Terrain generation using glacial and tectonic models

Conference Paper · May 2017

Krzysztof Mieloszyk
Gdansk University of Technology

Terrain generation using glacial and tectonic models

Krzysztof Mieloszyk

Gdańsk University of Technology
Faculty of Electronics, Telecommunications and Informatics
G. Narutowicza 11/12
Poland, 80-233 Gdańsk

krzysztof.mieloszyk@gmail.com

ABSTRACT

Terrain models are key elements of most applications featuring virtual world. Industries such as Computer Games, Flight Simulation or Movie Industry require that they are as realistic as possible. Currently used algorithms afford the opportunity to generate high quality terrain offline using a lot of calculations or to create it by the user as a result of a long process of manual modeling. Generating terrain on the flight is only possible with application of procedural methods using noises or fractal models thus giving unrealistic results. The following article presents terrain generating technique using the keys geophysically based models taking into account their interactions. This method admits realism in quality similar to physical simulation methods, generating ready "mesh" in seconds. Application of geometry subdivisions permits to reflect the impact of large-scale phenomena on small-scale components which allows terrain rendering, both on entire planet level, as well as on the level of local details for low flying observer.

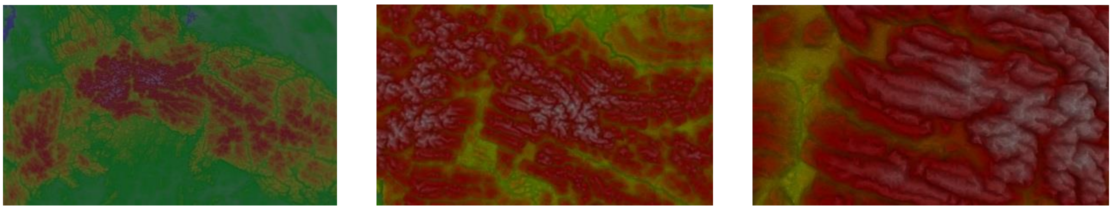

Figure 1. Terrain generated using tectonic and fluvial erosion models. Three different observer distances.

Keywords

Procedural, terrain generation, geophysically based, glacial erosion, tectonic, dynamic modeling

1. INTRODUCTION

Terrain generation is an area of research developed for over 30 years. It is one of the most widely exploited subjects of virtual reality and computer graphics. Virtual terrain, itself, is one of the basic elements of many types of applications, such as games, movies, flight simulators. The area of terrain exploration demands not only current availability for user, within a few kilometers but also on country, continent or the globe scale which requires storing large amount of data or data streaming. Using procedural algorithms allows dynamic terrain generation reducing the size of data only to the amount necessary to render landscape around current position of the observer. The process of modeling itself involves selection of the parameters which describe specific nature of the terrain requested by the user. This permits to reduce to a minimum the work required to create different locations of the world, where manual editing on a global scale would be impossible. Most of hitherto procedural generating procedures focused on exploring fractals related issues and methods of noises generation, treating them as a source of functions differentiating terrain formation to combine them by increasingly sophisticated algorithms.

This was an attempt to reproduce the laws of physics without examining their nature. All these studies, however, reached the barrier of interpretation the semantics of landscape surface as the effect of the case. Simulation methods based on physical process modeling are free of those disadvantages. The principle of their operation is based on data set act to hundreds of iterations of implemented equations. The processed data set is most frequently represented by a regular mesh in a given scale, which in turn is subjected to various simulations. There is one disadvantage of this method to be mentioned, which is, a very high computation consuming, limiting their application to a given section, forcing the need to perform calculations on a batch computing principle.

The following article presents a new method of procedural terrain generation, taking into account the most important geophysical processes. The algorithm is based on the assumption that the shape of the earth is the result of many interrelated relations of cause and effect, and as such should be modeled. On the other hand, random factors should be eliminated or minimized as possible to be replaced with models of physical processes adapted to procedural approach.

