Animating Wave Motion using Gerstner Waves

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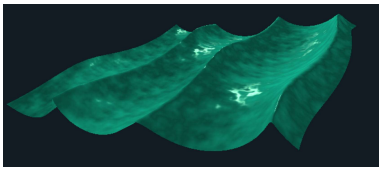

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How Do Waves Work?

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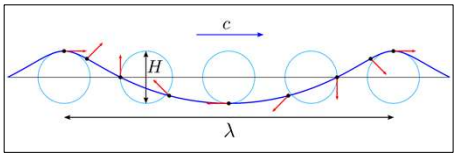
First of all, the water in waves doesn't "flow". It moves in a circular pattern. The equation for this is called a Trochoidal wave, or a Gerstner wave, named after mathematician Franz Josef Gerstner who discovered this in 1802.

Click on the Wikipedia link below for more information. It's an interesting read.



https://en.wikipedia.org/wiki/Trochoidal_wave

If you scroll down in the Wikipedia article, you will see a section called **In Computer Graphics**. I adapted the following equations and code from that section. I am assuming deep water so that the hyperbolic tangent term drops out. Feel free to put it back. I also changed the wave density components to an angular direction (γ) instead.

Gerstner Wave Equations

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Horizontal Motion → $x' = x - \sum_{m=0}^{M-1} A_m cos\gamma_m sin\theta_m$

Vertical Motion → $y' = \sum_{m=0}^{M-1} A_m cos\theta_m$

Horizontal Motion → $z' = z - \sum_{m=0}^{M-1} A_m sin\gamma_m sin\theta_m$

(x, y, z) = original vertex coordinates

(x', y', z') = displaced vertex coordinates

$\theta_m = k_m cos\gamma_m x + k_m sin\gamma_m y - \omega_m t - \emptyset_m$

$A_m = Amplitude$ $\omega_m = \sqrt{g k_m}$

$\gamma_m = Wave\ propagation\ angle$ $t = time$

$k_m = Wave\ density$ $\emptyset_m = Wave\ phase\ shift$

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gerstner.glib

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```
##OpenGL GLIB
Perspective 70
LookAt 0 0 7  0 0 0  0 1 0
Timer 60

Vertex   gerstner.vert
Fragment gerstner.frag
Program  Gerstner                       \
                uTimeScale <1. 2. 100.>         \
\
                uAm0 <0. .2 1.>                 \
                uKm0 <0.1 1. 5.>                \
                uGamma0 <-1.57080 0. 1.57080>   \
\
                uAm1 <0. 0. 1.>                 \
                uKm1 <0.1 2. 5.>                \
                uPhiM1 <0. 0. 6.28>             \
                uGamma1 <-1.57080 0. 1.57080>   \
\
                uLightX <-20. 0. 20.>           \
                uLightY <1. 10. 20.>            \
                uLightZ <-20. -20. 20.>         \
                uKa <0. .1 1.>                  \
                uKd <0. .6 1.>                  \
                uKs <0. .3 1.>                  \
                uShininess < 1. 2. 200.>        \
                uColor {.1 1. .8 1.}            \
                uNoiseAmp <0. 0. 1.>            \
                uNoiseFreq <.1 .1 2.>           \
\
QuadXZ  -0.2  3.  300  300
```

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gerstner.vert, I

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```
#version 330 compatibility

uniform float   uTimeScale;
//uniform float   uG;
//uniform float   uH;

uniform float   uAm0;
uniform float   uKm0;
uniform float   uGamma0;

uniform float   uAm1;
uniform float   uKm1;
uniform float   uPhiM1;
uniform float   uGamma1;

uniform float   Timer;

uniform float   uLightX, uLightY, uLightZ;
vec3 eyeLightPosition = vec3(  uLightX,  uLightY,  uLightZ );

out vec3                vNC;
out vec3                vEs;
out vec3                vLs;
out vec3                vNs;

const float PI = 3.14159265;
const float G = 1.;

void
main( )
{
                float newx = gl_Vertex.x;
                float newy = 0.;
                float newz = gl_Vertex.z;

                float dxda = 1.;
                float dyda = 0.;
                float dzda = 0.;

                float dxdb = 0.;
                float dydb = 0.;
                float dzdb = 1.;
```

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gerstner.vert, II

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```
// m = 0
{
                float phiM0 = 0.;  // m=0 is the phase baseline
                float wm0 = sqrt( G*uKm0 );
                float thetam = gl_Vertex.x*uKm0*cos(uGamma0)+ gl_Vertex.z*uKm0*sin(uGamma0)  - wm0*Timer*uTimeScale  - phiM0;
                newx -= uAm0*cos(uGamma0)*sin(thetam);
                newy += uAm0 * cos(thetam);
                newz -= uAm0*sin(uGamma0)*sin(thetam);

                float dthetamda = uKm0*cos(uGamma0);
                float dthetamdb = uKm0*sin(uGamma0);
                dxda -= uAm0*cos(uGamma0)*cos(thetam)*dthetamda;
                dyda -= uAm0*sin(thetam)*dthetamda;
                dzda -= uAm0*sin(uGamma0)*cos(thetam)*dthetamda;
                dxdb -= uAm0*cos(uGamma0)*cos(thetam)*dthetamdb;
                dydb -= uAm0*sin(thetam)*dthetamdb;
                dzdb -= uAm0*sin(uGamma0)*cos(thetam)*dthetamdb;
}

