ShadeMotion
Simulation of shade patterns of trees on a plot

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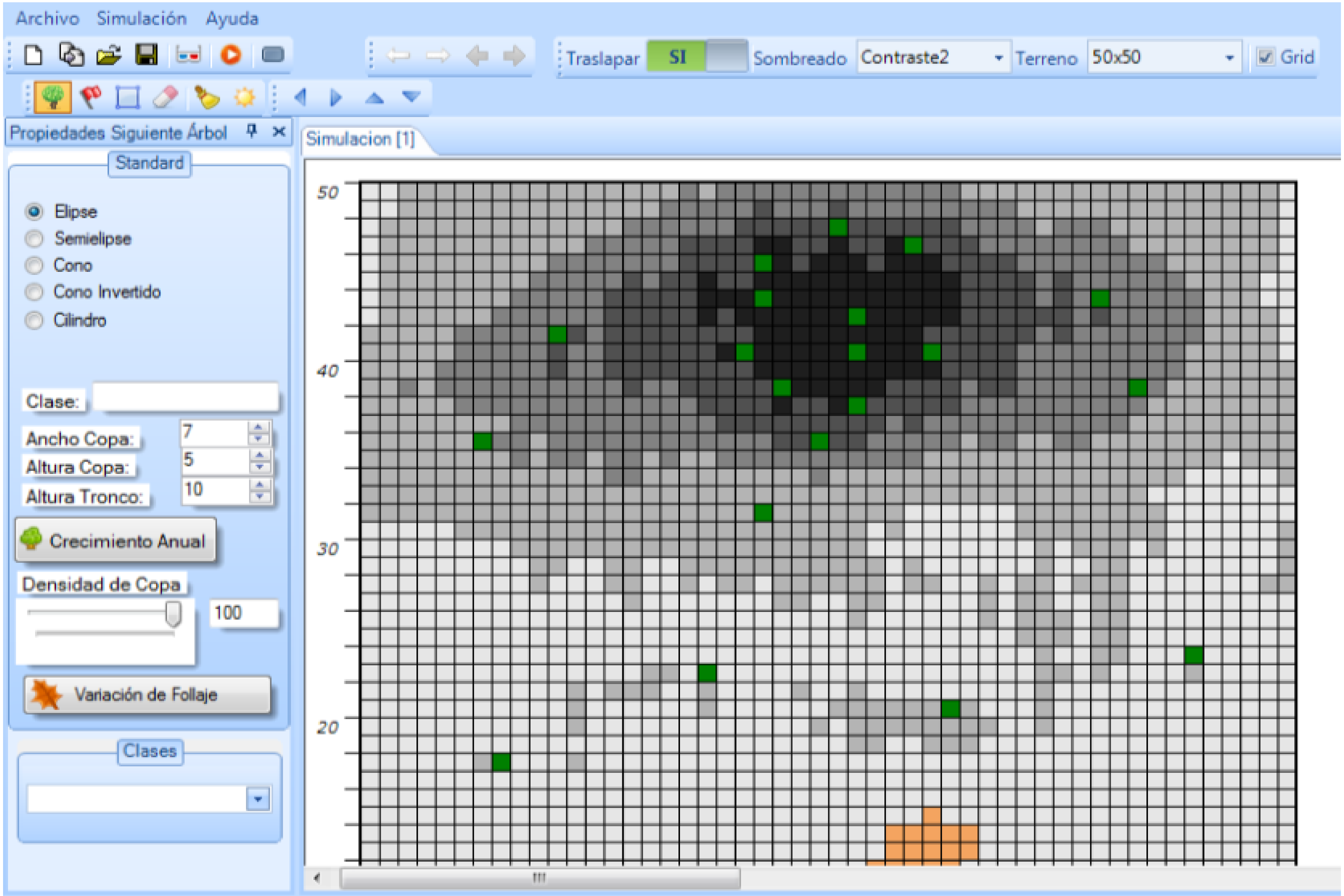
Scope

- Very detailed radiation transmission models have been developed by other researchers
- We wanted to develop a simple, visual, exploratory model that could be used to quickly explore different planting patterns of trees on a plot and their effects on shading pattern
- User can then adjust the planting pattern of trees (e.g. thinning or planting) to achieve a specific shade pattern and shading level

An example


Archivo
Simulación
Ayuda
Traslapar
SI
Sombreado
Contraste2
Terreno
50x50
Grid
Propiedades Siguiente Árbol
Simulacion [1]
Standard
Elipse
Semielipse
Cono
Cono Invertido
Cilindro
Clase:
Ancho Copa:
7
Altura Copa:
5
Altura Tronco:
10
Crecimiento Anual
Densidad de Copa
100
Variación de Follaje
Clases
50
40
30
20

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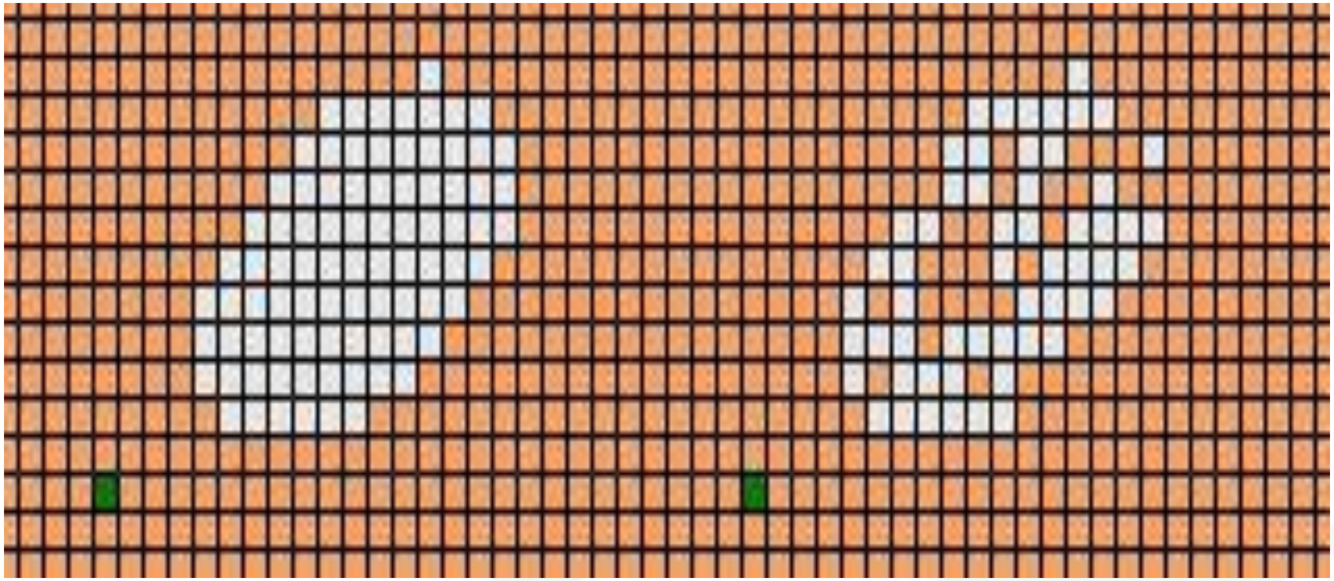
Features #1