2. RELATED WORK

Procedural Methods

Decisive work in the field of procedural terrain generation was [MAN83], presenting fractal nature of various natural objects, such as mountainous landscape or shoreline drawing. Another work was [FFC82] presenting a method of putting to use composition of many random noise octaves to generate coastlines and topography of small planets. The algorithm itself was based on the use of "Midpoint displacement" involving calculation of a new point in the middle of the polygon as the average height of its vertices and then adding the noise of higher and higher octave and of a lower amplitude. This allowed to densify the mesh and maintain large-scale terrain shape character in smaller and smaller details. Another approach towards making use of noises proposed applying function generating Perlin noise [PERL85] inside which following octaves for a given point in space are calculated and summed up. Random noise itself has been replaced by an array of disorders, which pseudo-random value was calculated on the basis of interpretation of a given point in space. This resulted in a higher level of universality and abstraction of a generating function by making its result dependent only on space. However, this is at the expense of resignation from taking into account the nature and characteristics of the same geometry. The work [EMPP98] presenting ready usage of procedural methods to generate terrain constituted development of these algorithms. Although landscape created by these methods could be virtually infinite, it missed completely natural elements, such as valleys and rivers, and water reservoirs were modeled as a horizontal plane at the given height. Partial reason for this was the application of fractals and random functions eliminating physical processes differentiating terrain in reality. The work devoted to rivers' generation was the article [KMN88] where its author proposed to generate a sector of land, taking into account drainage network, and then on its basis the topography. However, the scale of this algorithm was limited to one valley only. The example of using the procedural algorithm on a global scale was [DGGK11]. This work presented dynamic generation of planet, taking into account the position of the user and resulting from this level of detail (LOD). Despite high performance, river system presented there did not have a natural topology of the network. Application of pseudo-random functions there did not take into account the nature of gravitational runoff which results from the topography. Random height and reference to its physical nature problem solution has been presented [MIE12] in a procedural method of generating orographic processes taking into account collision of tectonic plates. Vertical movement was calculated as the change in the volume segment of a sphere (planet) which is a pyramid, as a result of vertexes movement on its surface, according to the speeds of plates and microplates. The disadvantage of this approach is a slight horizontal movement of characteristic elements, such as riverbeds or ridges depending on the number of levels of detail included. The approach of simultaneous and correlated generation of many geophysical processes such as tectonics and hydro topology of rivers, on the following scale densities (detail degrees) of the mesh, did not include such important phenomena as glacial erosion.

Simulation Methods

Simulation methods to the needs of computer graphics have been developed over many years. Most of works have been devoted to erosion modeling based on various algorithms. Some of them even take into account Navier-Stokes equations, eg. work [BTHB06]. In this case problem solution was based on 3D voxel grid of a small section of land. Works on the simulation of other phenomena are however scarce. The attempt to simulate the process of terrain uplift has been shown in [ALEX06] presenting a method of modeling of two plates overlapping and a gradual deformation of the place of collision. The field of analysis is limited here to a small section and does not account for such phenomena as for example faults. In a global way to the whole issue has been approached by the author of [VITA12], focusing on simulation of continental drift, their decay and tectonic plates overlapping process. Despite presenting terrain uplifts as a superposition of two continents, also here no reference has been made to faults formation. This may be because of their high detail in relation to the scale of the globe. All simulation methods focused on a very accurate reflection of modeled processes require a long computation time, often based on regular grids.

Their Simulation calculation complexity can be represented simply as $o((n + m) * i)$, where n is the number of nodes, m is the number of adjacency, and I is the number of iterations. For correct propagation of a modeled interaction, the minimum iteration count cannot be less than the number of nodes representing the maximum path length of the modeled flow. This limits significantly the possibility of their application for the needs of a user whose behaviour is very dynamic and completely non-deterministic.