// m = 1
{
                float wm1 = sqrt( G*uKm1 );
                float thetam = gl_Vertex.x*uKm1*cos(uGamma1)+ gl_Vertex.z*uKm1*sin(uGamma1)  - wm1*Timer*uTimeScale  - uPhiM1;
                newx -= uAm1*cos(uGamma1)*sin(thetam);
                newy += uAm1 * cos(thetam);
                newz -= uAm1*sin(uGamma1)*sin(thetam);

                float dthetamda = uKm1*cos(uGamma1);
                float dthetamdb = uKm1*sin(uGamma1);
                dxda -= uAm1*cos(uGamma1)*cos(thetam)*dthetamda;
                dyda -= uAm1*sin(thetam)*dthetamda;
                dzda -= uAm1*sin(uGamma1)*cos(thetam)*dthetamda;
                dxdb -= uAm1*cos(uGamma1)*cos(thetam)*dthetamdb;
                dydb -= uAm1*sin(thetam)*dthetamdb;
                dzdb -= uAm1*sin(uGamma1)*cos(thetam)*dthetamdb;
}
```

University Computer Graphics

gerstner.vert, III


```
vec3 newVertex = vec3( newx, newy, newz );
vMC = newVertex;

vec3 ta = vec3( dxda, dyda, dzda );
vec3 tb = vec3( dxdb, dydb, dzdb );
vNs = normalize( gl_NormalMatrix*cross( tb, ta ) );
                                                    // surface normal vector

vec4 ECposition = gl_ModelViewMatrix * vec4( newVertex, 1. );
vLs = normalize( eyeLightPosition - ECposition.xyz );          // vector from the point
                                                               // to the light position
vEs = normalize( vec3( 0., 0., 0. ) - ECposition.xyz );        // vector from the point
                                                               // to the eye position

gl_Position = gl_ModelViewProjectionMatrix * vec4( newVertex, 1.);
}
```

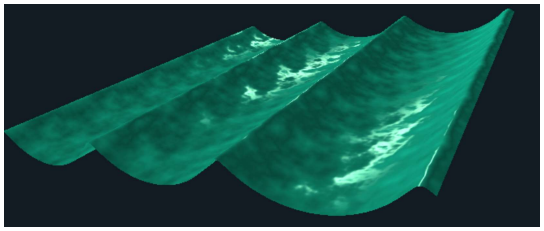

gerstner.frag, I


```
#version 330 compatibility

in vec3                 vMC;
in vec3                 vNs;
in vec3                 vLs;
in vec3                 vEs;

uniform float           uKa, uKd, uKs;
uniform vec4            uColor;
uniform float           uShininess;
uniform sampler3D       Noise3;
uniform float           uNoiseAmp;
uniform float           uNoiseFreq;

const vec4 WHITE = ( 1., 1., .8, 1. );

vec3
RotateNormal( float angx, float angy, vec3 n )
{
        float cx = cos( angx );
        float sx = sin( angx );
        float cy = cos( angy );
        float sy = sin( angy );

        // rotate about x:
        float yp =  n.y*cx - n.z*sx;        // y'
        n.z      =  n.y*sx + n.z*cx;        // z'
        n.y      =  yp;
        // n.x   =  n.x;

        // rotate about y:
        float xp =  n.x*cy + n.z*sy;        // x'
        n.z      = -n.x*sy + n.z*cy;        // z'
        n.x      =  xp;
        // n.y   =  n.y;

        return normalize( n );
}
```


gerstner.frag, II

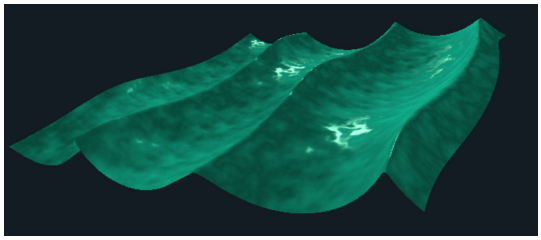

```
void
main( )
{
        vec4 nvx = texture3D( Noise3, uNoiseFreq*vMC );
        vec4 nvy = texture3D( Noise3, uNoiseFreq*vec3(vMC.xy,vMC.z+0.5) );

        float angx = nvx.r + nvx.g + nvx.b + nvx.a;        //  1. -> 3.
        angx = angx - 2.;
        // -1. -> 1.
        angx *= uNoiseAmp;

        float angy = nvy.r + nvy.g + nvy.b + nvy.a;        //  1. -> 3.
        angy = angy - 2.;
        // -1. -> 1.
        angy *= uNoiseAmp;

        vec3 normal = normalize( vNs );
        vec3 light  = normalize( vLs );
        vec3 eye    = normalize( vEs );

        normal = RotateNormal( angx, angy, normal );

        vec4 ambient = uKa * uColor;

        float d = max( dot(normal,light), 0. );
        d = abs( dot(normal,light));
        vec4 diffuse = uKd * d * uColor;

        float s = 0.;
        if( dot(normal,light) > 0. )                       // only do specular if the light can see the point
        {
                vec3 ref = normalize( 2. * normal * dot(normal,light) - light );
                s = pow( max( dot(eye,ref),0. ), uShininess );
        }
        vec4 specular = uKs * s * WHITE;
        gl_FragColor = vec4( ambient.rgb + diffuse.rgb + specular.rgb, 1. );
}
```


Example



m = 0

Example



m = 0, 1