- Any number of tree species
- -Tree crown shapes
  - Sphere, hemi-sphere, conic, elipsoid, hemi-elipsoid (version 3)
  - Ellipsoidal (includes spherical), Semi-ellipsoidal (includes semi-spherical), Conic, Inverted cone, Cilinder (version 4)
- Crown density
  - Opaque to fully open (0-1)
- Monthly leaf fall pattern



Crown density: 100% and 60%, respectively

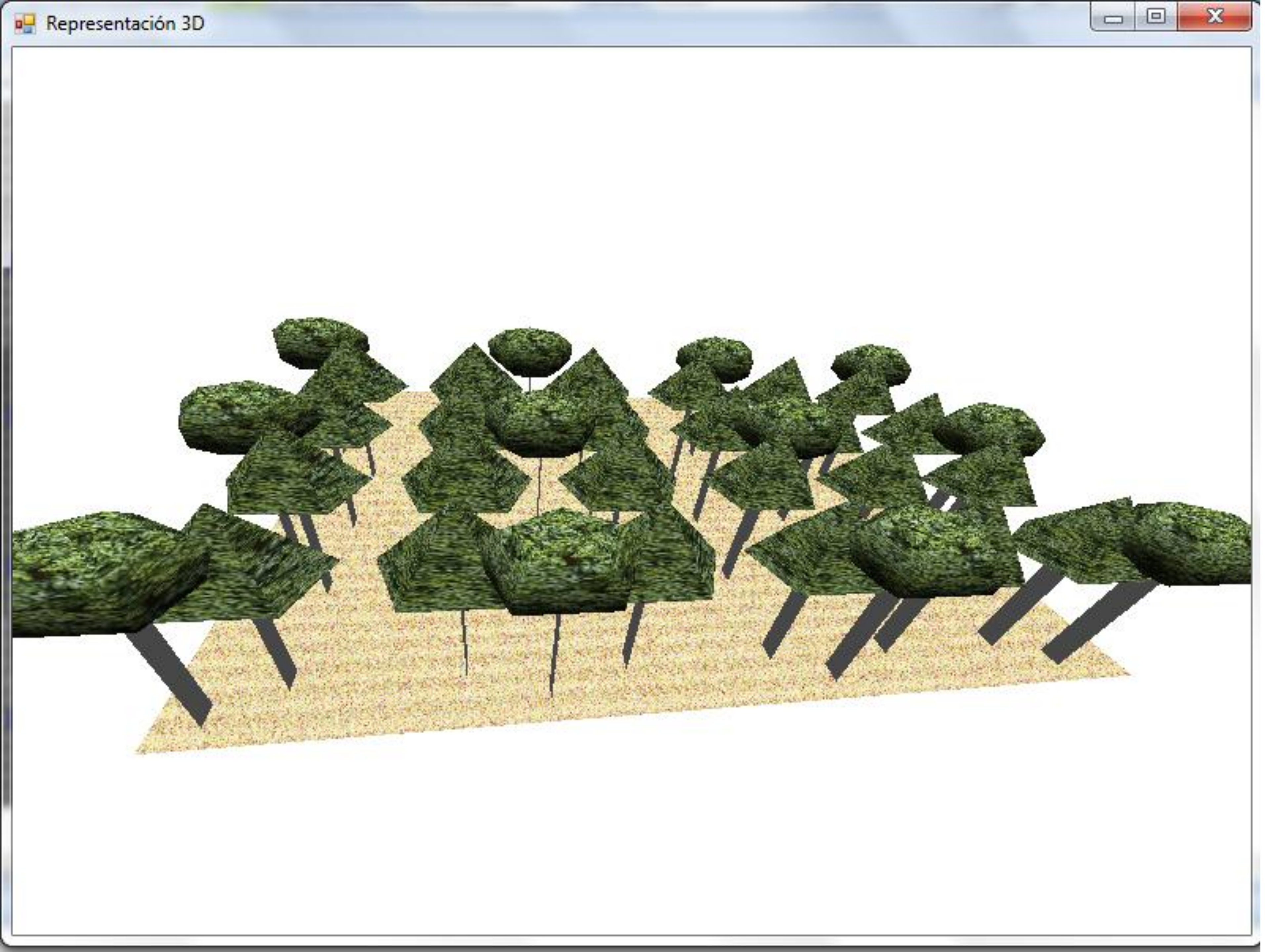
Monthly leaf fall pattern

Features #2

- Spanish and English interfaces
- Any latitude on Earth
- Horizontal and tilted planes
  - No plot size limit if using GPS positioning
  - > 9 ha if using Cartesian coordinate system
- Any number of trees in any spatial planting arrangement
- Range of simulation
  - Various years (tree growth and changes in population numbers) in Version 4.0
  - Fraction of one year (e.g. from 15/2 to 24/9)
  - Range of hours within day (e.g. from 8:30 to 17:00)
  - Variable time intervals between hours (e.g. steps 15, 23 or 60 minutes)