3. ALGORITHM OVERVIEW

Scale of natural phenomena

All geophysical phenomena occur on the Earth at the same time, affecting each other mutually. Nevertheless, terrain analysis at different levels of detail shows different degrees of their summative impact on the character of the topography. Dividing the entire planet by consecutive scales, ranges of heaviest impact of each of the phenomena or its disappearance can be determined, which has been shown in the presentation [MIE12]. The character of impact of each modeled process depends on current terrain topology. Consequently, along with other processes it affects the topology of the next mesh subdivision. However, it is necessary, to complete the said scale with glacial erosion as the most intense of all geophysical phenomena (Figure 2). There are two types of processes. The first 'Local' in which the scope of impact is limited to the nearest neighborhood of counted grid. The second 'Flow' where the range of impact propagates throughout the whole flow modeling path even between two extremely distant parts of the planet.

Figure 2. Diagram depicts the occurrence of geophysical phenomena on various degrees of subdivision, along with the approximate size of the triangular side (on the scale of the Earth) and the number of necessary polygons to full representation of this level of subdivision. Solid range represents ‘Flow’ processes type, wireframe represents ‘Local’ type.

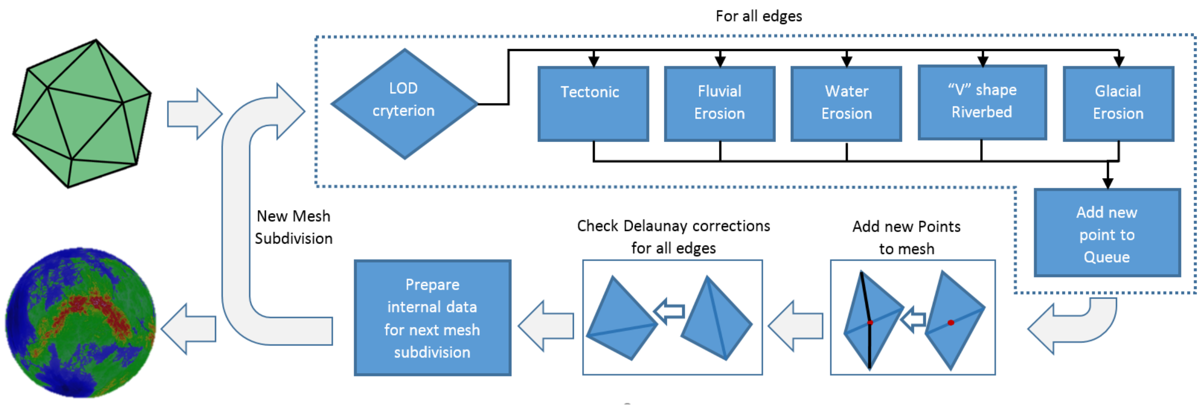

Figure 3. Generation pipeline

Generation Pipeline

Icosahedron which constitutes the simplest figure of sphere representation is the basic form of the algorithm. Performing its “subdivision" each edge is analyzed in accordance with adopted criteria “Level Of Details", specifying whether the division is necessary. Position of a new point created on the edge is determined taking into consideration all modeled physical processes forming the topography. Thus prepared, the point is stored in the list of vertices of which the whole geometry will be extended. The next stage of pipeline generation is the execution of division of assigned edges by new points. Such a densified mesh is degenerated by many obtuse triangles and requires verification and topological correction for compliance with the model of triangulation Delaunay. Once this stage is concluded, the mesh is ready for rendering, but often the amount of detail is not satisfactory for the user and the whole cycle of subdivisions must be repeated several times. Performing complete consecutive runs of mesh subdivision allows to model each of the phenomena, taking into account at the same time, their mutual dependences in a multiscale observable in the final form of generated terrain.

