ICACSE2023 Scopus
16th - 17th December 2023,
De La Salle University, Manila, Philippine (Hybrid Conference)
UMS UNIVERSITI MALAYSIA SABAH
DLSU De La Salle University

Swarm Intelligence for Shape Reconstruction in the Context of the European Project PDE-GIR: Recent Advances and Future Trends

PDE-GIR

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MINISTERIO DE CIENCIA E INNOVACIÓN
UNIÓN EUROPEA
FONDO EUROPEO DE DESARROLLO REGIONAL
"Una manera de hacer Europa"
AGENCIA ESTATAL DE INVESTIGACIÓN
Marie Skłodowska-Curie Actions

Outline of this talk

1. PDE-GIR Project
2. Shape Reconstruction Problem
3. PDE+Artificial Intelligence for SR
4. Some Illustrative Examples
5. Future Research

PDE-GIR project

PDE-GIR project is aimed at developing advanced PDE based techniques, exploiting their applications through exchanges of research and innovation staff, international and intersectoral collaborations, and knowledge transfer.

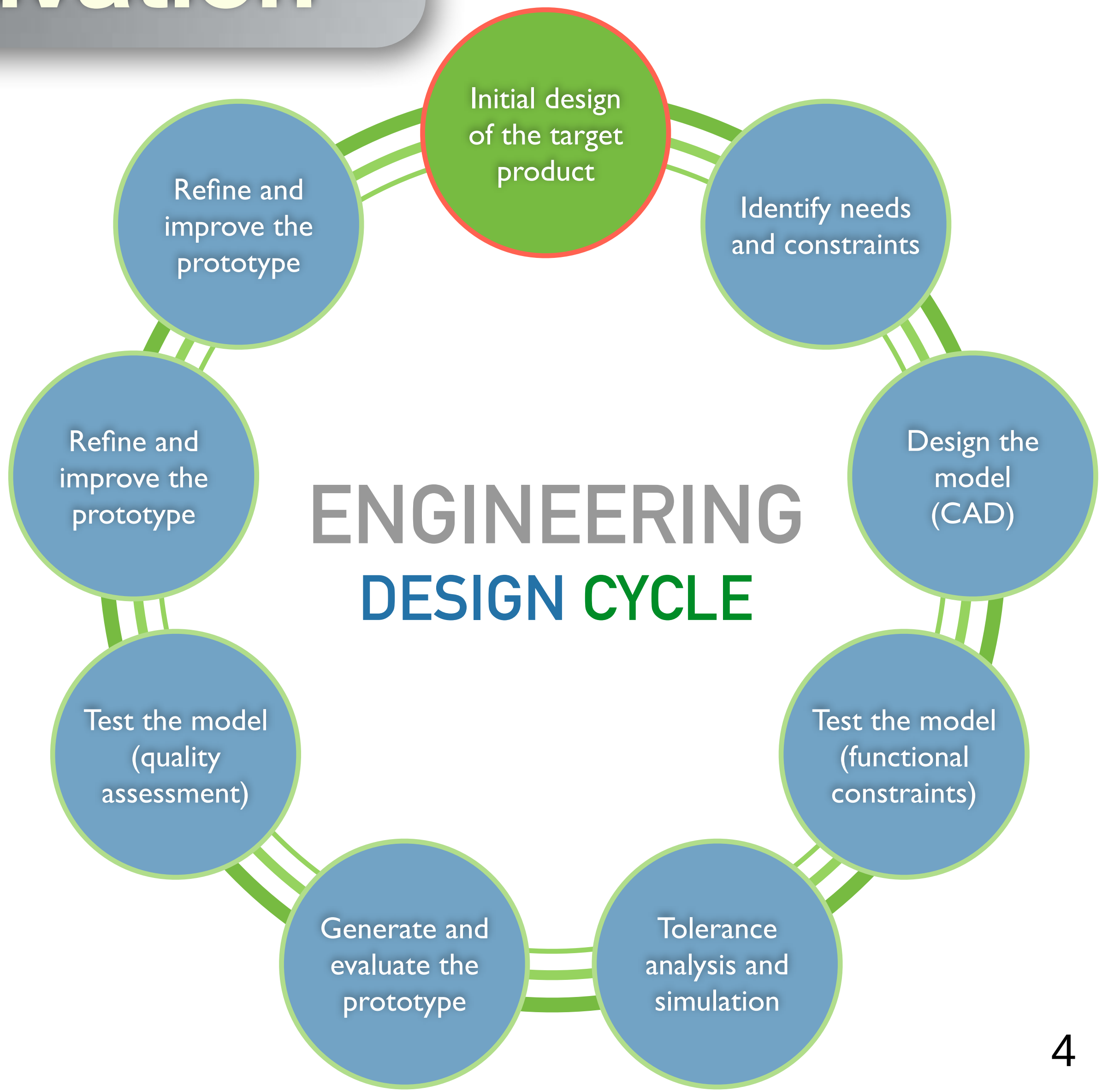
EU H2020 MSCA-RISE Program
Jan. 2018 - Oct. 2023
535,000€ (direct funding)

PDE-Based Geometric Modelling, Image Processing and Shape Reconstruction

Motivation

FORWARD ENGINEERING

1. Design (CAD model)
2. Test & Analysis
3. Prototype generation
4. Refine & Improve
5. Industrial manufacturing
6. Final physical product



