Ocean waves rendering in real-time

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January 23, 2003 Paris FRANCE

Maritime training simulation

- Tool objectives
  - Pedagogical tool for initial learning in nautical domain (maritime secondary schools)
  - Training simulator
  - Certified by the French Department of Sea, in accordance with the International Maritime Organization norm (STCW norm)

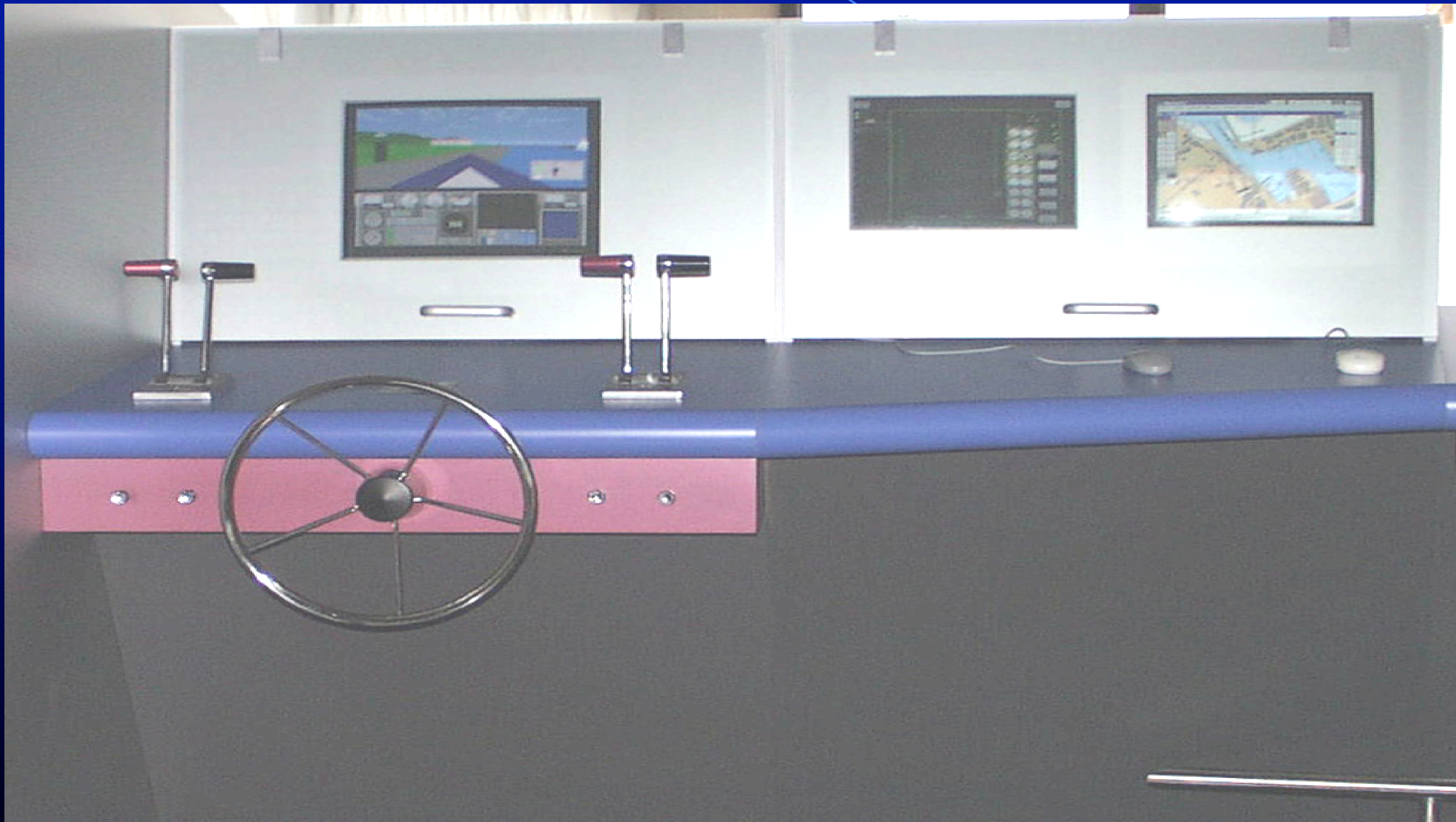
- Real-time tool improvements
  - Take into a better consideration the ship environment (coast, sea depth, current, wind, waves)
  - Improve the ship behavior due to the ship environment

Talk plan

- What is our training simulator ?
- Wave generation and propagation : swell and wind sea models
- Wave shape in real-time
- Wave course in real-time

A tool for initial learning

The trainee post



Wave generation and propagation : swell and wind sea models

- Use the linear formula of the Navier-Stokes equations (water particle speed derive from a potential)
  - A unique wave : Fournier & Reeves [FR86], Gonzato [Gon97]
  - Several waves : Mastin [Mas87], Tessendorf [Tes00]
- Resolve the general equations of mechanical fluids (The Navier-Stokes equations)
  - Foster & Metaxas [Fos96] [Fos97], Layton [Lay01]

The wave shape and the wave course

- Split the physic phenomenon into two parts
  - A cut view to define the waves shape (parametric equations to study the wave shape)
    - A unique wave : Fournier & Reeves [FR86], Gonzato [Gon97]
    - Several waves : Mastin [Mas87], Tessendorf [Tes99]
  - A bird's eyes view to model the waves course starting from the wind, the current and the sea bed (wave tracing algorithm to study the wave propagation and the refraction phenomenon)
    - A unique wave : Ts 'o & Barsky [TB87], Gonzato [Gon99]
    - Several waves : No theory today
- Two main parameters in real-time : ship position and time.