Tectonic uplift

Tectonic movements are the most important element affecting terrain, as one of the few processes are responsible for vertical lifting of the earth crust. To fully reflect this, we have to model the cause of tectonic plate movements. Since each point moves along the surface of a sphere with a radius R, this can be represented as the cross product of its position and the rotation vector of the entire plate [JD94]. In subsequent mesh divisions, if the point is at the edge of which the vertices have different speeds, it needs to be determined to which of the plates it will belong to. Because the shape of the geometry should be in correlation with the phenomena occurring on the modeled mesh, preferred speed will be the one whose movement direction is as perpendicular to the edge as possible. This allows to create potential fault lines, where speeds are the same (figure 4). As a result of the difference in velocity between the two vertex edges, with the time their mutual displacement and consequently deformation occur. According to Hook's law, there is a stress change that can be calculated for tension and compression according to equation (1) and for shearing stress according to equation (2).

$$\text{Stress} = \frac{\mathbf{V}_{dif} \circ \mathbf{N}_E}{\mathbf{N}_{V\,dif} \circ \mathbf{E}} \qquad (1)$$

$$\text{Stress} = \frac{\left|\mathbf{V}_{dif} \times \mathbf{N}_E\right|}{\left|\mathbf{N}_{V\,dif} \times \mathbf{E}\right|} \qquad (2)$$

Where

$\mathbf{V}_{dif}$ is velocity difference vector equal $\mathbf{V}_{\mathrm{P1}} - \mathbf{V}_{\mathrm{P0}}$.
Vectors $\mathbf{N}_E$ and $\mathbf{N}_{V\,dif}$ are equal normal vectors edge $\mathbf{E}$ and $\mathbf{V}_{dif}$.

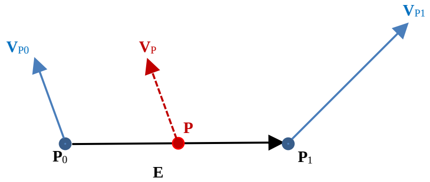

Figure 4. Method of determining the velocity for created as the result of edge division point P.

This allows to test whether at a given edge stresses over its nominal strength have occurred, leading to a structural fracture. As a result there is a mutual shift of plates leading to stress relaxation. In such situation, the speed of the new point should be the average speed of the vertices of the edge on which it arises. The result of the above calculations is the formation of correlated lines of faults perpendicular to the direction of collisions (figure 1). Accompanying uplift/downlift can be calculated using empirical formulas up to 10 level of mesh division equation (3) and above 10 level of mesh division equation (4). Calculation is performed for a normalized planet size with a radius of "1.0".

$$\mathrm{H_{lift}} = \sqrt[subdivision]{\text{Stress}} * 0.0005 \qquad (3)$$

$$\mathrm{H_{lift}} = \frac{\text{Stress} \; * 0.001}{2^{\,subdivision}} \qquad (4)$$

Where the position of the new point is equal to the sum of the center of the edge on which it is formed and the tectonic correction $\mathrm{H_{lift}}$.

Riverbed modeling

An important feature of landscape separated by rivers, is the characteristic "V" shaped valleys profile. Therefore, it is important that the newly added details of topography should take into account the same angle of inclination of the opposite slopes. When dividing the edge which surroundings are of riverbed character and the height of the point added to the edge is known, $\mathbf{P}_{Correct}$ should be determined as a corrected position of point $\mathbf{P}$. This is achieved by a horizontal shift of the point in accordance with the direction of the vector $\mathbf{N}_{AB}$ (Figure 9) which is the normal $\mathbf{P}_B - \mathbf{P}_A$ vector projected on the plane. Distance L_A for which both angles are equal can be calculated using the equation (5). This allows to assign a new revised position of point P on the basis of the equation (6) (figure 10).

$$L_A = \frac{L * \frac{A_h}{B_h}}{1 + \frac{A_h}{B_h}} \qquad (5)$$

$$\mathbf{P}_{new\;correct} = \mathbf{P}_{new} + \mathbf{N}_{AB} \cdot (\mathrm{L}_A - (\mathbf{P}_{new} - \mathbf{P}_A) \circ \mathbf{N}_{AB}) \qquad (6)$$

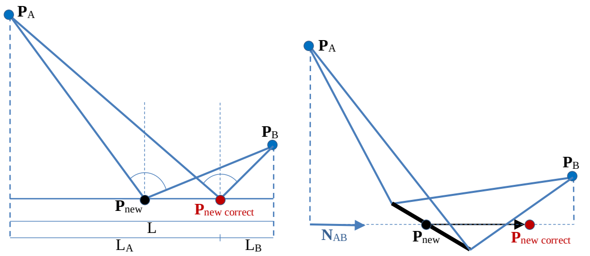

Figure 9. Equalize of riverbed slopes angle as horizontal correction.