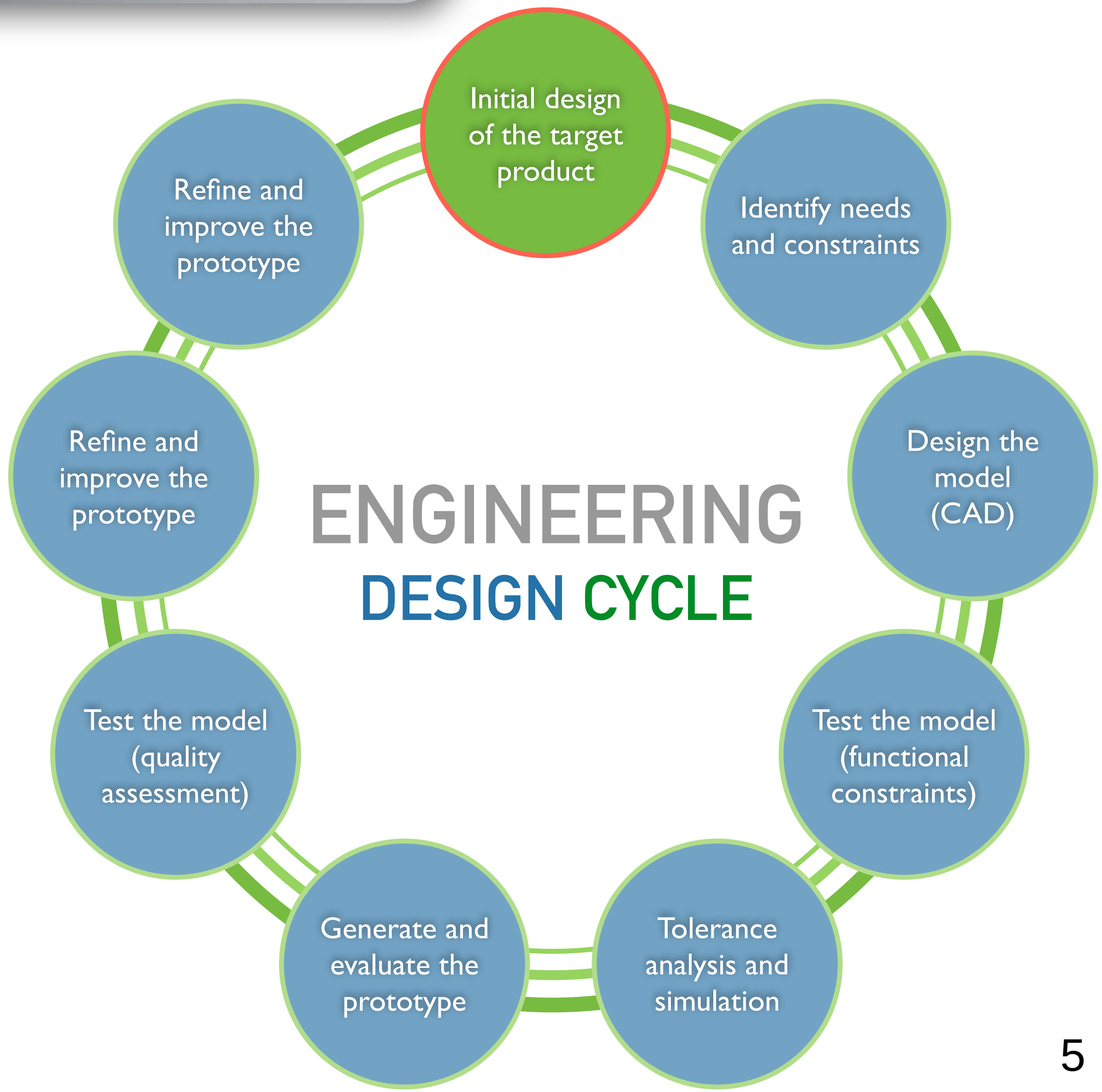
Motivation

FORWARD ENGINEERING

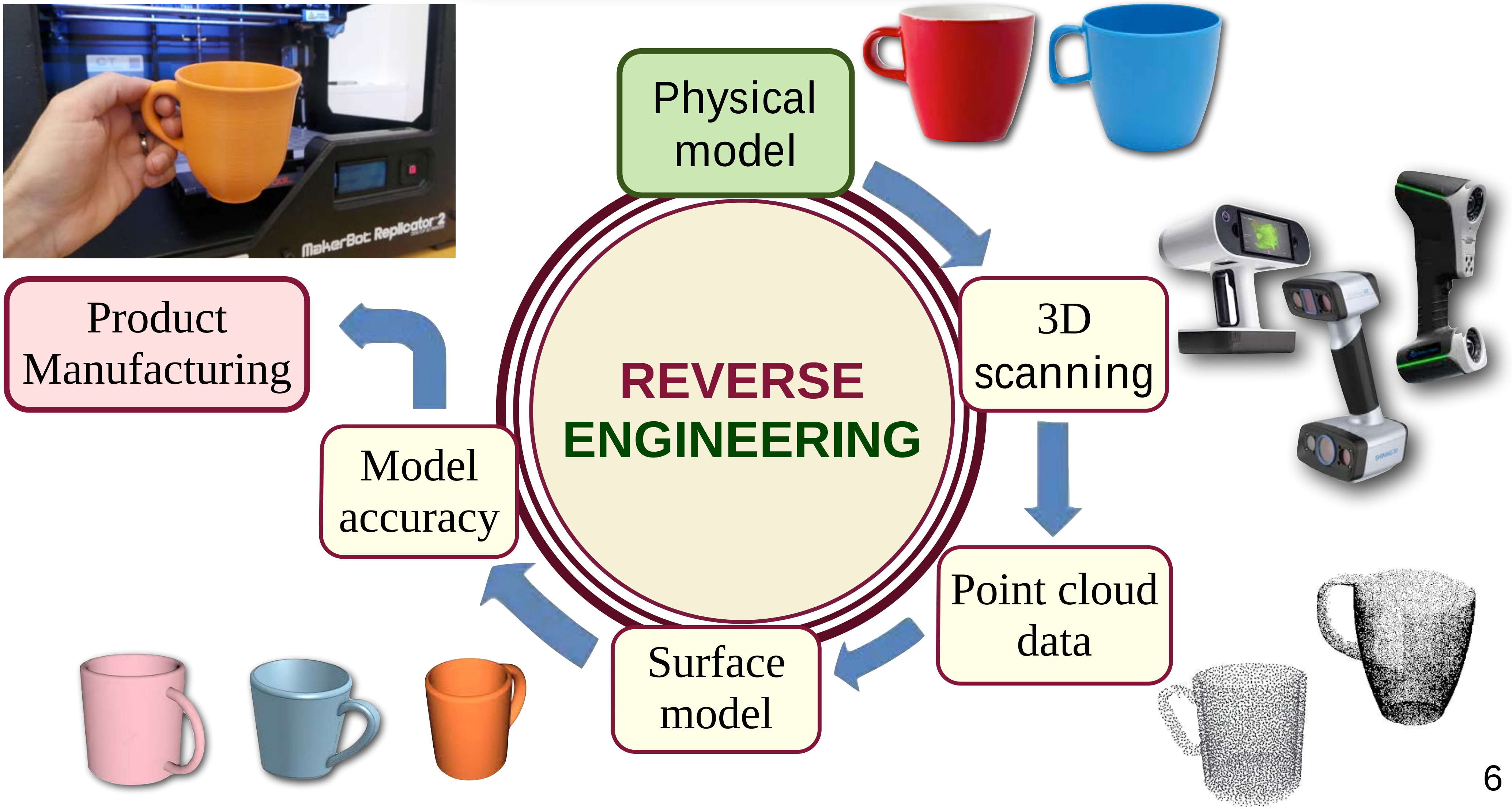
1. Design (CAD model)
2. Test & Analysis
3. Prototype generation
4. Refine & Improve
5. Industrial manufacturing
6. Final physical product

REVERSE ENGINEERING

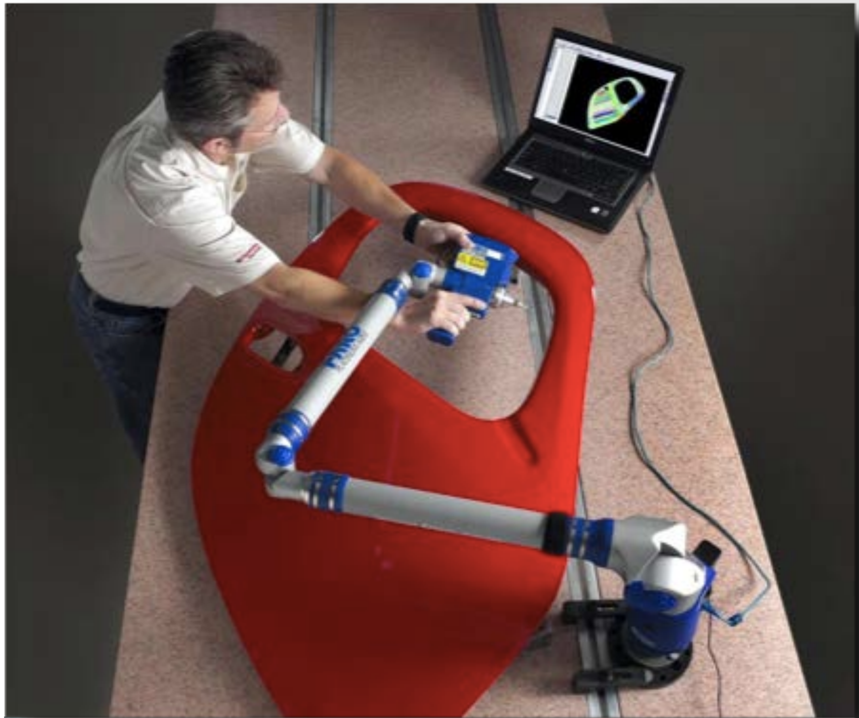
1. Physical product
2. 3D scanning
3. Point cloud data
4. Surface reconstruction
5. Test & Analysis
6. Final CAD model

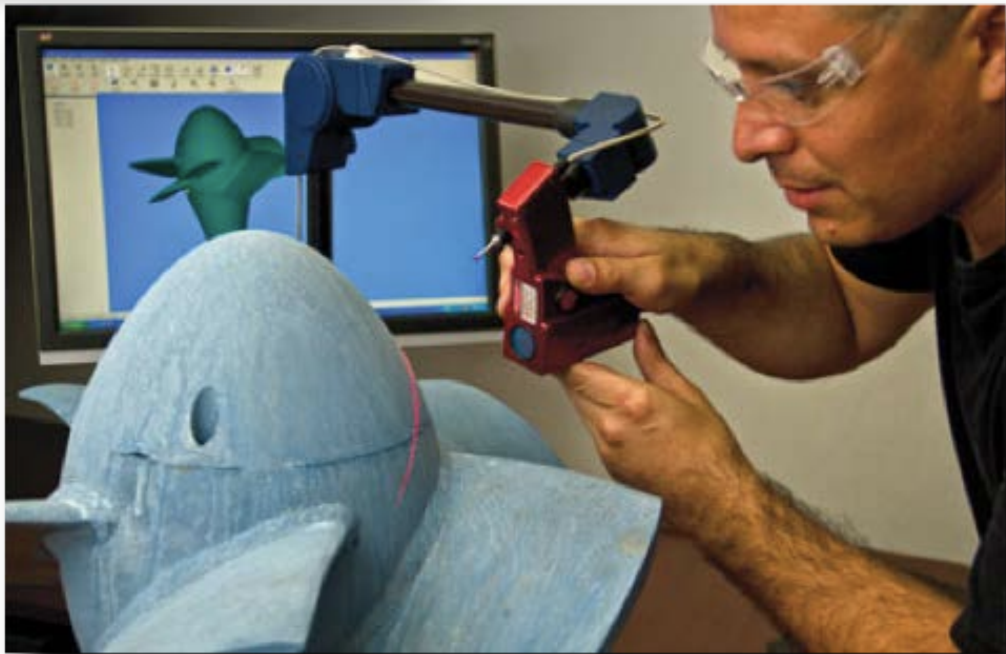


Motivation


Physical model
3D scanning
Point cloud data
Surface model
Model accuracy
Product Manufacturing
REVERSE ENGINEERING
MakerBot Replicator 2