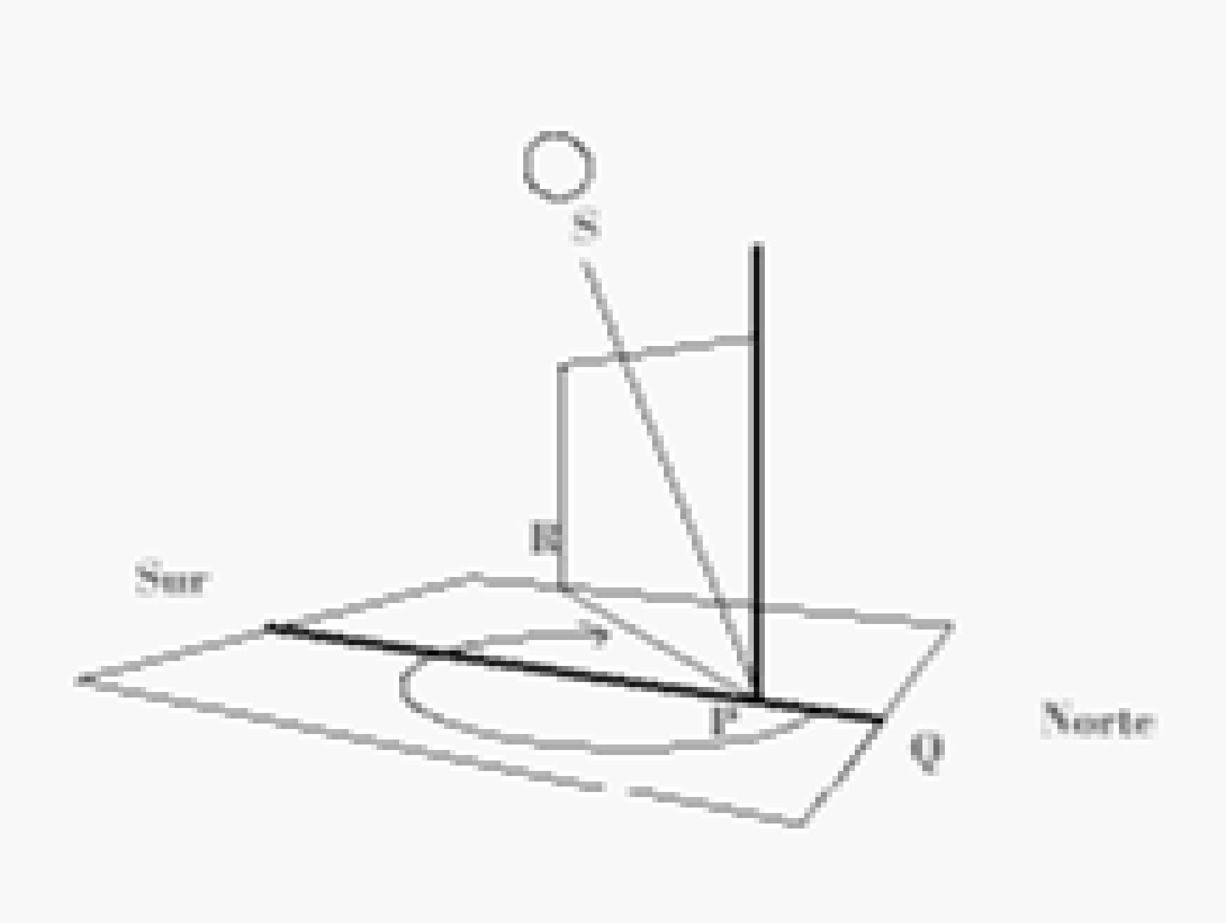
Features #3

- Various options for data entry and storing outputs
  - Mouse/screen
  - GPS, cartesian coordinates
  - Excell, others
- 3-D visualization of trees in plot
- Shading recorded
  - With or without shade overlap
- Shade evaluated at variable heights
  - ground level or above crop canopy


Representación 3D

The position of the sun in the sky

- Three key parameters
  - Latitude on Earth
  - date of the year
  - hour of the day
- Two angles are determined by these parameters
  - Elevation
  - Azimuth
- For a tilted plot two additional angles are required
  - Plot's inclination angle (slope's angle)
  - The "azimuth" of maximum slope of the plot



Elevation: angle SPR

Azimuth: angle QPR (in this figure this angle is greater than 180º)

The Sun's position is computed according to the following equations

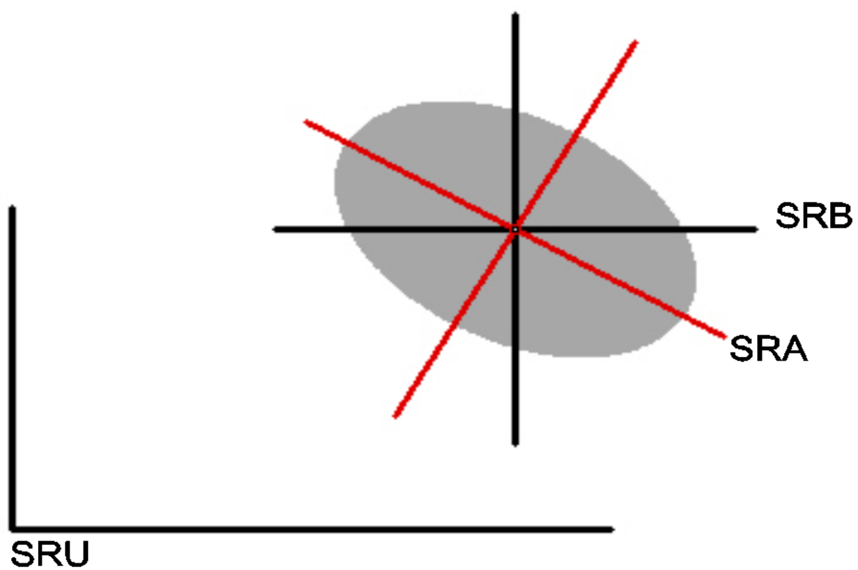
$$hor = 15\,(hora - 12)$$

$$decl = 23.45\,sen((360/365)\,(d + 284))$$

$$elev = sen^{-1}[cos(lat)\,cos(decl)\,cos(hor) + sen(lat)\,sen(decl)]$$

$$azim = cos^{-1}\left[\frac{cos(lat)\,sen(decl) - sen(lat)\,cos(decl)\,cos(hor)}{cos(elev)}\right]$$