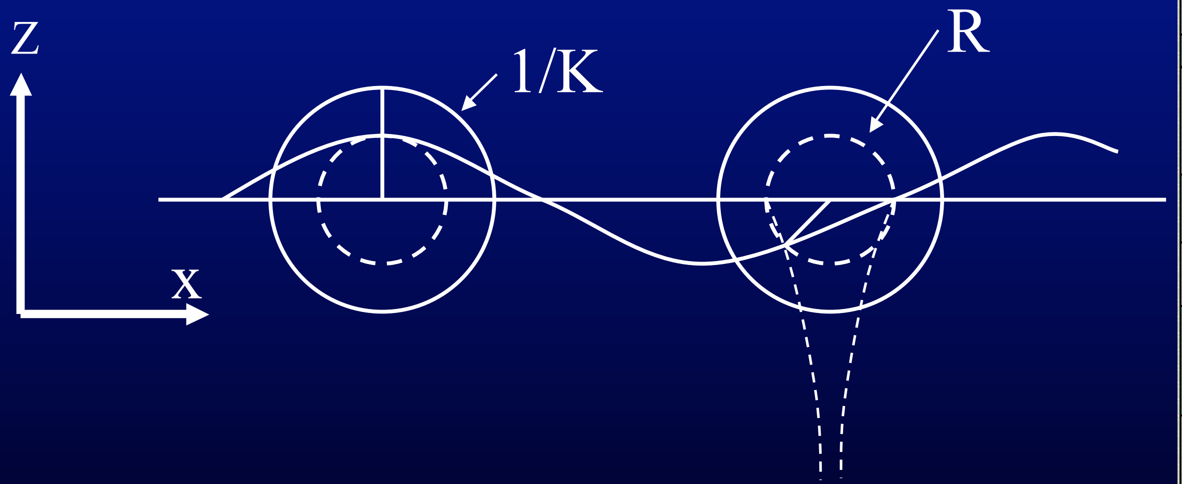
Wave generation and propagation process

Swell in open sea (a single sinusoid)

- Our model : the Gerstner's theory

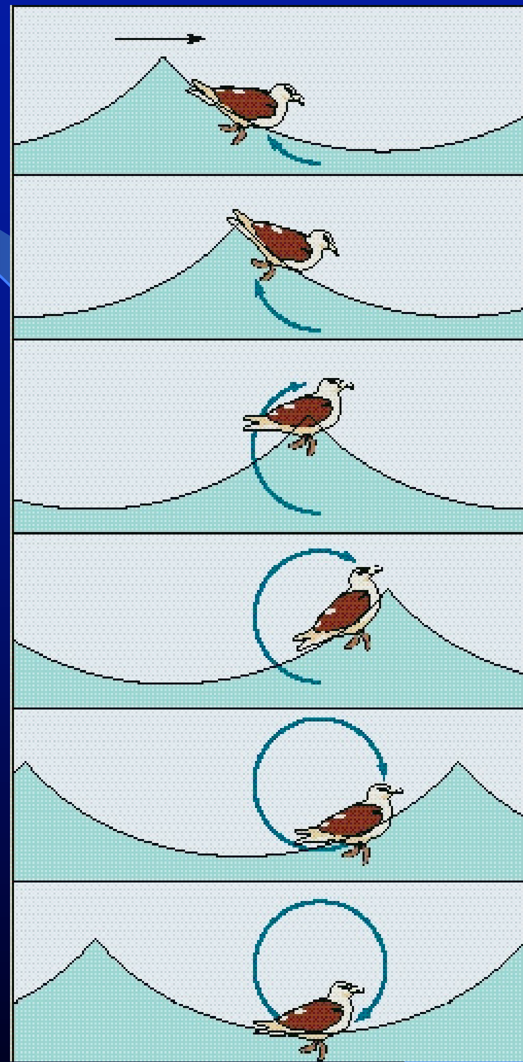
$$\begin{cases} x = D(x_0, t, U_{x_0}) = x_0 + R\sin(\varphi) \\ z = H(x_0, t, U_{x_0}) = z_0 - R\cos(\varphi) \end{cases}$$