Motivation





Motivation

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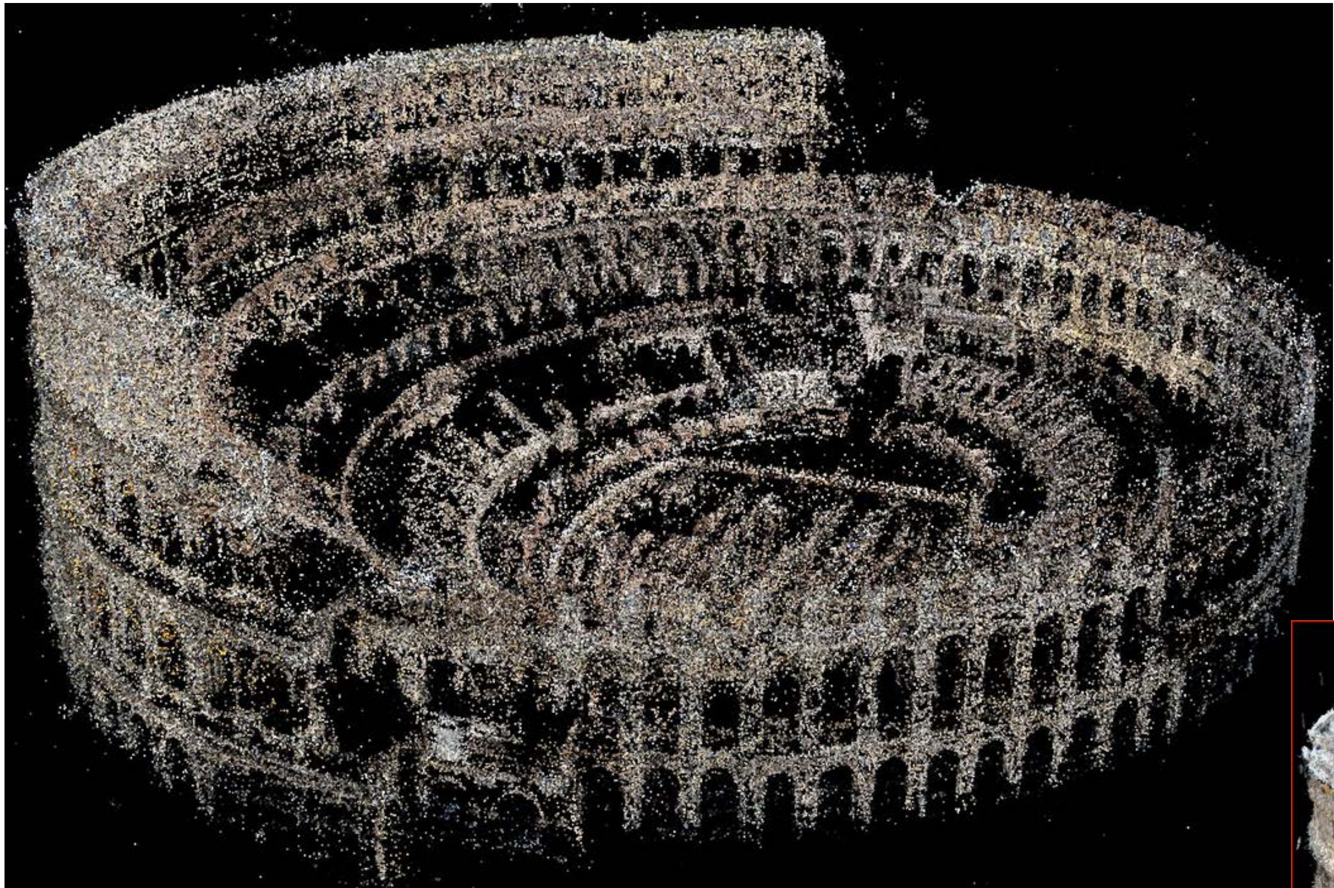
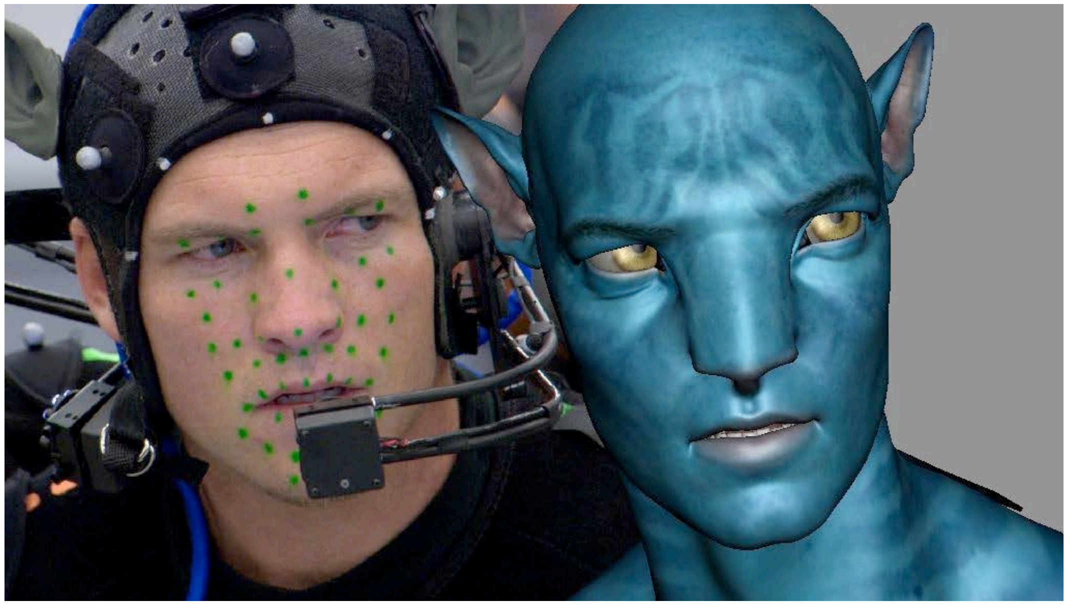


Point cloud

Mesh Model

ROMAN COLISEUM
(Univ. Washington)