Three coordinate systems (SRA, SRB and SRU) needed for analysis



Analytic expression of the shade, rotations and translations

- Three steps to develop the analytical expression of the shade projected by a tree on the ground
  - First calculate anaytic expression of the shade with a coordinate axis centered in the shade (SRA)
  - Second, we rotate SRA to align it with SRU. We call this SRB
  - Third, we traslate the origin of SRB to SRU

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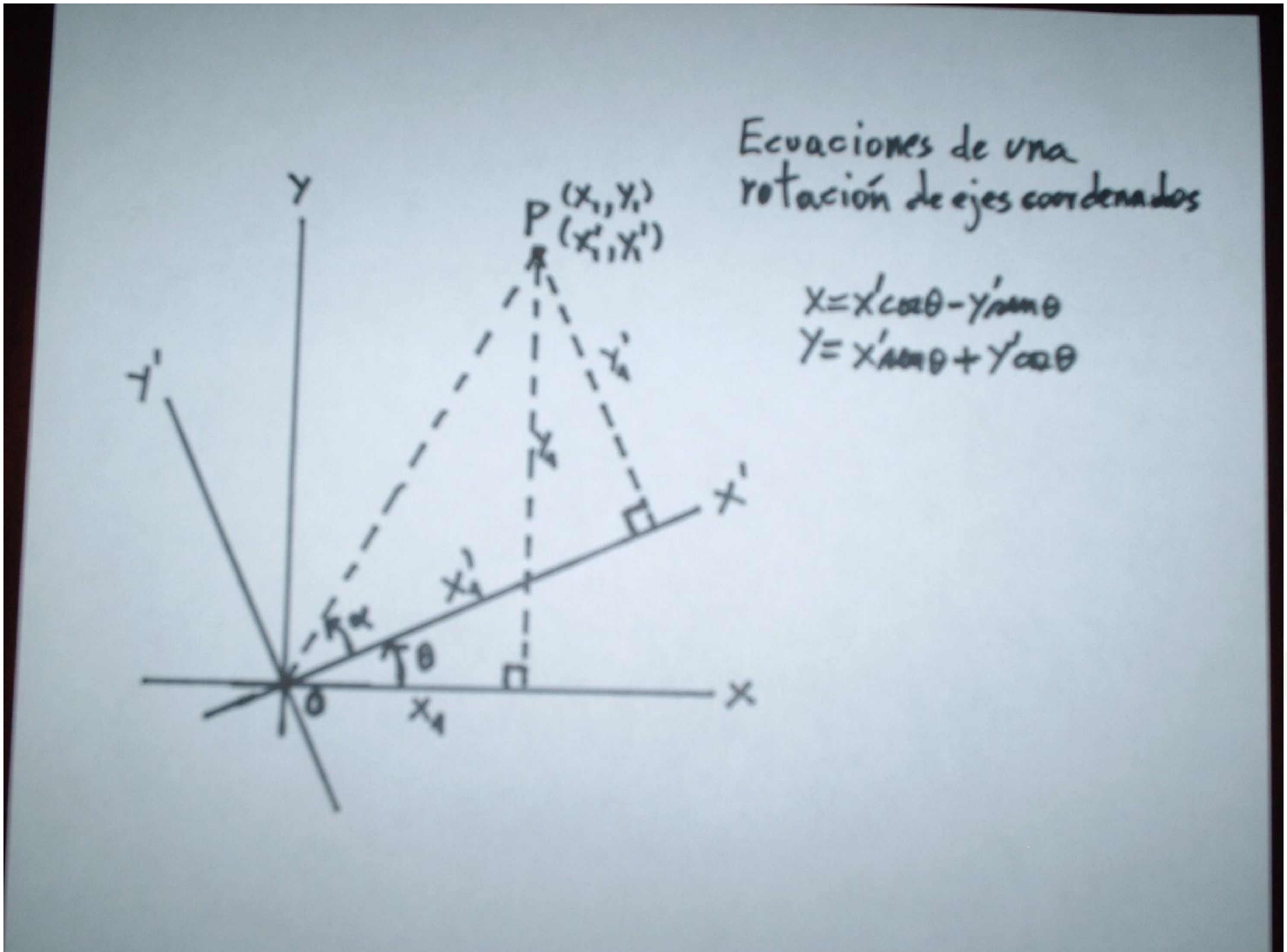
Rotation of axes