$$\varphi = \omega t + \int_0^{x_0} K(U_x)\,dx$$



The sea shape is a trochoid

depth



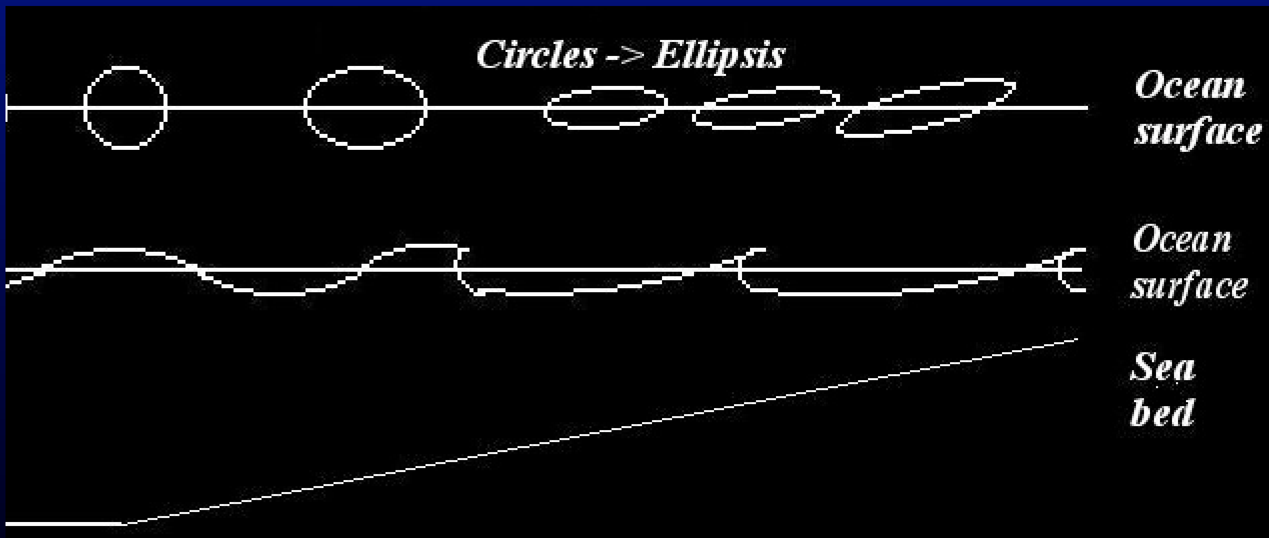
Swell near the shore (a single sinusoid)

- Biesel's theory : an improvement of Fournier-Reeves's model put forward by Gonzato [GL97], Tidal current effect was added

$$x = D\left(x_0, t, U_{x_0}, h_{x_0}\right) = x_0 + R\square'_{\square} S_x \sin\left(\square\right) + R\square_{\square} S_z \cos\left(\square\right)$$

$$z = H\left(x_0, t, U_{x_0}, h_{x_0}\right) = z_0 \square R\square'_{\square} S_z \cos\left(\square\right) + R\square_{\square} S_x \sin\left(\square\right)$$

$$\square = \square\square t + \int_0^{x_0} K\left(U_x, h_x\right) \square x$$



Wind sea in open sea (a sum of sinusoids)

$$H(x,t) = \sum_{K} \tilde{h}(K,t)\exp(iK.x)$$ IFFT z axis

$$D(x,t) = \sum_{K} -i\frac{K}{k}\tilde{h}(K,t)\exp(iK.x)$$ IFFT x axis

$$\tilde{h}(K,t) = \tilde{h}_0(K)\exp(iw(K)t) + \tilde{h}_0^{*}(-K)\exp(-iw(K)t)$$

$$\tilde{h}_0(k) = \frac{1}{\sqrt{2}}(\xi_r + i\xi_i)\sqrt{P_h(k)}$$ Circle equation

$$P_h(K) = A\frac{\exp\left(-1/(KL)^2\right)}{K^4}\left|\hat{K}\cdot\hat{W}\right|^2$$ Phillips spectra

STATISTICAL APPROACH constant anytime, anywhere

Our wind sea model

- Improvement of Tessendorf 's model

$$\tilde{h}(K,t)=\tilde{h}_0^{*}(K)\exp(-i\omega(K)t)+\tilde{h}_0(-K)\exp(i\omega(K)t)$$

$$\tilde{h}_0(k)=\sqrt{\frac{Ph(k)}{4}}$$ Circle equation

$$\tilde{h}_0(k)=\sqrt{S_z\frac{Ph(k)}{4}+iS_x\frac{Ph(k)}{4}}$$ Ellipsis equation

$$S_x=\frac{1}{e^{-K_x\left|U\frac{K}{k}\right|}},S_z=S_xe^{-K_z\left|U\frac{K}{k}\right|},\cos(\theta)<0$$ Opposite tidal current