Motivation

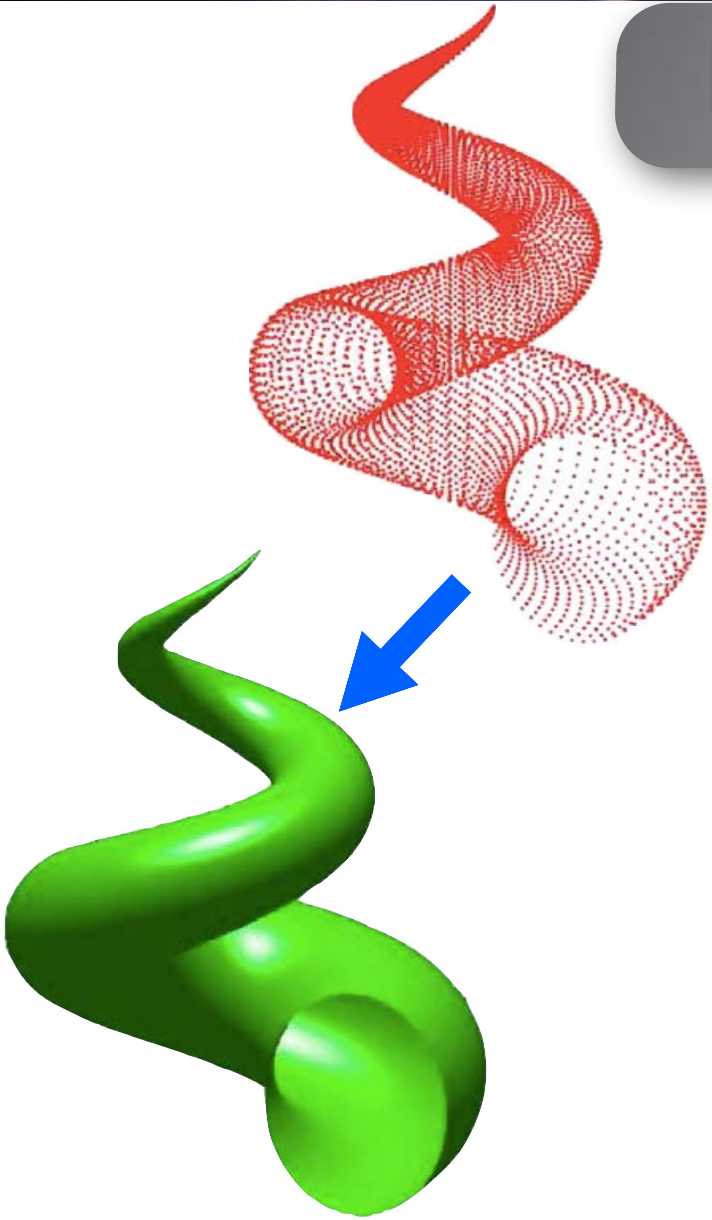


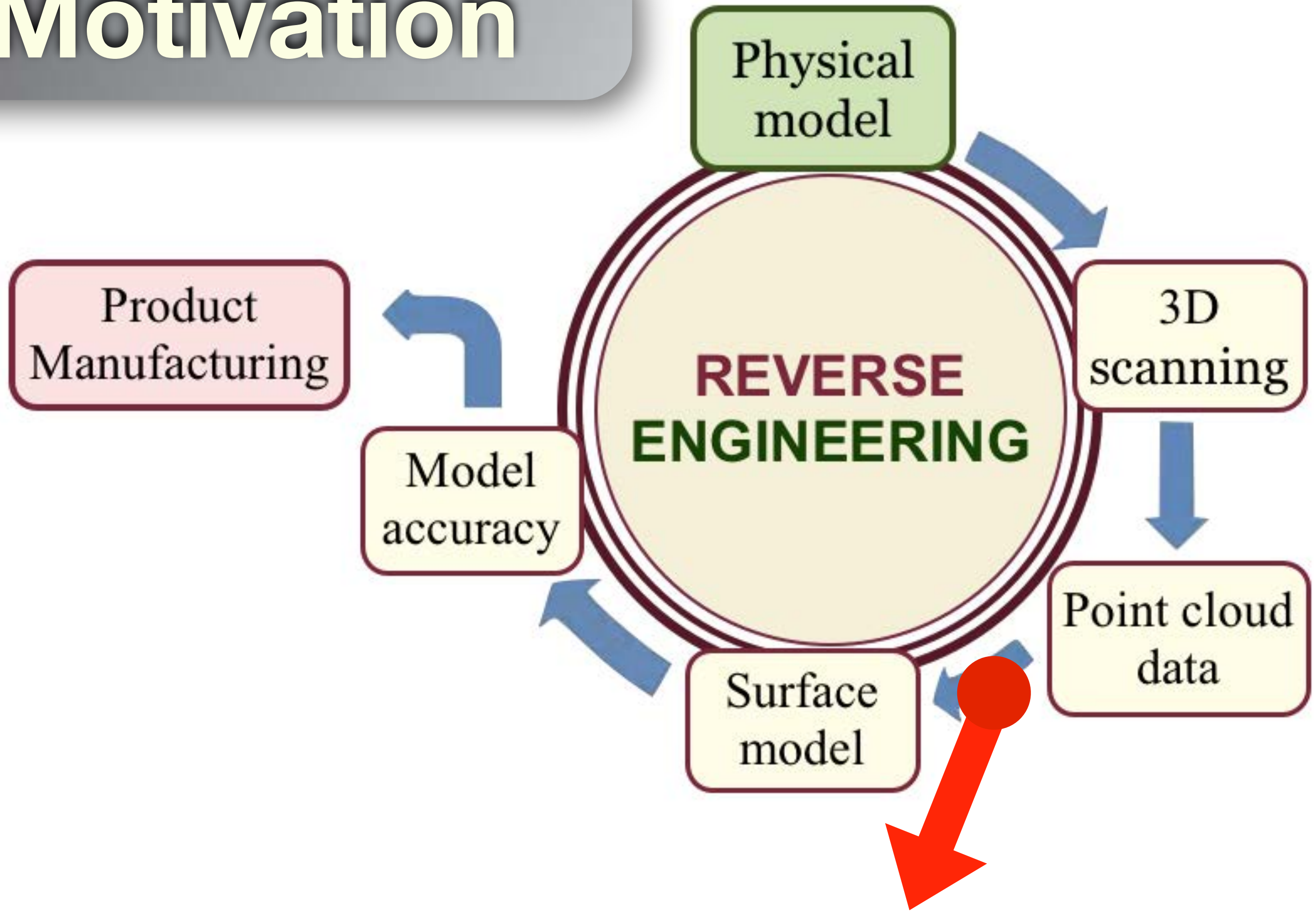
Motivation

REVERSE ENGINEERING IN INDUSTRY
What for?

1. Gain knowledge about how a product works
2. Repurpose obsolete products
3. Analyze the quality of shape
4. Intellectual/Industrial property infringement assessment
5. Modify the original product shape for mass customization

Motivation





SURFACE RECONSTRUCTION

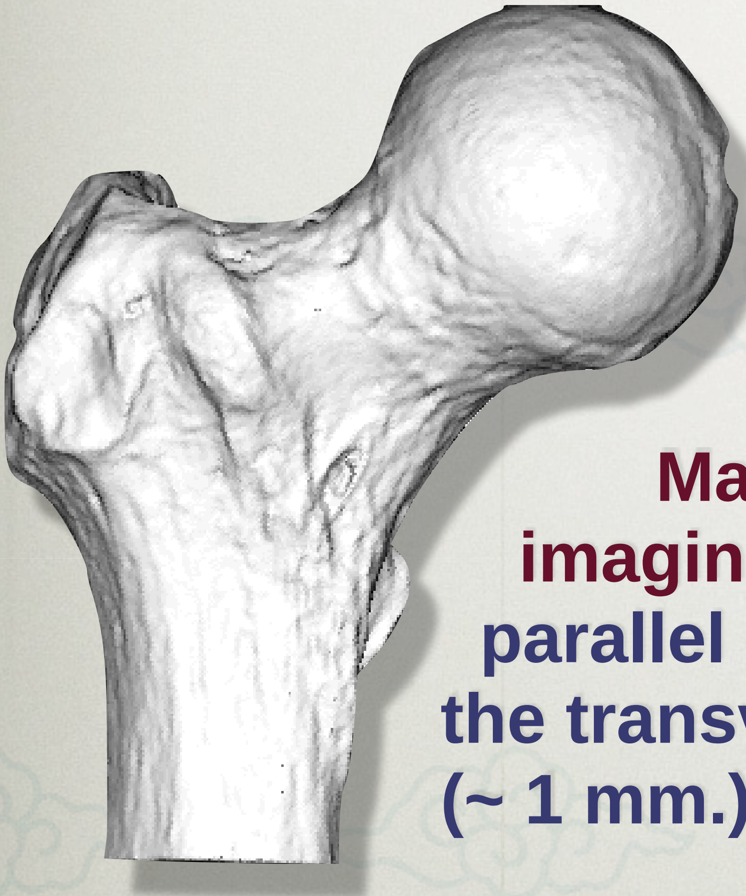
By **surface reconstruction** we mean the construction of an **unknown surface** (implicit, parametric, free-form, etc.) from a **given input** (cross sections, profile curves, data points, etc.)

Input:

- cross-sections
- clouds of data points
- profile curves
- mixed information

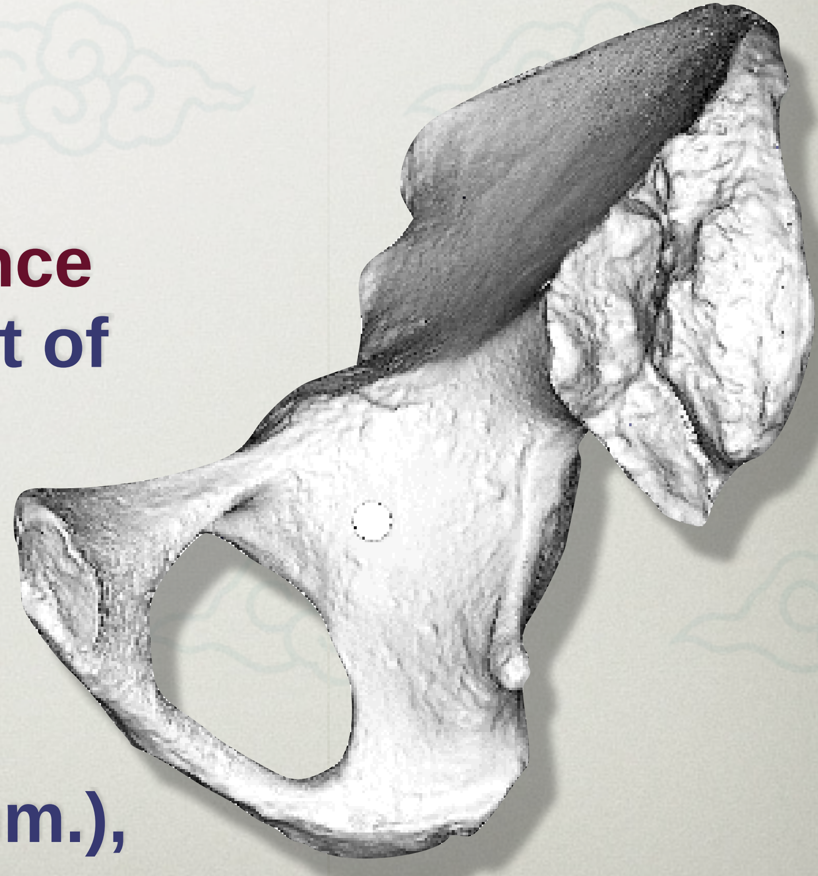
Output:

- implicit surfaces
- polynomial surfaces
- rational surfaces
- free-form surfaces



Computer tomography: scanned projections from different point-views to generate a 3D volume

Magnetic resonance imaging: input is a set of parallel sections along the transversal axis (~ 1 mm.)



Others: confocal microscopy (~10^{-4} mm.), electron microscopy (~10^{-8} mm.), etc.

However, many classical optimization techniques tend to fail when:

- The objective function is **not differentiable**
- The objective function is computed through a **black-box** procedure
- Little or **no information** about the problem is given
- Derivatives are **too difficult or expensive** to obtain
- It is expected that **many optima exist**
- Data are affected by **noise, missing data** or other **artifacts**

When using metaheuristic methods?

- An easy problem with very large instances
- An easy problem with hard real-time constraints
- Difficult problems with medium size and/or difficult input structures
- Optimization problems with time-consuming objective functions and/or constraints
- Non-analytical models of optimization problems: black box scenario (objective function)
- Non-deterministic complex models: uncertainty, robust optimization, dynamic, multi-objective,...
- Non-differentiable (even non-continuous) underlying functions of data
- Input data subjected to noise, imperfect sampling and other artifacts

Metaheuristic methods:

Advantages:

- Generally produce higher quality results (given enough time) than simple heuristics
- Make few (or none) assumptions about your problem
- Are very general (can be used when nothing else works)

NO FREE LUNCH THEOREM

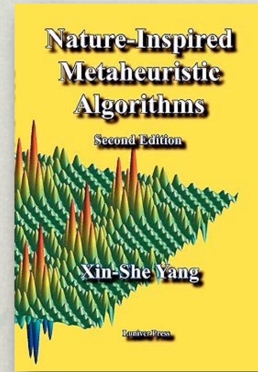
Drawbacks:

- They take a lot longer as they have to generate and evaluate many solutions rather than just one heuristics
- Parameter tuning is always a challenge
- Convergence to optima is not guaranteed

Some metaheuristic methods:

TYPE	METHOD	COMMENTS
EARLY WORKS	Tabu Search	Glover (1986)
	Random Search	Rastrigin (1963)
	Pattern Search	Hooke & Jeeves (1961)
	Grammatical Evolution	Ryan et al (1998)
	Path Relinking	Glover (1996)
PHYSICS & CHEMISTRY INSPIRED	Simulated Annealing	Kirkpatrick et al. (1983)
	Stochastic Diffusion Search	Bishop (1989)
	Harmony Search	Geem et al. (2001)
	Intelligent Water Drops	Shah-Hosseini (2007)
	Electromagnetism Approach	Birbil & Fang (2003)