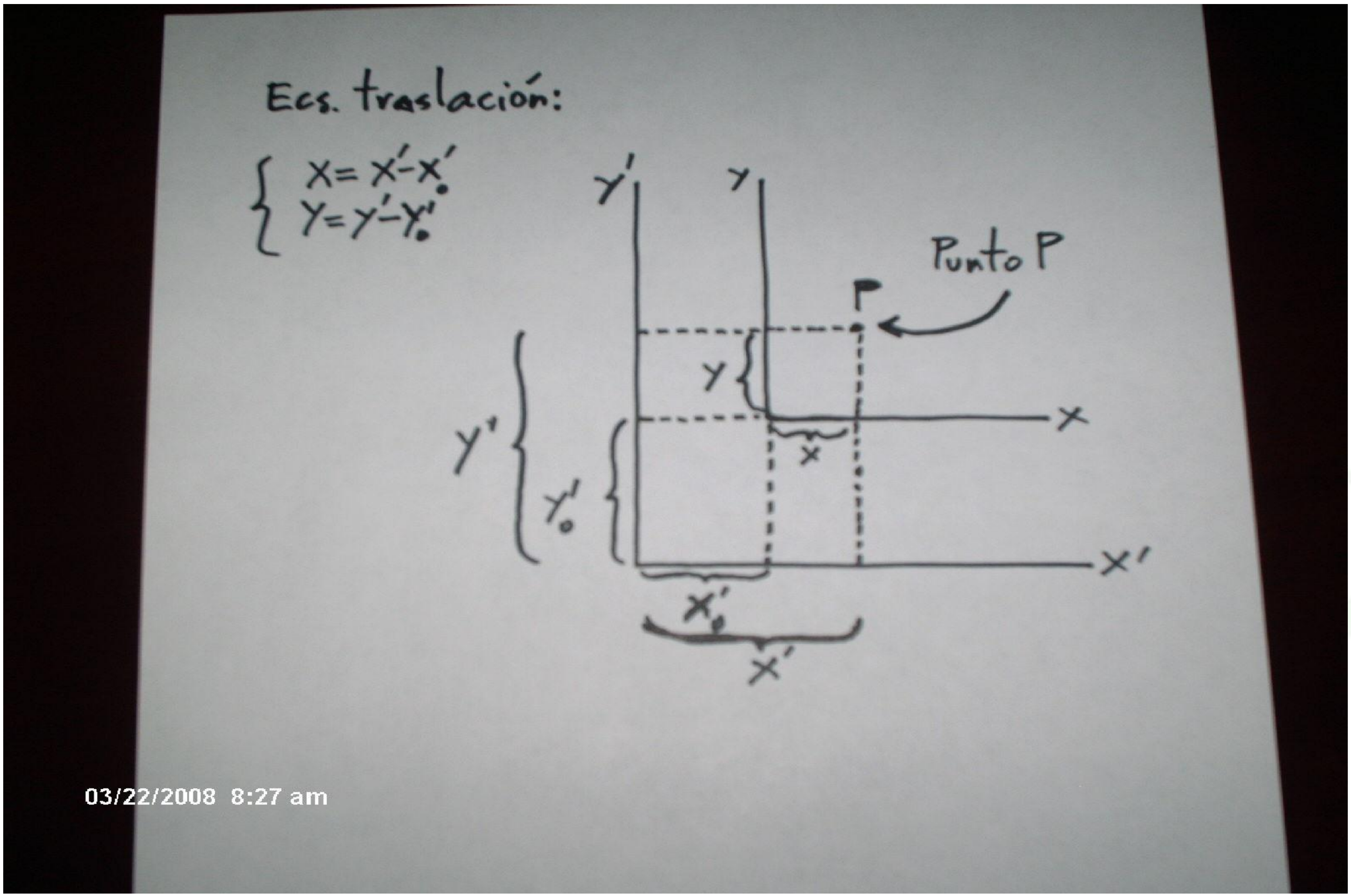


Equations to rotate axis

$$x = x' \, cos(\theta) - y' \, sen(\theta)$$

$$y = x' \, sen(\theta) + y' \, cos(\theta)$$

Translation of origin of a Cartesian coordinate system



Moving the origin of the coordinate system

$$x' = x'' - x_0$$

$$y' = y'' - y_0$$

- An example with ellipsoidal shade
- The analytical expression of an ellipsoidal shade in SRA

$$\frac{x^2}{a^2} + \frac{y^2}{(bcotan(elev))^2 + a^2} < 1$$

- This is modification of the equation of an ellipse with origin centered at its center of the ellipse

$$(x/a)^2 + (y/b)^2 = 1.$$

The equation of the ellipse with axes rotated (SRB)

$$\frac{((x' \, cos(azim+180) - y' \, sen(azim+180))^2}{a^2} +$$

$$\frac{x' \, sen(azim+180) + y' \, cos(azim+180))^2}{(b \, cotan(elev))^2 + a^2} < 1$$

A final translation of the coordinate axes to the left-lower corner of the plot produces the final expression of the shade with respecto to SRU:

$$\frac{(((x'' - x_0)\,cos(azim + 180) - (y'' - y_0)\,sen(azim + 180))^2}{a^2} +$$

$$\frac{(x'' - x_0)\,sen(azim + 180) + (y'' - y_0)\,cos(azim + 180))^2}{(b\,cotan(elev))^2 + a^2} < 1$$

A cell covered by the shade should satisfy this expression in the variables x’’ and y’’

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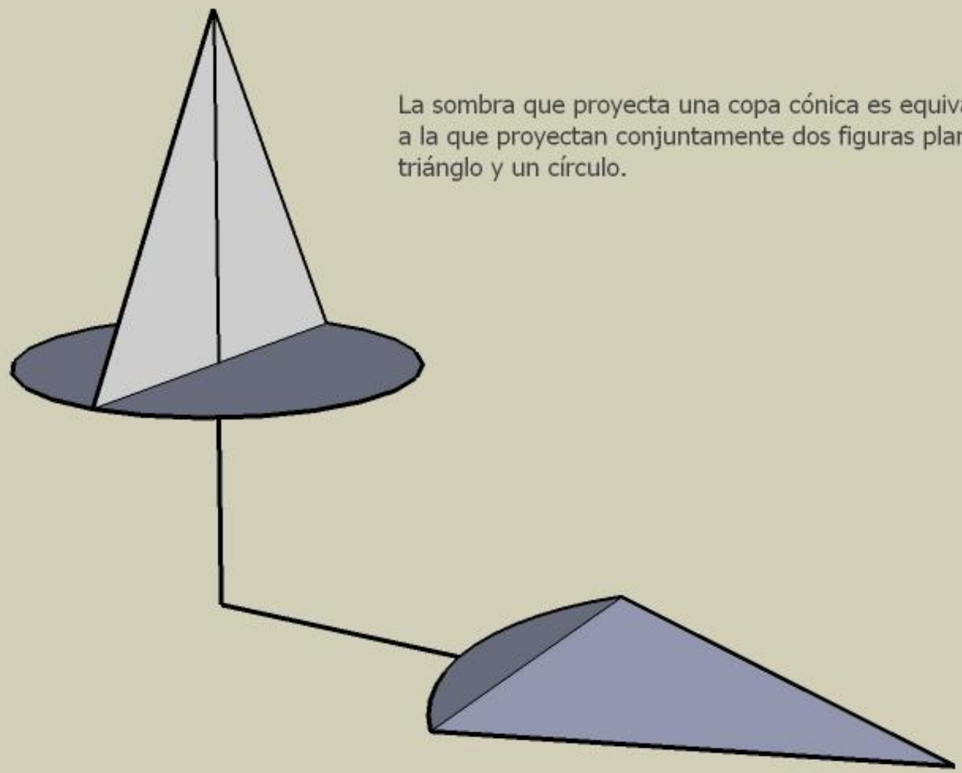
Conic crowns require more analysis because the shade is expressed by a set of inequalities for both the base of the crown and the crown itself



La sombra que proyecta una copa cónica es equivalente a la que proyectan conjuntamente dos figuras planas: un triánglo y un círculo.

