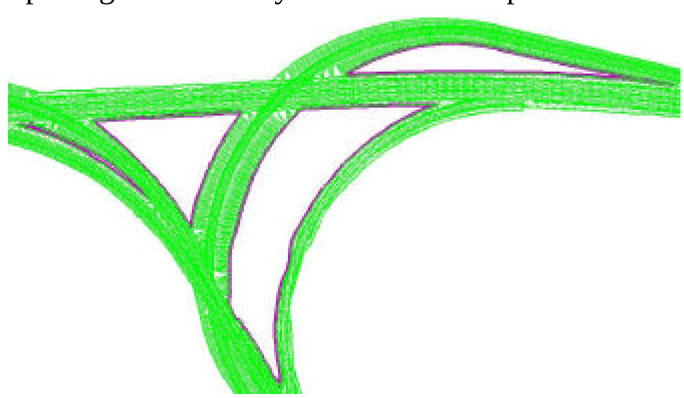


Surface with an Exterior boundary

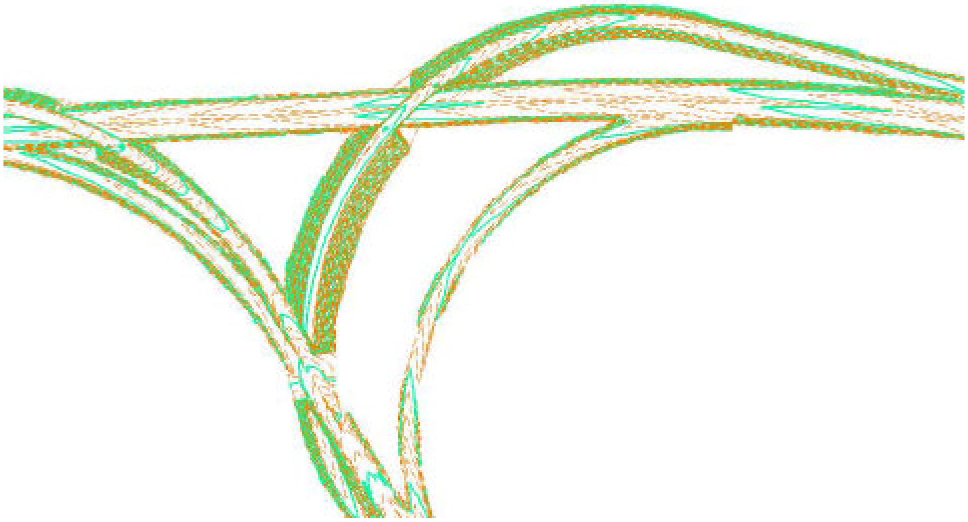
Interior Points

For existing surfaces, Interior Shapes can be used to designate areas that were not surveyed such as yards, building, and lakes. For proposed surfaces, Interior Shapes can be used to represent areas not to be graded. The screenshots below show the same proposed surface prior to and after importing the four Interior shapes. The first implies that the existing ground between the ramps be graded linearly between the ramps.



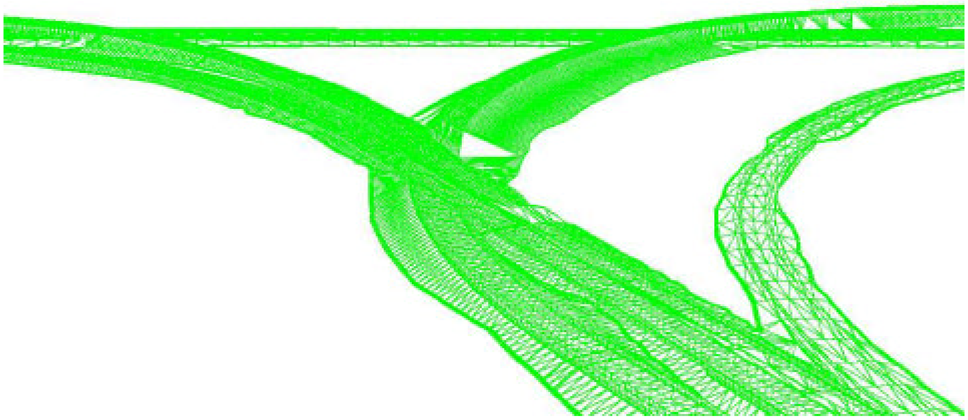


The contours to the right show contours only where appropriate. The model is limited by appropriate Exterior and Interior Shapes.