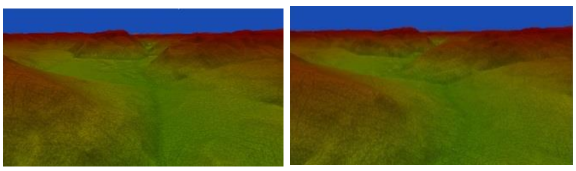

Figure 10. Terrain generated without described model (left), and using “V” riverbed model (right)

Snow cover modeling

Snow and ice as solid form of water are not only a visual element of landscapes but have strong influence on terrain shaping from geophysical point of view. In typical annual cycle snow is usually deposited as a result of snowfall in winter and then melts in summer. Not everywhere, however, this balance equals "zero". Taking into account many factors such as altitude, local climatic conditions or snowfall, places where the snow remains all year round can be designated. The lines which divide these areas have been named as "line of eternal snow". The height of its occurrence depends on many factors such as altitude temperature gradient, average ambient temperature T_{Base}, ambient heat T_{Heat}, slope and abundance of precipitation, or local environmental stability Environment Stability factor P_{es}. The last coefficient determines the susceptibility of a given location to factors such as the exhaustion of air masses as a result of different-temperature wind or the average amount of attaining sunlight. To calculate its value for each mesh point P, the Edge Opening factor of each edge connected to it should be added to it, using the following equation (7) for concave forms and equation (8) for convex forms, calculated for both triangles belonging to the said edge.

$$Edge_{\ Opening} = 1 - \mathbf{N}_{T0} \circ \mathbf{N}_{T1} \qquad (7)$$
$$Edge_{\ Opening} = \mathbf{N}_{T0} \circ \mathbf{N}_{T1} - 1 \qquad (8)$$

When performing the next mesh subdivisions, the Environment Stability factor calculation must be repeated for each point and the calculated value added to the existing one. For the new point **P**, value of this coefficient is equal to the values of the coefficients of the edge points on which it was formed. Local temperature can be calculated using equation (9)

$$T_P = T_{Base} - 2500 * P_{height} + \frac{T_{Heat}}{P_{es}} - P_{SnowCover} \quad (9)$$

And the height of the "eternal snow line" or isotherms 0° at a given point in the terrain (equation 10)

$$P_{height\ to\ 0} = \frac{T_{Base} + \frac{T_{Heat}}{P_{es}} - P_{SnowCover}}{2500} \qquad (10)$$

Where

$$P_{SnowCover} = 3{,}8 * P_{Aspect} * P_{SnowMass} \qquad (11)$$

If angle of snow repose of point P is more than 60°, P_{Aspect} represents cosine of angle between slope and horizon, should be equal 0. Thus calculated height to the "0" isotherm allows the rendering of the snow taking into consideration nature of terrain. You can observe, like in real snow accumulates in the hollows and is blowed out from the ridges and steep peaks (figure 11).

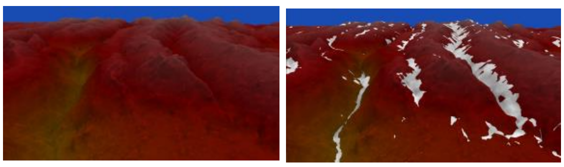

Figure 11. Terrain generated without snow cover (left) and with internal microclimate condition (right).