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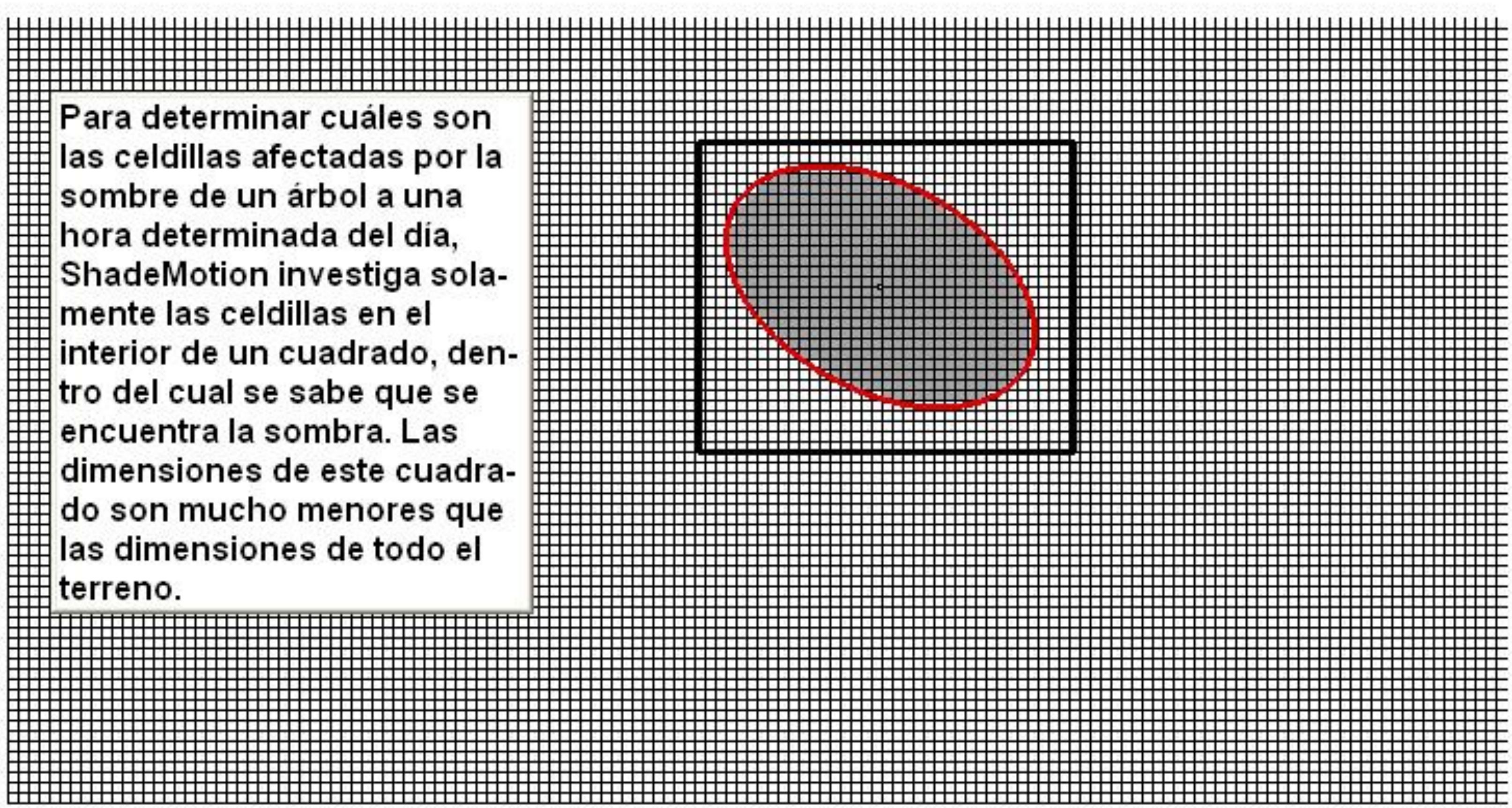
The analytical expressions for shades in tilted planes are far more complex than in horizontal planes because the shade is “deformed” by the specific orientation of the shade respect the changing slope of the terrain.

Adjustments for the “deformation” of the shade are mathematically complex.