$$P_h(K)=A\ln(1+W)\left|\hat{K}\cdot\hat{W}\right|^2$$ Capillary wave spectra

PHYSICAL APPROACH depending on the ship environment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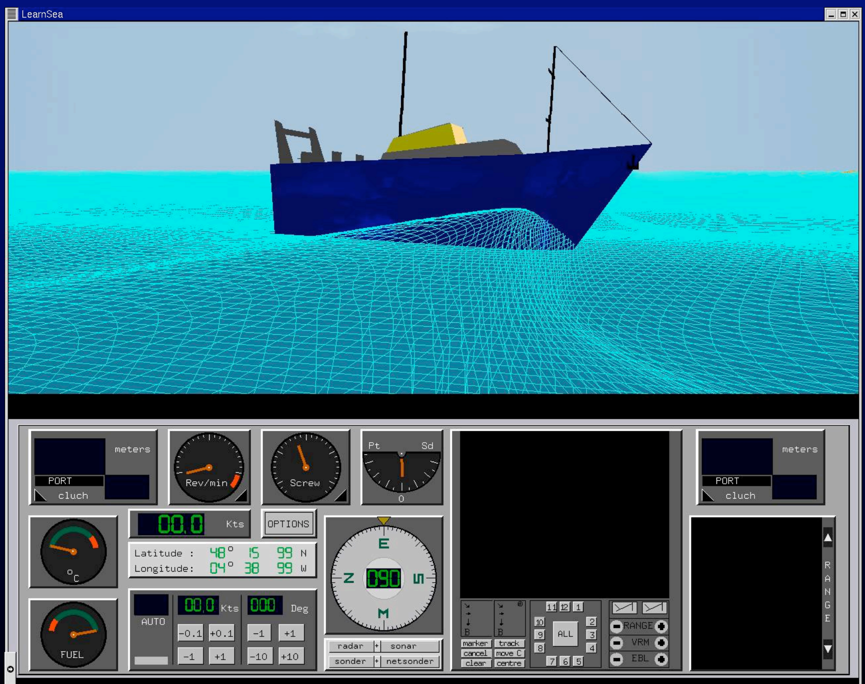
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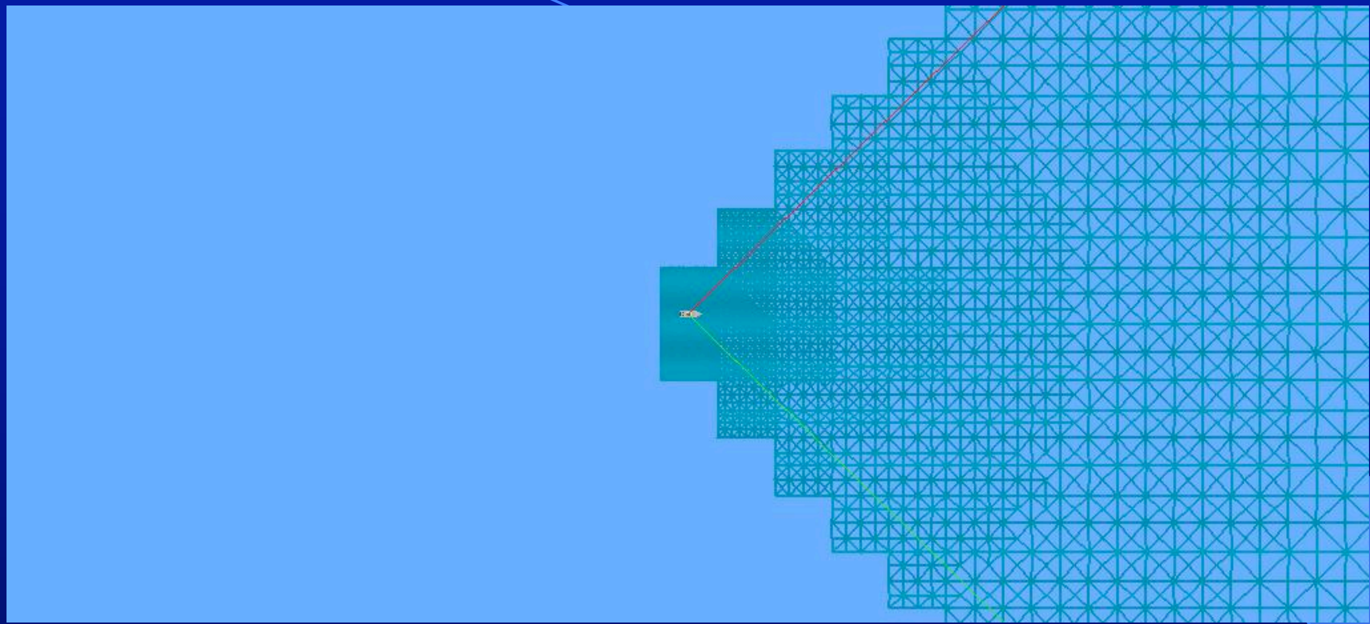
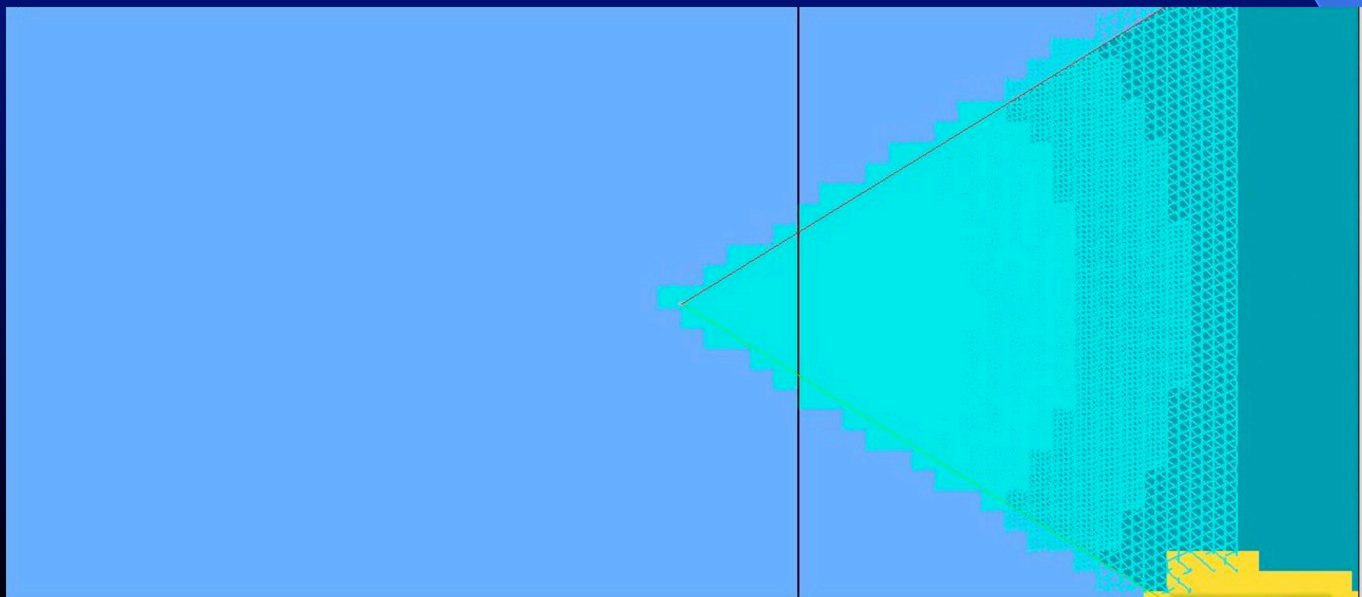
Wave shape in real-time :