Unlike old, manual methods, the digital terrain model is truly a three dimensional model. The source for the traditional Civil Engineering "terrain model" and its various 2D representations is the triangle mesh.

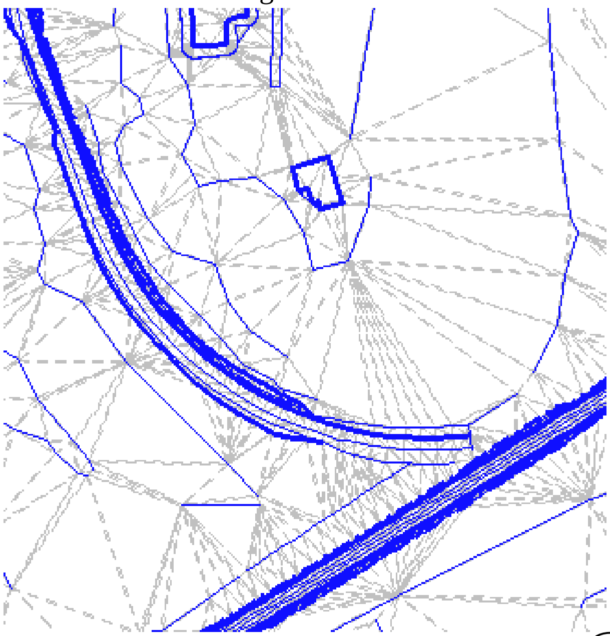
Displaying the triangles reveals a 3D wireframe model of the terrain (if you rotate the view towards an isometric view, render the view, and squint, you can see the terrain relief).



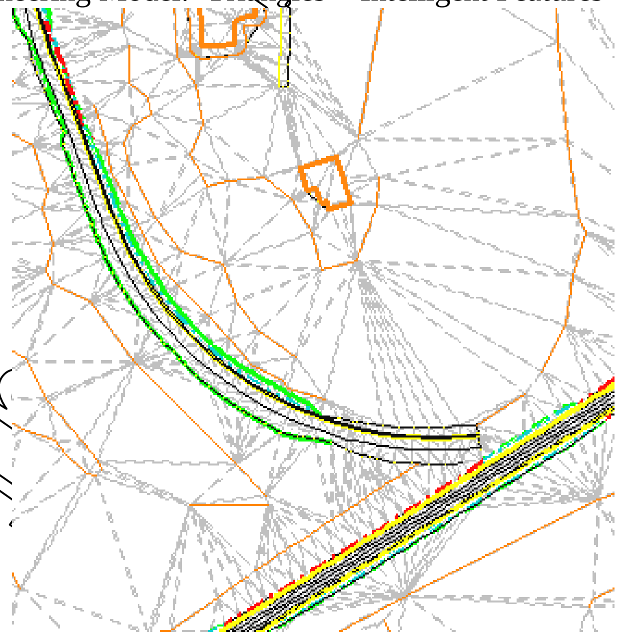
The Feature-Based Engineering Model

Beyond a "mesh of triangles," the old DTM contains no other information. The new, intelligent Feature-based model incorporates the "mesh of triangles" functionality, but also allows us to store significant intelligence with every object in the DTM.

Terrain Model: Triangles + "Dumb" Breaklines Only



Engineering Model: Triangles + Intelligent Features



Additionally, we now have the option of modeling objects that are not at-grade. This allows us to represent above- or below-ground utilities, for example.

The new DTM model incorporates the same "old" triangle model for defining the "ground surface". Both models use the five Point Types which control how the triangle network is created.

Every object in the new DTM is known as a Feature. The Feature has a number of new properties including a Name, an optional Description, and Feature Style (what type of object is it?), as well as the Feature [Point] Type.

The Exclude from Triangulation toggle allows Features to be excluded from the "ground surface." This property allows modeling above- or below-grade utilities.