The basic simulation loop

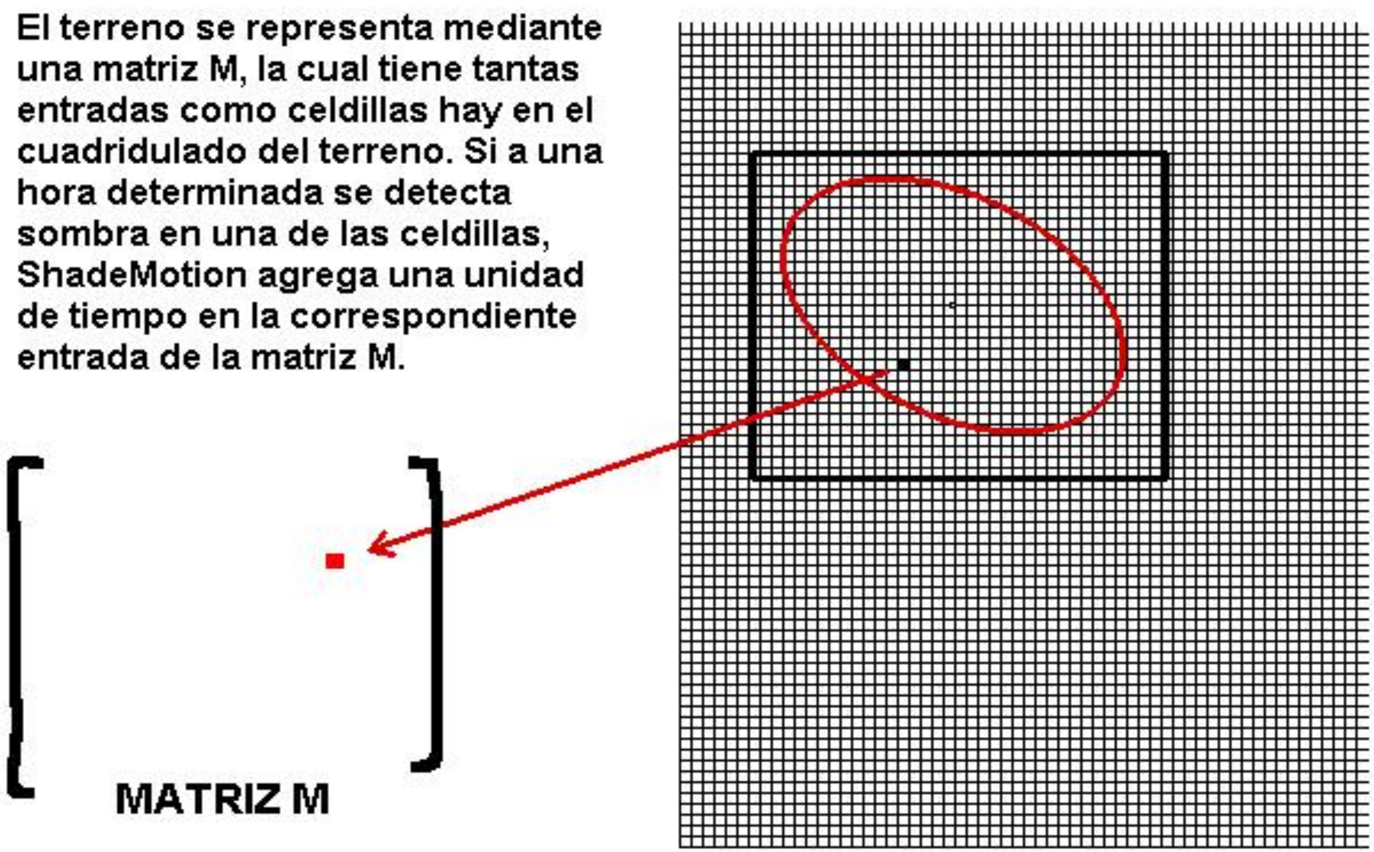
- Simulation parameters provided (latitude, year, day, hour range, step)
- Position #1 of sun calculated for a specific latitude, day and time of day
- For tree #1 the analytical expression of shade is determined
- Coordinates in the ground inspected for shade (mathematical inequalities)
- Shade (0/1) recorded for each coordinate position; overlaps recorded
- Tree #2 is then analyzed
- Solar position is changed and recalculations take place

Scanning shades to determine which coordinate points are under shade



Storing shading information

El terreno se representa mediante una matriz M, la cual tiene tantas entradas como celdillas hay en el cuadridulado del terreno. Si a una hora determinada se detecta sombra en una de las celdillas, ShadeMotion agrega una unidad de tiempo en la correspondiente entrada de la matriz M.



Applications

- Designing appropriate planting designs to achieve a required shading level and pattern
- Using shade levels estimated by ShadeMotion as covariable in competition studies (e.g. in systematic spacing designs)
- Estimation of solar radiation by linking ShadeMotion estimations with radiation flux at particular localtions, date and time of year

tp://www.shademotion.com/en/index.html

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Important: The new version of ShadeMotion (ShadeMotion 3.0) is available only in Spanish at this moment. An English version will be available soon.

Version 3.0 has some interesting new features like:

- Anual tree growth can be accounted for
- It is possible to open two or more simulations (in order to make comparisons)
- It is possible to see results after imposing some conditions or filters
- More types of results available
- More crown types available
- Trees can be grouped by classes or species
- The user can chosse the orientation of corrdinate axis
- Among other things...

What is ShadeMotion?
ShadeMotion is a software that calculates the position and shape of shades projected onto the ground by the crowns of trees planted on flat, horizontal or tilted plots in any location on Earth and at different dates and times. Shademotion's main purpose is to answer questions such as:

How many hours of shade are accumulated at each point of a plot where trees are planted, during a certain period of time?