1.125 10^{13} triangles per frame

The third level data structure



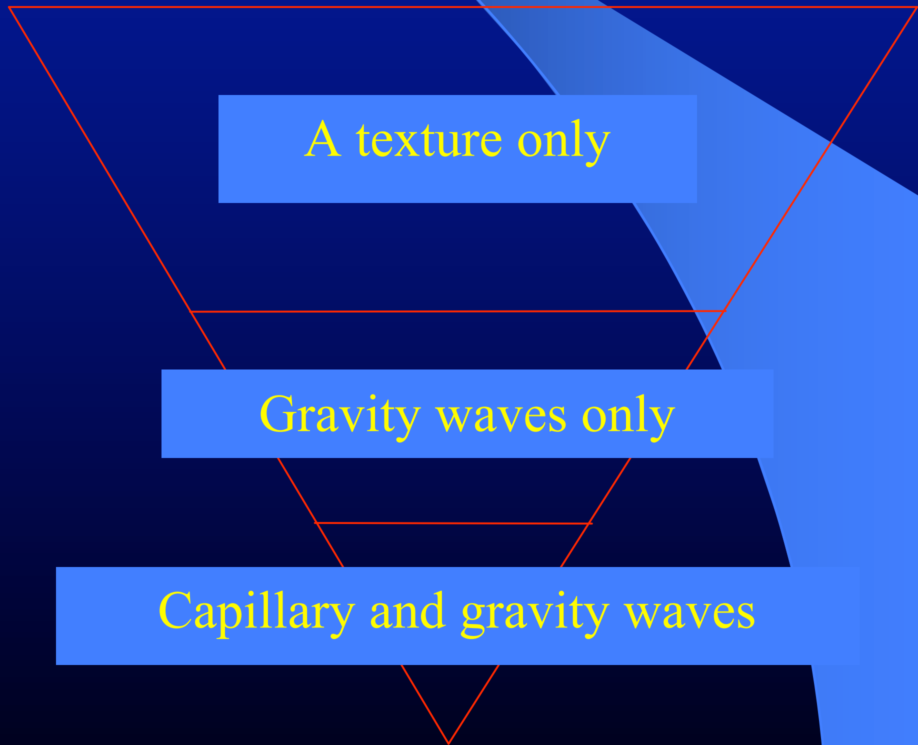


View frustum culling
Surface progressive culling inside the frustum

$$\frac{1}{N}\sum_{i=0,i=i+2}^{N-1}\frac{\left|H(x_{i+1},t)-\left(H(x_{i+2},t)+H(x_i,t)\right)/2\right|}{d_{x_{i+1}-camera}/d_{projectionplan-camera}}<threshold$$