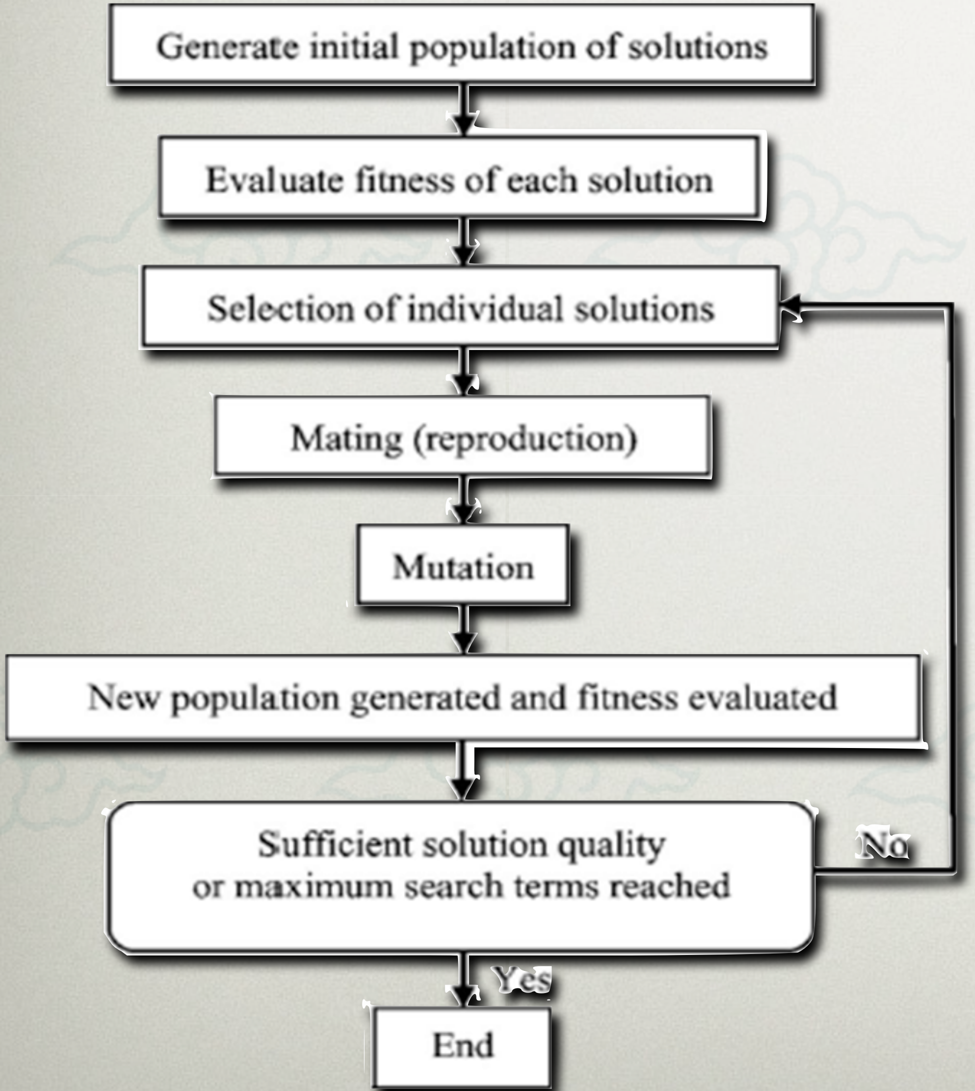
Some other popular **metaheuristic** methods:



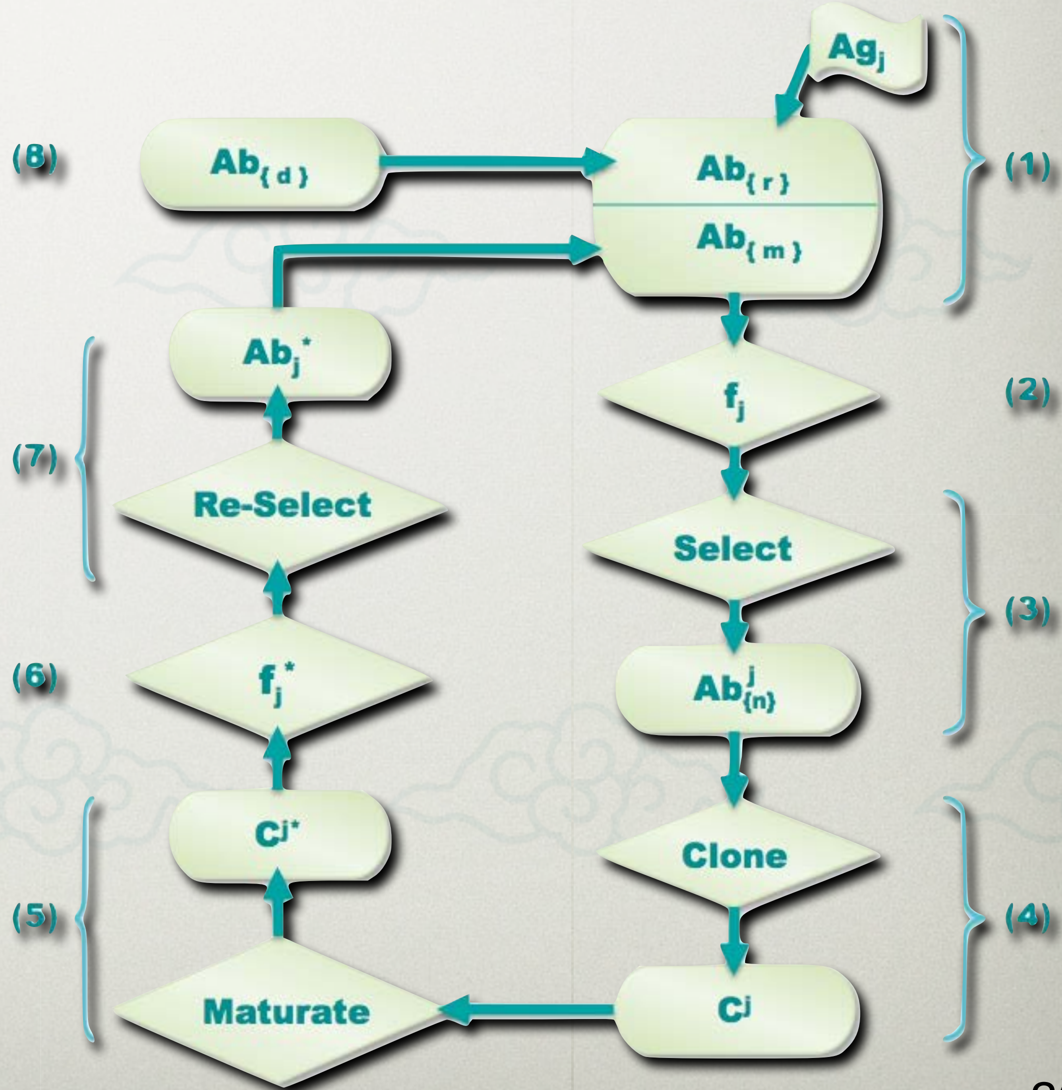
Xin-She Yang: *Nature-Inspired Metaheuristic Algorithms (2nd. Edition).* Luniver Press (2010)

TYPE	METHOD	COMMENTS
SWARM INTELLIGENCE	Ant Colony Optimization	Marc Dorigo (1992)
	Particle Swarm Optimization	Kennedy & Eberhart (1995)
	Artificial Immune Systems	
	Firefly Algorithm	Xin-She Yang (2009)
	Artificial Bee Colony	Karaboga & Basturk (2007)
	Bee Colony Optimization	Lučić & Teodorović (2001)
	Cuckoo Search	Xin-She Yang (2011)
BIO-INSPIRED	Genetic Algorithms	Holland (1975)
	Differential Evolution	Storn & Price (1997)
	Bio-geography optimization	Dan Simon (2008)
	Evolutionary Computing	
	Genetic Programming	Koza (1992)
	Bacterial Foraging	Passino (2002)
	Random Search	Rastrigin (1963)
	Pattern Search	Hooke & Jeeves (1961)
	Grammatical Evolution	Ryan et al (1998)

Genetic Algorithms (GA)



Artificial Immune Systems (AIS)