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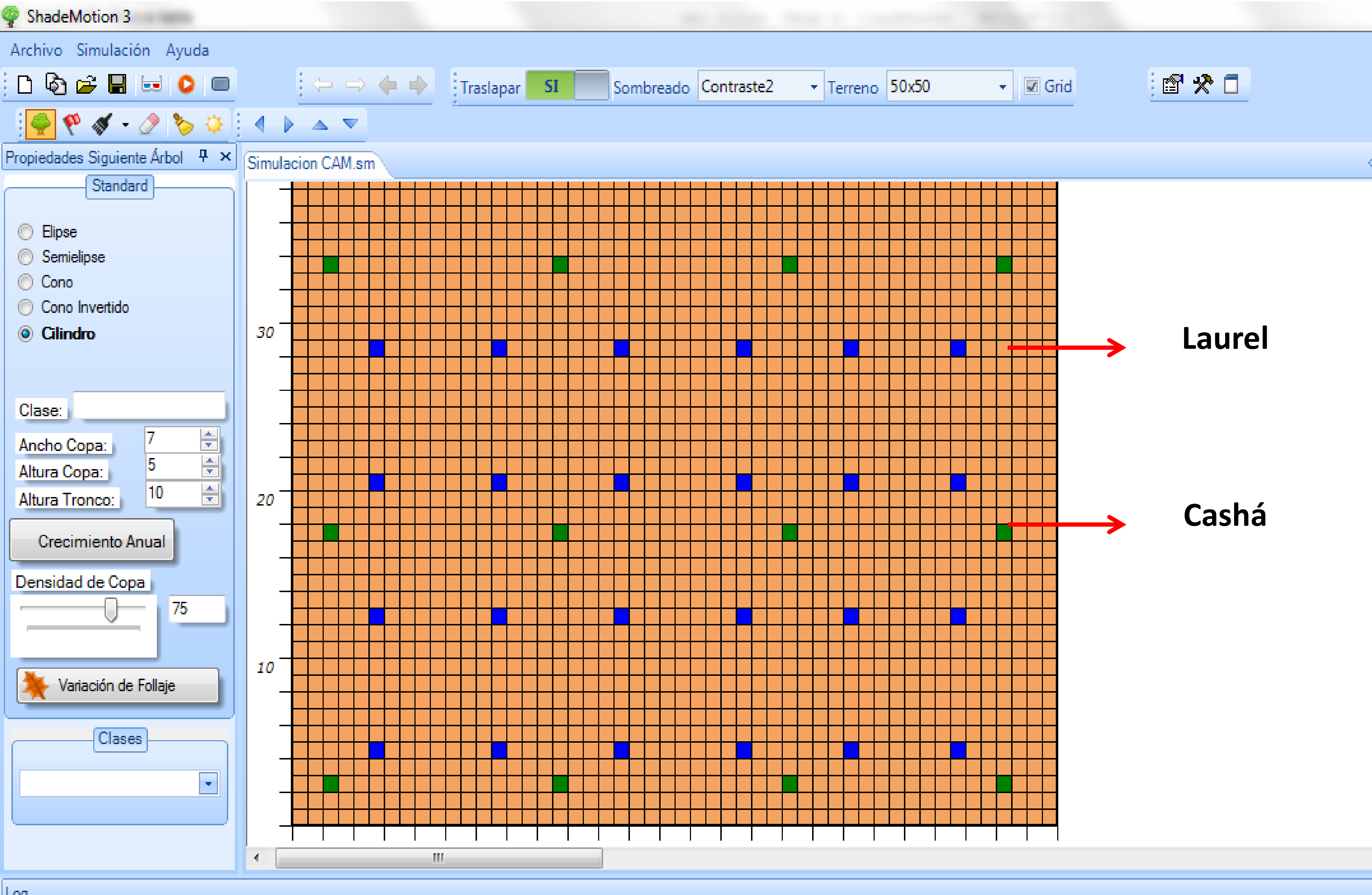
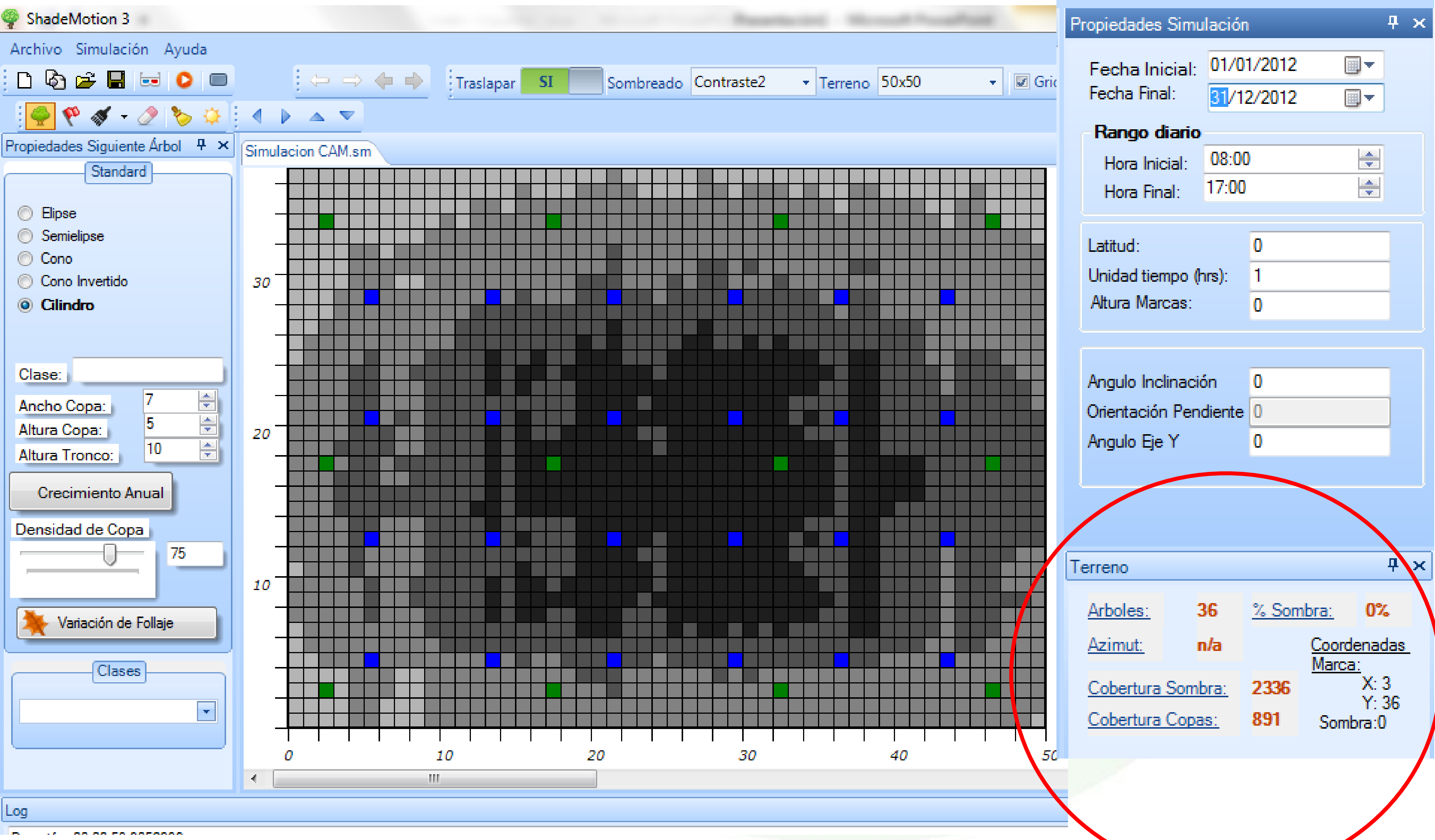
An example
Laurel (16x16m) with Casha (8x8m)



One year simulation (08:00-17:00)



Comparing shading patterns of various tree planting designs
2500 m2 plots, one year, 07:00-17:00

Cacao and tree spacings (m x m)	% Cover	Hours shade				
		Mean	std	Max	Min	% shade
cacao(4x4)-laurel(8x8)	20	822	192	1245	288	22,51
cacao(4x4)-laurel(12x12)	10	366	102	577	10	10,04
cacao(4x4)-laurel(12x12)-casha(8x8)	22	1042	240	1493	198	28,54
cacao(4x4)-laurel(12x12)-casha(8x12)	18	800	206	1207	120	21,91
cacao(4x4)-laurel(16x16)-casha(8x8)	14	670	225	1146	0	18,37

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ShadeMotion 3.0 can be downloaded from
www.shademotion.com

ShadeMotion 4.0 will be released in a couple of months


Thank you