Approximation of the delta segment projection

$$\frac{H_{wave}}{d_{wave-camera}/d_{projectionplan-camera}}$$



Real-time optimizations

Using the rfftw library instead of the fftw library divides by two the number of computations

Grids are not closed in real-time thanks to a plan placed under the sea

Normals sum rather than the slope vector computation

$$K_r = \frac{1}{\left(1+\cos(\theta_i)\right)^8}, K_t = 1 - K_r$$

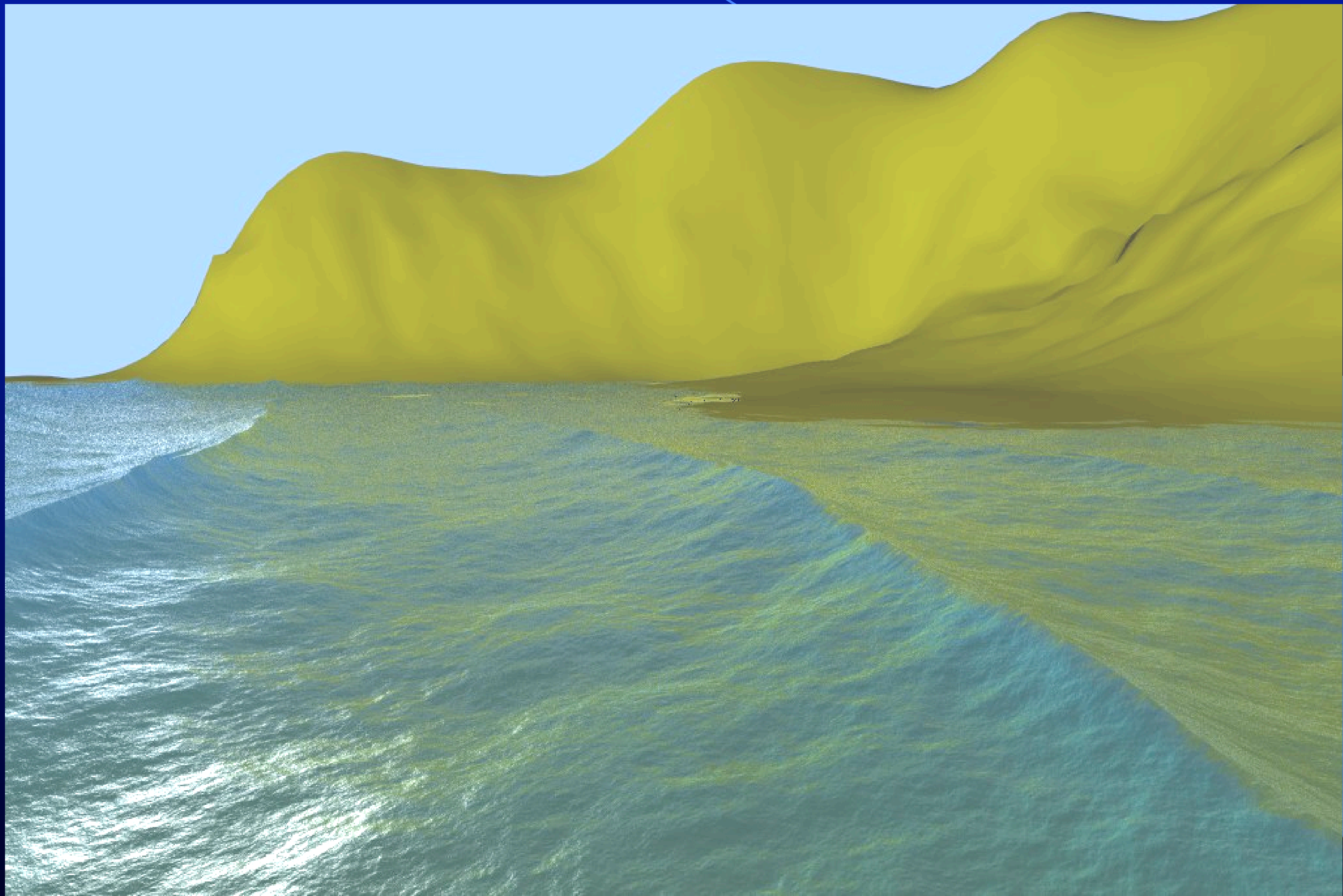
Fresnel coefficients approximation

Nishita colour water formula approximation

Results

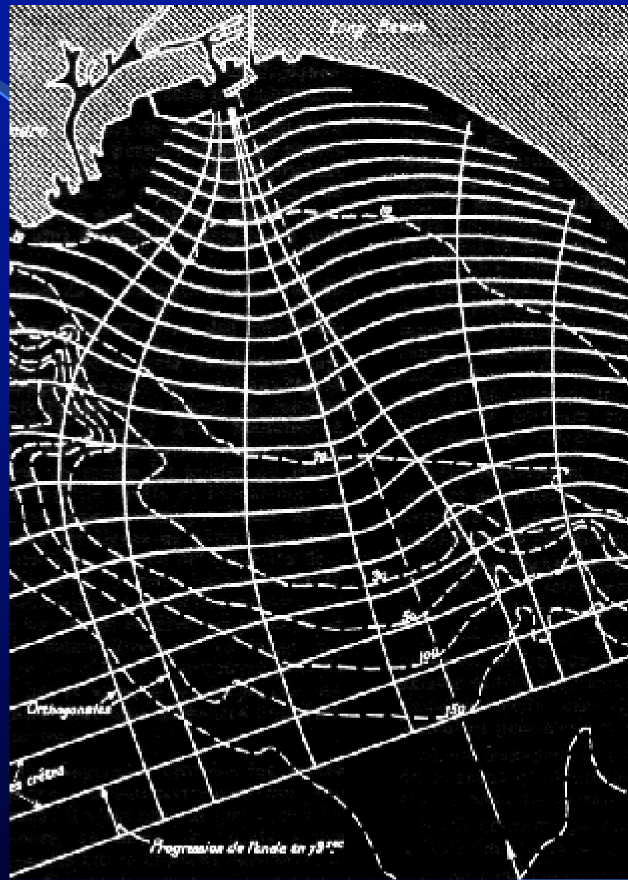
- Waves shape varies with the ship environment (wind, tidal current, depth)
- Patch length 128 m (greatest wavelength : 256 m)
- 1 point each 0.5 m around the ship
- 10 fps
- Future maritime school hardware configuration : a Pentium 4 high frequency and a Nvidia Geforce FX

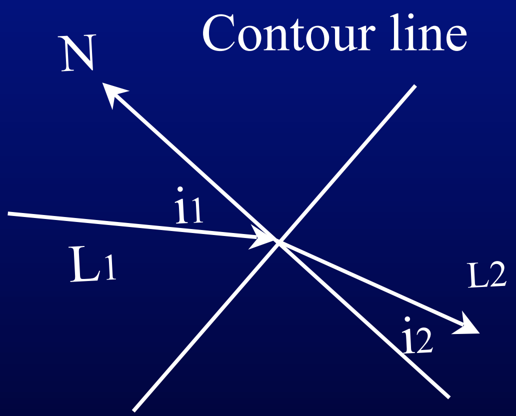
Waves course in real-time ?



Previous works on refraction

- Waves refraction
  - Physic : use of waves map with scale change if necessary
  - Computer graphics : based on Snell law (current and sea bed)