Glacier flow modeling

Snow cumulated throughout the whole year remains in hollows and high parts of terrain, transforming slowly into ice. Over time, as a result of the pressure of new layers of snow and the slope of the terrain, ice begins to move in the direction of the gravitational drop. However, due to plasticity of ice and the forces of internal friction, its motion is laminar and the direction of motion is correlated with the directions of adjacent glacier tongue. The amount of accumulating and melting glacier can be determined on the basis of glacial mass balance [MA99]. For this purpose, for each triangle, the height $P_{height\ to\ 0}$ (from equation 10) is calculated determining local increase or loss of ice. Thus accumulated mass moves in accordance with direction of the gravitational flow, retaining the laminar character. Local flow direction $\mathbf{N}_{P\ Ice}$ in new point **P** divisive edge can be determined as a sum of $\mathbf{N}_{i\ Ice}$ multiply by $P_{i\ ice\ sum}$ for all vertexes of both triangles connected to the edge and normalized of gravitational flow of both triangles $\mathbf{N}_{TA}, \mathbf{N}_{TB}$. Final result should be normalized to get pure direction vector (equation 12).

$$\mathbf{N}_{P\ Ice} = \left\| \|\mathbf{N}_{TA} + \mathbf{N}_{TB}\| + \sum \mathbf{N}_{i\ Ice} * P_{i\ Ice\ sum} \right\| \quad (12)$$

Flow direction allows to define to what degree the quantity of ice from a given triangle spreads through its edges to neighboring triangles. Simplifying it by a graph, where the vertices are triangles, and the edges determine the direction and degree of outflow, we obtain a directed graph. For each triangle, to the mass of ice that flows from neighboring triangles Ice_{IN} adds the value $P_{height\ to\ 0}$ multiplied by the area of the triangle $T_{surface}$. So, the collected mass of Ice_{sum} is based on the equation (13) we send to the neighbors in the direction and proportion of the flow. Because model analyzed here is not a dynamic simulation, it can be reduced to the problem of determining steady state flow. Using Vertex Sequencing Technique of Depth First Search, we set a full directed graph defining the propagation of the calculated values. This reduces the amount of necessary calculations from o((n+m)*i) to o(n+m) which is equivalent to one simulation iteration. Starting with graph vertexes that show no edges, you can calculate the total ice flow and thereby model the formation of ice sheets and glaciers. Where the triangle glacier coverage and its thickness is proportional to calculated Ice_{Sum}.

$$Ice_{Sum} = Ice_{IN} + T_{surface} * P_{height\ to\ 0} \qquad (13)$$

Glacier erosion

Glacial erosion being the result of the movement of ice masses affects significantly the change of landform, matching the terrain to their own flow, removing all the bumps gradually. The degree of erosion depends primarily on the speed of movement of ice, reaching the highest value in the center of glacier tongue and gradually decreasing towards the edges. This allows to designate the isotachs of the same velocity determining final form of the terrain which as a result of glacier movement takes the characteristic "U" shaped profile [BG09]. Normal bottom valley vectors are dependent on local position of the core center. Creating new points of geometry basing on the edge division, their appropriate location should be taken into consideration so that their normal vectors are perpendicular to the isotachs (figure 12). Using the equations 14,15,16 correction vectors $\mathbf{P}_A$ and $\mathbf{P}_B$ are designated on the basis of point **P** projection on normal $\mathbf{N}_A$ and $\mathbf{N}_B$, and then, on the basis of their averaging, positions of point $\mathbf{P}_{glacier}$ forming the bottom of the glacier valley.

$$\mathbf{P}_A=\mathbf{N}_A * \left((\mathbf{P}-\mathbf{A})\circ \mathbf{N}_A\right) \quad (14)$$
$$\mathbf{P}_B=\mathbf{N}_B * \left((\mathbf{P}-\mathbf{B})\circ \mathbf{N}_B\right) \quad (15)$$

$$\mathbf{P}_{glacier}=\mathbf{P}-\frac{\mathbf{P}_B+\mathbf{P}_A}{2} \quad (16)$$

If point **B** does not have contact with the glacier, the length of its correction vector $\mathbf{P}_B$ should be equal to 0. This equation is designated to calculate the shape of a glacial valley with a flattened bottom where the core speed center is located above the surface of the ice. In the case of a deep valley where erosion is long-lasting, deep-seated and center of core is below ice surface, correction of vectors calculation $\mathbf{P}_A$ as lover vertex (equation 17) and $\mathbf{P}_B$ as upper vertex (equation 18) should be applied, according to the equations.