Particle Swarm Optimization

$$R_1, R_2 \in U[0,1]$$

iteration

inertia weight

global best position

particle's best position

$$V_i^{k+1} = w\,V_i^k + \gamma_1 R_1 [P_{g,b}^k - P_i^k] + \gamma_2 R_2 [P_{i,b}^k - P_i^k]$$

velocity of particle i

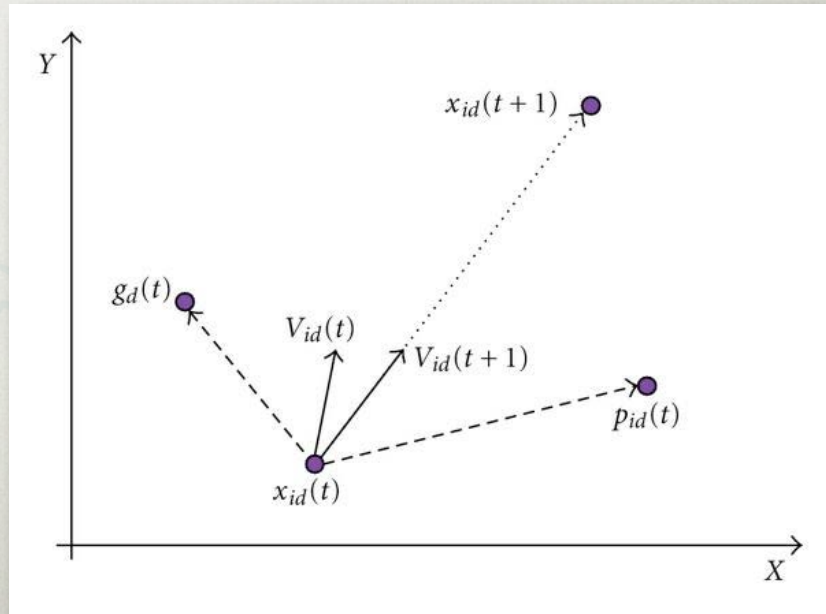
social parameter

cognitive parameter

iteration

$$P_i^{k+1} = P_i^k + V_i^k$$

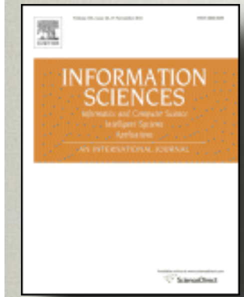
position of particle i



The Firefly Algorithm

The Algorithm

```
Begin
1) Objective function: f(x)
2) Generate an initial population of n fireflies x(i)
3) Formulate light intensity I associated with f(x)
4) Define absorption coefficient γ
While (t<MaxGeneration)
    for i=1:n
        for j=1:n
            if I(i)>I(j), then move firefly i towards j
            end if
            Vary attractiveness with distance r via exp(-γ r);
            Evaluate new solutions and update light intensity;
        end for j
    end for i
    Rank fireflies and find the current best;
end while
Post-processing the results and visualization;
end
```



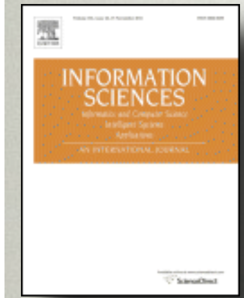
A. Gálvez, A. Iglesias,: *"Particle swarm optimization for non-uniform rational B-spline surface reconstruction from clouds of 3D data points"*. Information Sciences (I.F. 8.1). Vol. 192 (1), 174-192 (2012)

Basic Data:

- **NURBS 20412 parameters**
- **9150 data points**

Results:

- **CPU time: <4 min.**
- **error: 10^{-12} - 10^{-14}**



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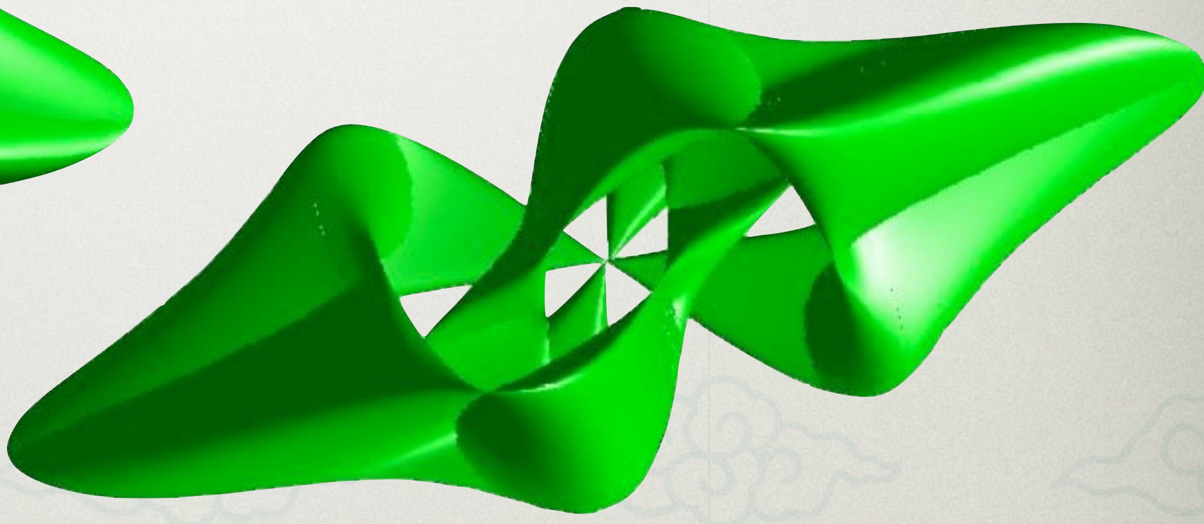


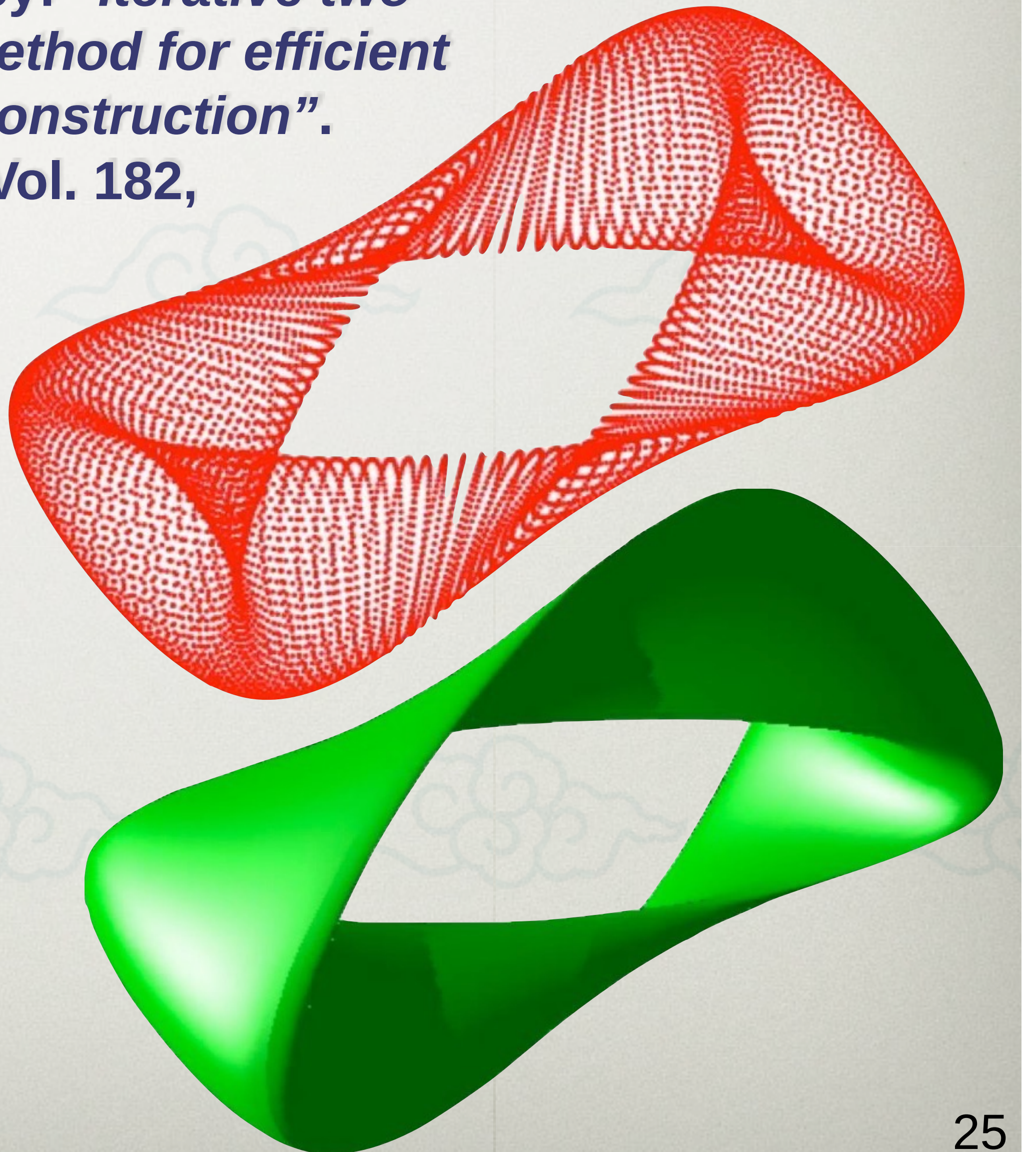
Basic Data:

- **NURBS 9557 parameters**
- **4132 data points**

Results:

- **CPU time: <3 min.**
- **error: 10^{-13} - 10^{-14}**

A. Gálvez, A. Iglesias, J. Puig-Pey: ***"Iterative two-step genetic-algorithm-based method for efficient polynomial B-spline surface reconstruction"***. **Information Sciences (I.F. 8.1), Vol. 182, Issue 1, 56-76 (2012)**

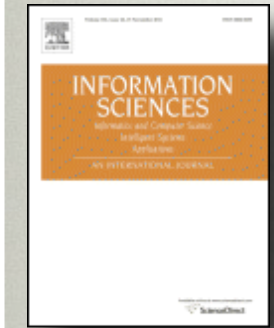


Basic data:

- **NURBS surface**
- **20933 parameters**
- **10500 data points**

Results:

- **CPU time: 2-3 h.**
- **error: 10^{-15}**



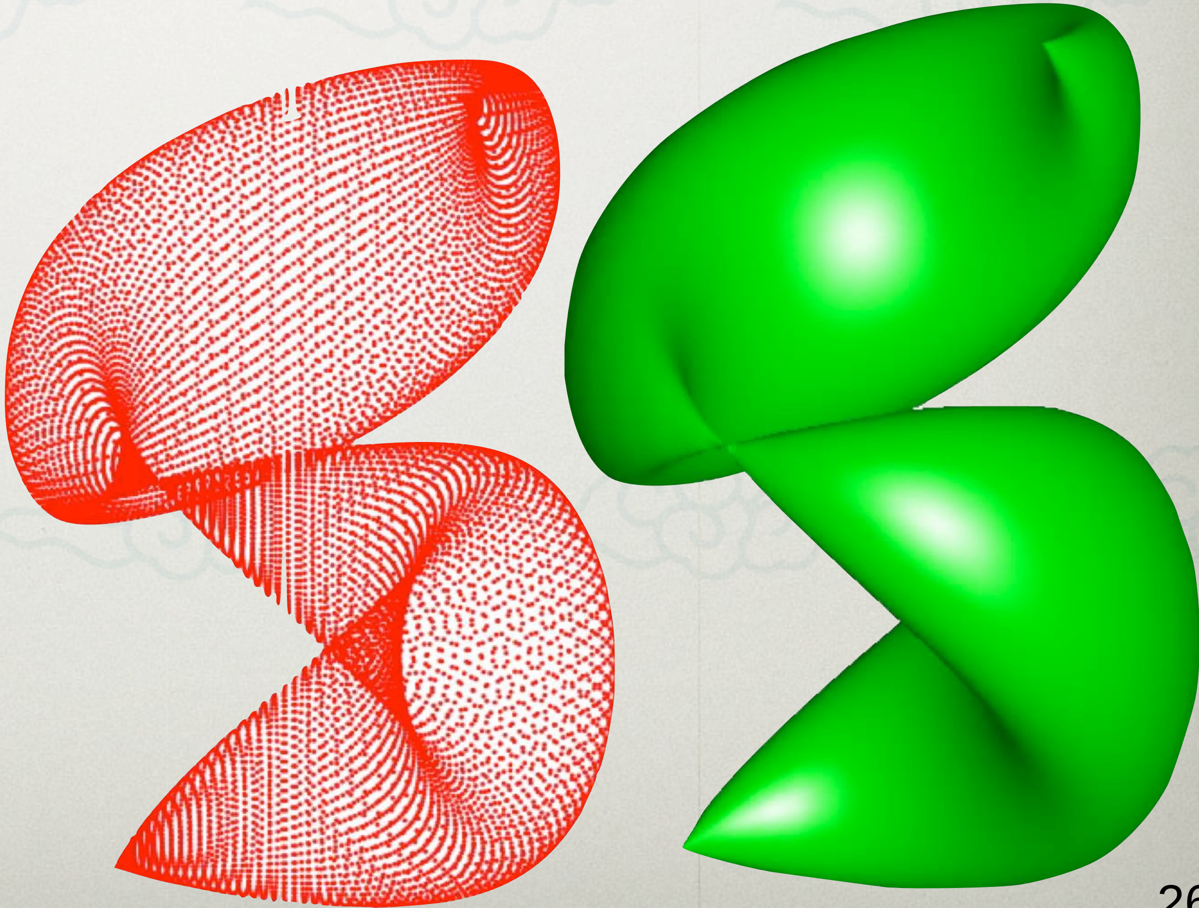
A. Gálvez, A. Iglesias, J. Puig-Pey: *"Iterative two-step genetic-algorithm-based method for efficient polynomial B-spline surface reconstruction"*. Information Sciences (I.F. 8.1), Vol. 182, Issue 1, 56-76 (2012)

Basic data:

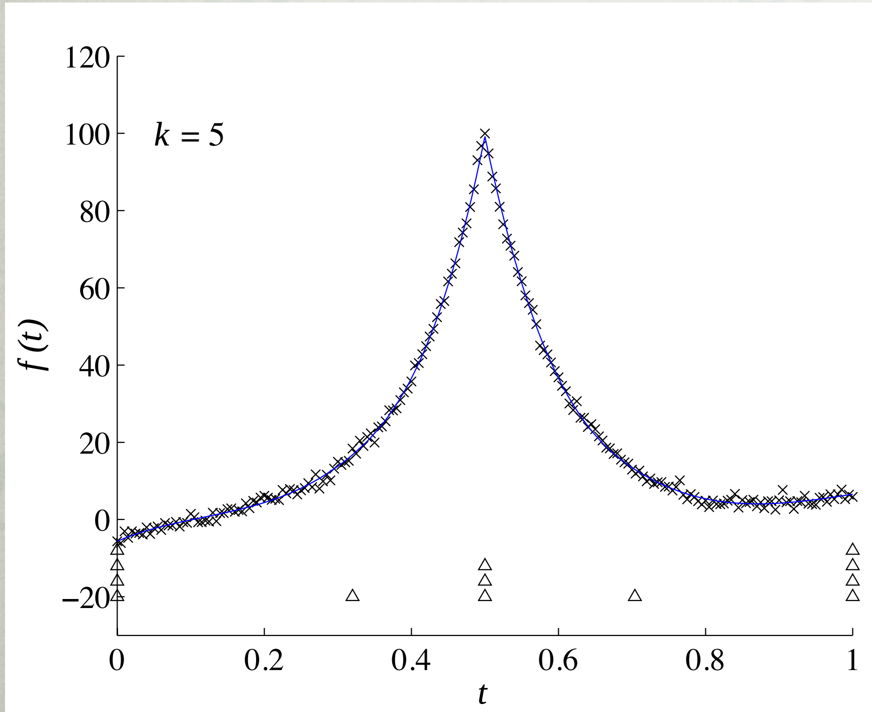
- NURBS surface
- 29280 parameters
- 14200 data points

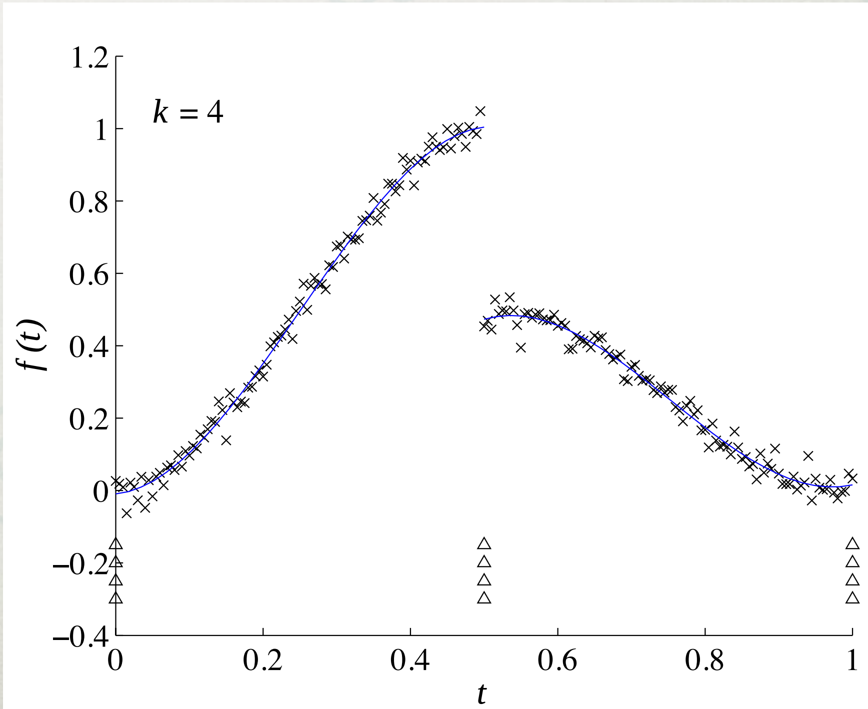
Results:

- CPU time: 14-20 min.
- error: 10^{-11}



A. Gálvez, A. Iglesias: *"Efficient PSO Approach for Data Fitting with Free Knot B-splines"*. Computer Aided Design (I.F. 4.3), Vol. 43, Issue 12, 1683-1692 (2011)