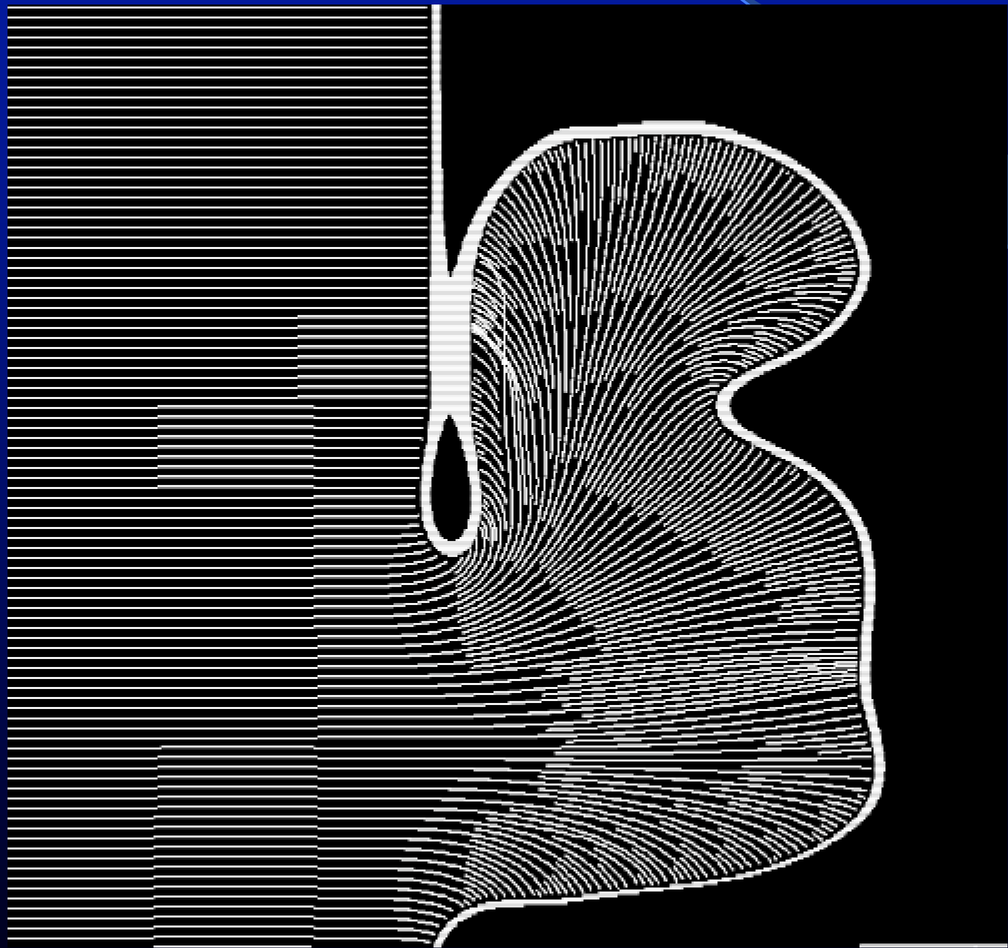




$$\frac{\sin(i_1)}{L_1} = \frac{\sin(i_2)}{L_2}$$

Refraction

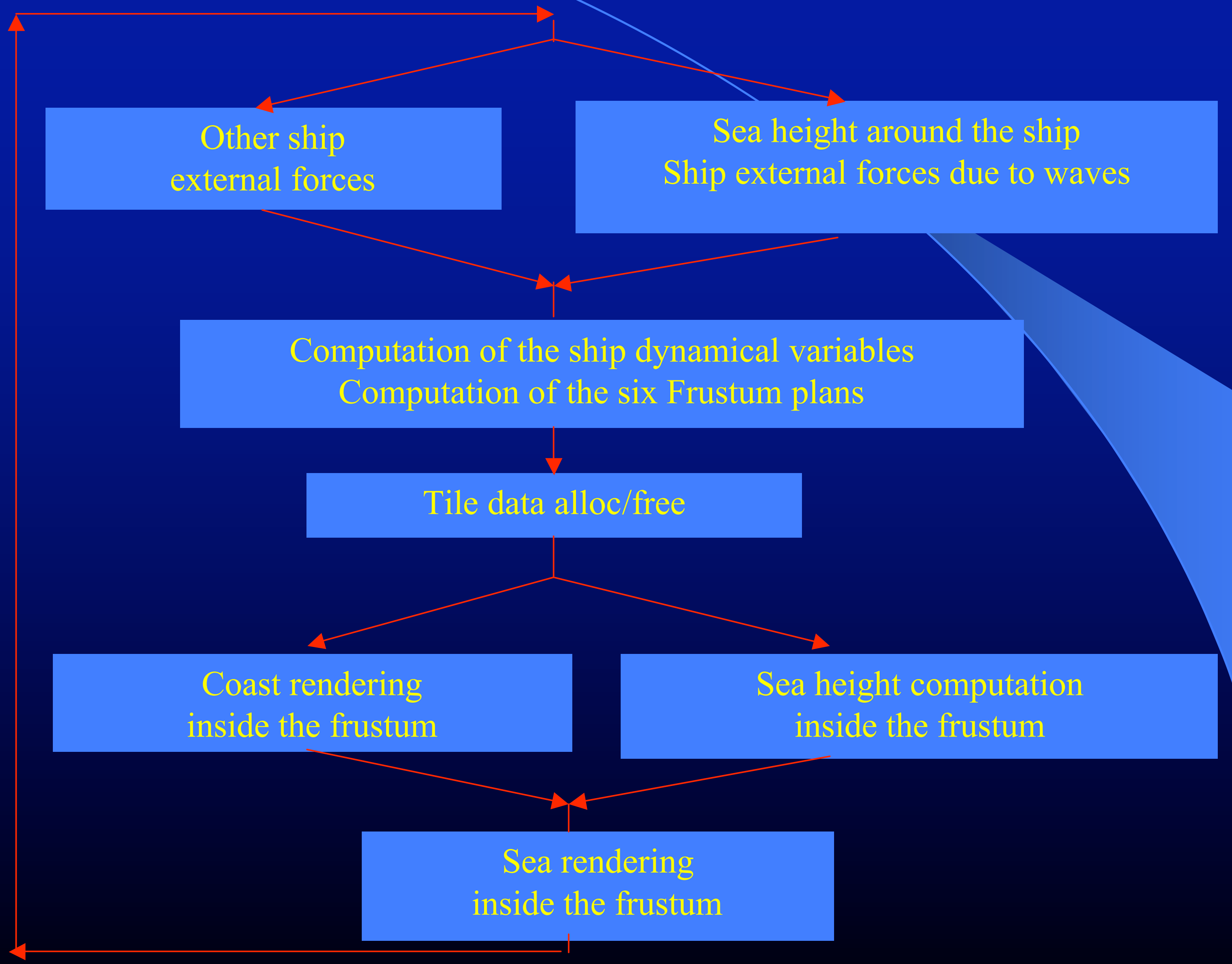
- Improvement of Ts 'o & Barsky algorithm



Pre-computed results of the wave tracing algorithm for each wave

- (x_0,y_0,z_0) the original position of the water particle
- K_x,K_z the horizontal direction of the wave propagation
- The wave height
- The non temporal phase (wavelength variations)
- A,A',B,B' the four coefficients of the ellipse when sea height is very low or due to the tidal current

Multi-thread programming



Objectives

- Wave tracing algorithm
- FFT for the capillary waves
- Usual sum for the gravity waves
- Multi-process
- Vertex shader programmation
- Real-time performance requires to limit the total number of waves to be studied
- Regarding the SGDL technology ?

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