$$\mathbf{P}_A=\mathbf{N}_A * \left((\mathbf{P}-\mathbf{A})\circ \mathbf{N}_A\right) * (1+(\mathbf{N}_A\circ \mathbf{N}_B)^2) \quad (17)$$
$$\mathbf{P}_B=\mathbf{N}_B * \left((\mathbf{P}-\mathbf{B})\circ \mathbf{N}_B\right) * (1-(\mathbf{N}_A\circ \mathbf{N}_B)^2) \quad (18)$$

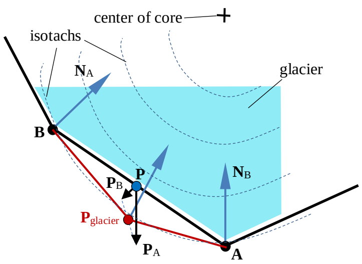

Figure 12. Correction of new point **P** to position $\mathbf{P}_{glacier}$ where the ice velocity and in consequence erosion is possibly low and in equilibrium with other points of valley.

Thanks to the above-presented generation method, it is possible to model terrains exposed to mountain glaciers activities, like ice caps in the last stage of glaciation (Figure 13, 14).

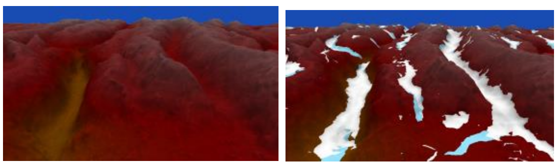

Figure 13. Generated glacier valleys (left), the same valleys with snow cover and glaciers (right)

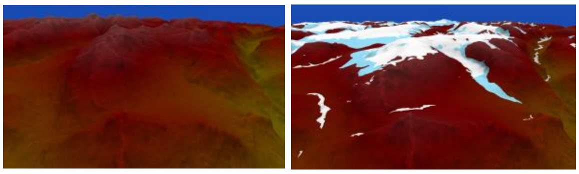

Figure 14. Pure mountain landscape (left), landscape in last stage of glaciation (right)

4. RESULTS

Experiments have been performed on a computer equipped with Intel (Core) i5-3230M 2.6GHz 2 Cores (4 Logical Processors) 4GB RAM. Application used for the study has been written in C++, where the terrain generation and rendering process are performed in two separate threads. Measurements have been executed by modeling all described geophysical processes and also fluvial erosion and water erosion (Figure 15). Used LOD allows to generate planet from user's position, assuming that the visible polygons both closer and more distant will be on the screen of similar size. Below table (1) shows the results of consecutive subsections of the planet of the Earth's size.

Mesh subdivisions	*Poligons*	*Time(s)*	*Min Triangle size (km)*
10	41288	0.75	6.250
12	101102	2.15	1.553
14	156560	3.89	0.391
16	121838	5.87	0.098
18	257122	7.81	0.024
20	301750	10.70	0.006

Table 1. Results of terrain mesh generation for user position taking in the consideration of LOD geometry reduction.

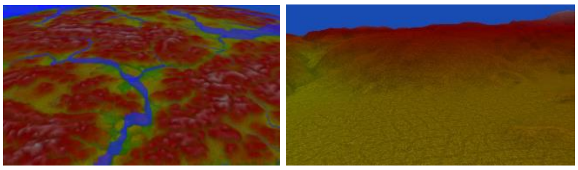

Figure 15. (left) River network with discharge ratio. (right) Eroded slope.

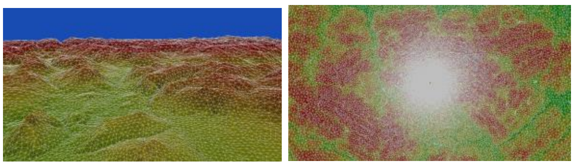

Figure 16. Generated with 14 subdivisions terrain geometry taking into account LOD with the wireframe mode: (left) View from the observer perspective, (in far distant and close details are similar in image scale), terrain geometry view from above (right).

