

## Three-dimensional morphological model of water lilies *Nymphaea* spp. for breeding historical study

Shiryu Kirié<sup>1</sup>, Christophe Pradal<sup>2</sup>, Hideo Iwasaki<sup>3</sup>, Koji Noshita<sup>4</sup>, Hiroyoshi Iwata<sup>1\*</sup>

1. Graduate School of Agricultural and Life Sciences, The University of Tokyo, Tokyo

2. CIRAD, UMR AGAP & Inria, Univ Montpellier, Montpellier, France

3. School of Advanced Science and Engineering, Waseda University, Tokyo

4. Graduate School of Science, Kyushu University, Fukuoka

For correspondence: [iwata@ut-biomet.org](mailto:iwata@ut-biomet.org)

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### Introduction

The water lilies *Nymphaea* spp. show a wide range of morphological features obtained through the horticultural breeding performed over 100 years, and diverse cultivars were created in the breeding history, such as those drawn by Claude Monet. We aim to understand how the floral morphologies have evolved to enhance their ornamental value. We propose a 3D morphological theoretical model to represent the floral structure of water lily. We will present a model to enable realistic representations from real data, such as the shape of the contour of a floral organ, and applications for our goal.

### Model overview

The theoretical morphological model of the water lily is an algebraic operator that allows composing morphological models of floral organs using a model of phyllotaxis to generate a 3D flower architecture. Each floral organ is generated from a function that computes a three-dimensional C-spline surface from the size and lateral and longitudinal curvature. The ovary was represented by a curved surface obtained by rotating a two-dimensional C-spline curve around the vertical axis. The spiral phyllotaxis operator was designed for the arrangement of floral organs on the ovary surface. Here, as the expression of the spiral phyllotaxis, intervals between adjacent organs are assigned based on the ratio of those sizes, and each floral organ is arranged with rotation by the golden angle (137.5°). These settings on the phyllotactic pattern is based on previous studies (eg. Prusinkiewicz et al. 2001 [1]). We adopted linear interpolation between angles of the outermost floral organ and the innermost floral organ for the expression of the series of elevation angles. A 3D morphological model is obtained by combining all these parametric operators.

### Result

Spline surfaces enabled flexible control of the theoretical morphological model. By extracting and applying parameters from image data of the floral organs, we were able to represent the morphology of water lilies as a three-dimensional form on a computer. Thus, even if it is challenging to acquire a three-dimensional morphology directly, it is possible to reproduce a morphology of the flower from the scanned two-dimensional image of each organ. The morphological model of the water lily flower can also be used to evaluate the three-dimensional morphological characteristics with geometrical indices, for example, using the convex hull, and these indices can be used to define an ideotype quantitatively. This information provides us the structural and qualitative understanding of morphological changes under the breeder's perspective.

### Discussion and conclusion

Diverse horticultural varieties of water lilies are commercially distributed, and they display a wide range of morphological characteristics to enhance ornamental values. In horticultural catalogs of water lily, There are some types of qualitative descriptions of flower shape, like the "stellate" or the "cup-like". The relationship between geometrical indices and qualitative descriptions can display occupation patterns indicating quantitative correspondence in the morphospace. This model can be applied to evaluate the characteristics of existing varieties and facilitating the breeding process of new cultivars by linking genotypic information and developmental mechanism. The *Nymphaea* spp. are expected to be used as "model clades" in recent years (Chanderbali et al. 2016 [2]), and this study, which enables comparison of morphological characteristics between different varieties, may be applicable to the study of flower evolution and development, and for ideotype design.

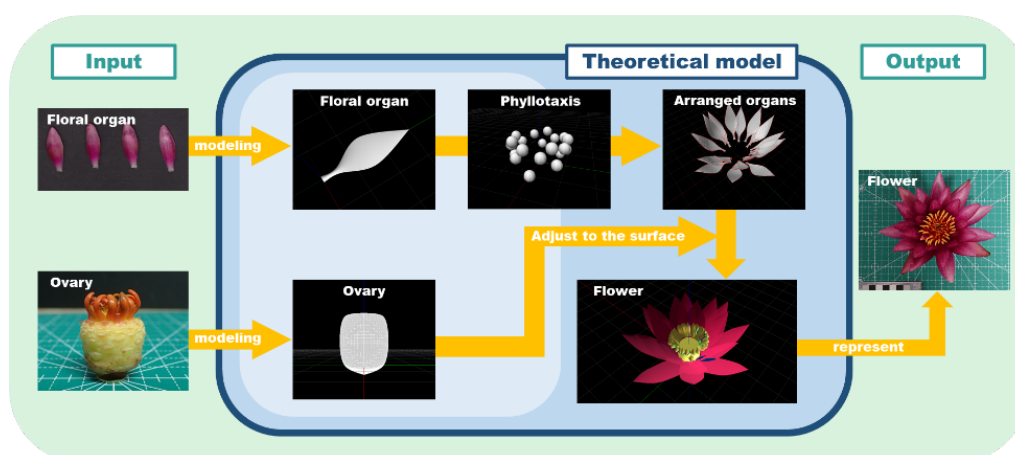


Figure: The overview of the modeling of flower morphology of *Nymphaea* spp.

### Reference

- [1] Prusinkiewicz et al. 2001, Proceedings of the 28th Annual Conference on Computer Graphics and Interactive Techniques, SIGGRAPH 2001, 289-300
- [2] Chanderbali et al., 2016, *Genetics*, 202:1255-65.

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Editorial office:

Institute of Horticultural Production Systems  
Herrenhäuser Strasse 2  
30419 Hannover  
Germany

tel.: +49-511 762 2638

e-mail: [fspm2020@gem.uni-hannover.de](mailto:fspm2020@gem.uni-hannover.de)