Through application of Triangular Irregular Network it is possible to generate smooth LOD for observer position (Figure 16). Applied rendering techniques from the assumption are similar to the presentation of map reliefs to avoid overfilling the image with visual effects. They make it difficult for recipients to focus on analyzing displayed terrain, hiding semantic defects by shadow generations, water reflections, grasses or atmospheric scattering.

5. CONCLUSIONS

Presented models constitute simplification of real processes, and assumed algorithms are not computationally complex. This is due, among other things, to the fact that the modeled physical processes are still subject to thorough geophysical studies. Physical processes modeled here are among the most important, but they do not exhaust the full spectrum of phenomena affecting the topography. Interaction process of each phenomenon is closely related to other phenomena, both in macro and micro scale. This was achieved by the use of degrees of division on which aggregation of the dependency of modeled processes occurs. Creating a "flow" models type, has allowed to replace classical simulation algorithm by flow graphs creation giving similar results in a much shorter time. The limitation of solution presented in this article is the widespread use of irregular data structures. At this stage, it is difficult to adopt it to regular grid structures dedicated to GPGPU. At this stage the application generates the mesh in a one-threaded way, so the current stage of development is the classical parallelization of presented algorithm.

In recent years, procedural methods have encountered less and less interest apparently because of having reached the limit of their possibilities which is the application of fractals and noises. Trends of research in this domain have started to turn to methods purely simulative or creating landscape features on the basis of patch composition. This work seeks to demonstrate new potential arising from the combination of procedural methods in which randomness is replaced by physical models as a new approach to terrain generation and new research direction.

6. REFERENCES

[MAN83] MANDELBROT B. B.: The fractal geometry of nature. Freeman and Company, New York, 1983.

[FFC82] FOURNIER A., FUSSELL D., CARPENTER L.: Computer rendering of stochastic models. Communications of the ACM 25, 6 (1982).

[PERL85] K. Perlin. An Image Synthesizer. Computer Graphics (SIGGRAPH 85 Proceedings), 19(3): 287-296, 1985

[EMPP98] EBERT D. S., MUSGRAVE F. K., PEACHEY D., PERLIN K., WORLEY S.: Texturing and Modeling: A Procedural Approach, 3rd ed. The Morgan Kaufmann Series in Computer Graphics. Elsevier, 1998.

[KMN88] KELLEY A. D., MALIN M. C., NIELSON G. M.: Terrain simulation using a model of stream erosion. ACM Trans. on Graph. (1988)

[DGGK11] DERZAPF E., GANSTER B., GUTHE M., KLEIN R.: River networks for instant procedural planets. Computer Graphics Forum – CGF 30, 7 (2011)

[MIE12] Mieloszyk K. Generating irregular terrain mesh using tectonics processes. Polish Conference On Computer Games Development 2012 http://wgk2011.eti.pg.gda.pl/article/36/ (Polish)

[BTHB06] BENES B., TˇEŠÍNSK`Y V., HORNYŠ J., BHATIA S. K.: Hydraulic erosion. Comp. Anim. and Virt. Worlds 17, 2 (2006).

[ALEX06] ALEX J.-E.: Creating landscapes with simulated colliding plates. RIT digital media library, (2006).

[VIITA12] VIITANEN L.: Physically Based Terrain Generation: Procedural Heightmap Generation Using Plate Tectonics. Metropolia Ammattikorkeakoulu, 2012.

[JD94] JAROSZEWSKI W., DADLEZ R.: Tectonic. Polish Scientific Publishers PWN (1994).

[MA99] MICKENSON D., ATTIG J.: Glacial Processes Past and Present. The Geology Society of America Inc. (1999).

[BG09] BENNETT M., GLASSER N.: Glacial Geology – Ice Sheets and Landforms. John Wiley & Sons Ltd. (2009).