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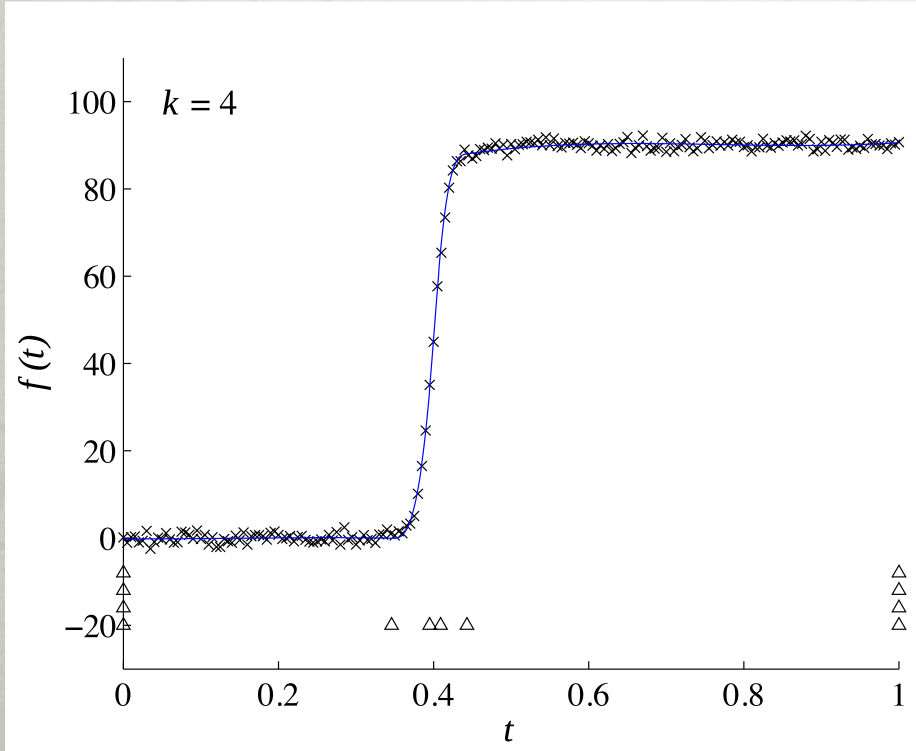
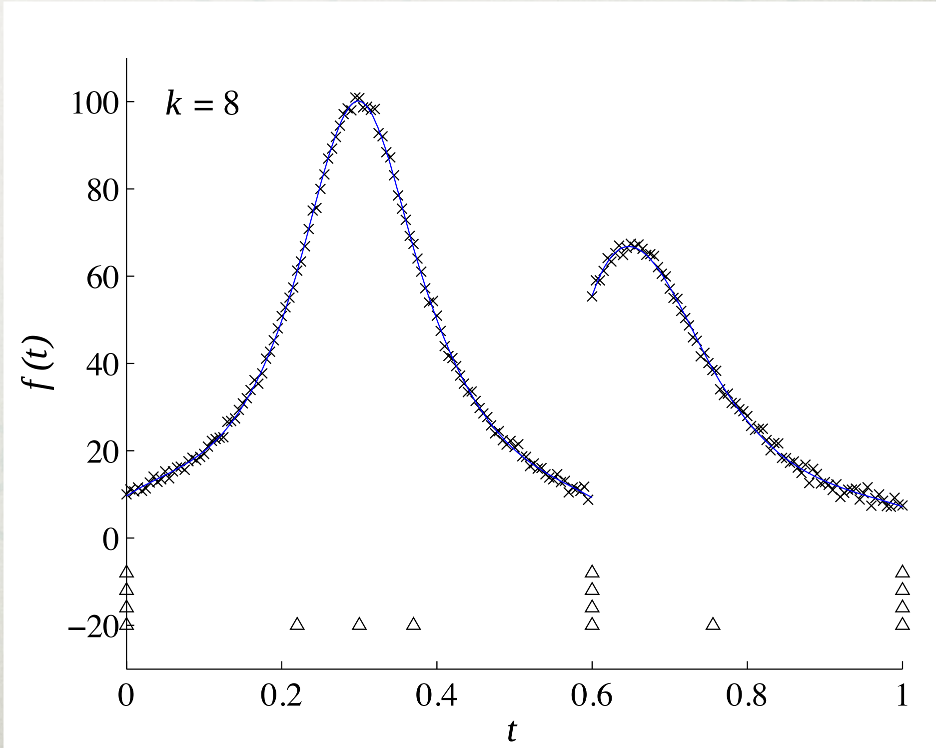
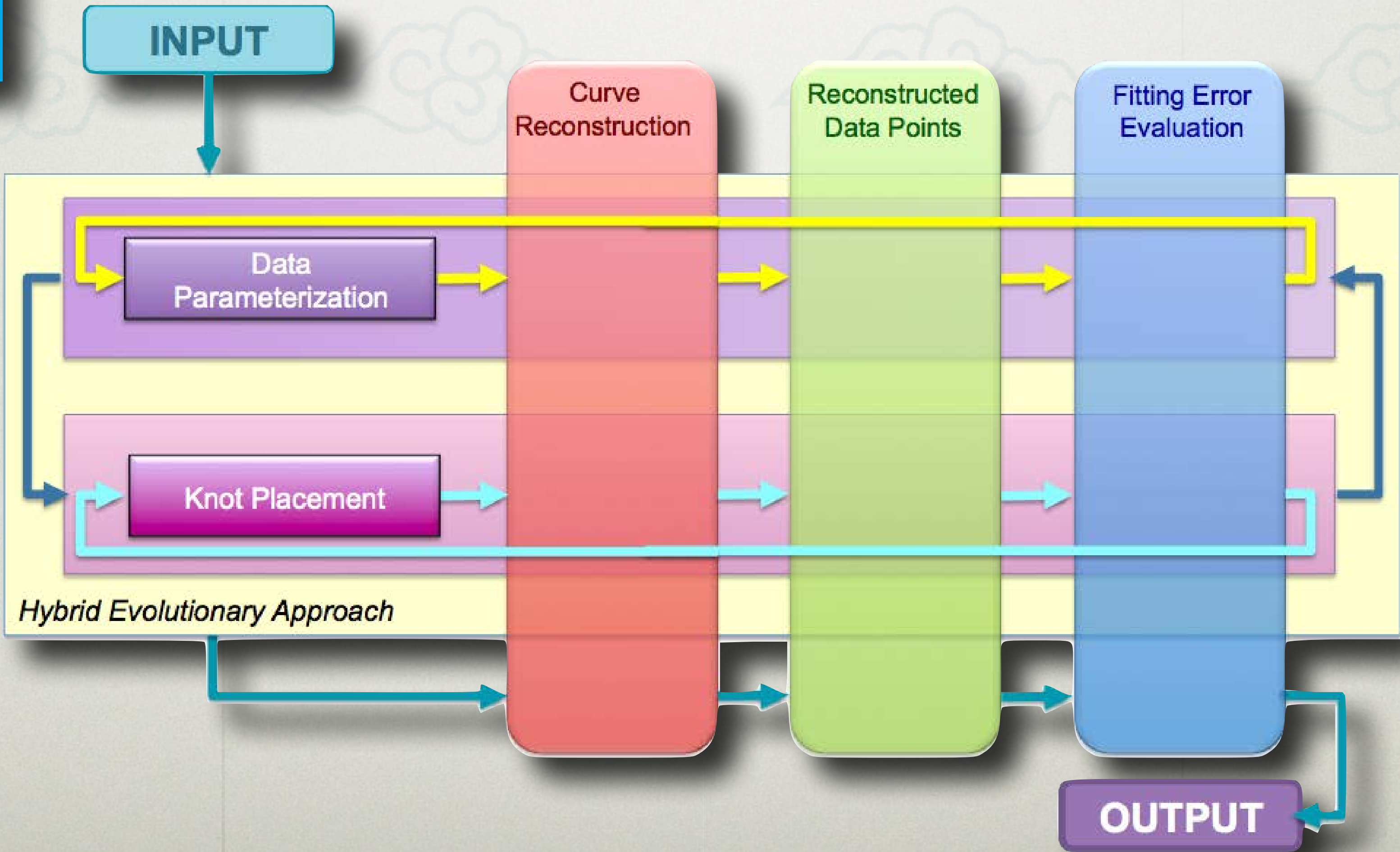




A. Gálvez, A. Iglesias: *"A New Iterative Mutually-Coupled Hybrid GA-PSO Approach for Curve Fitting in Manufacturing"*. Applied Soft Computing (I.F. 8.7), Vol.13, Issue 6, 1491-1504 (2013)



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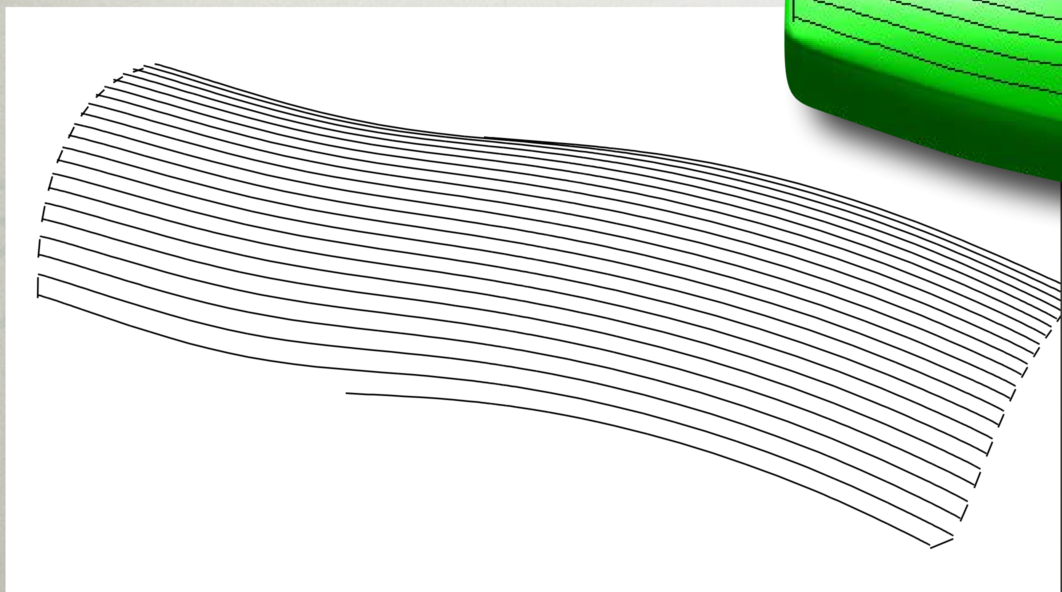

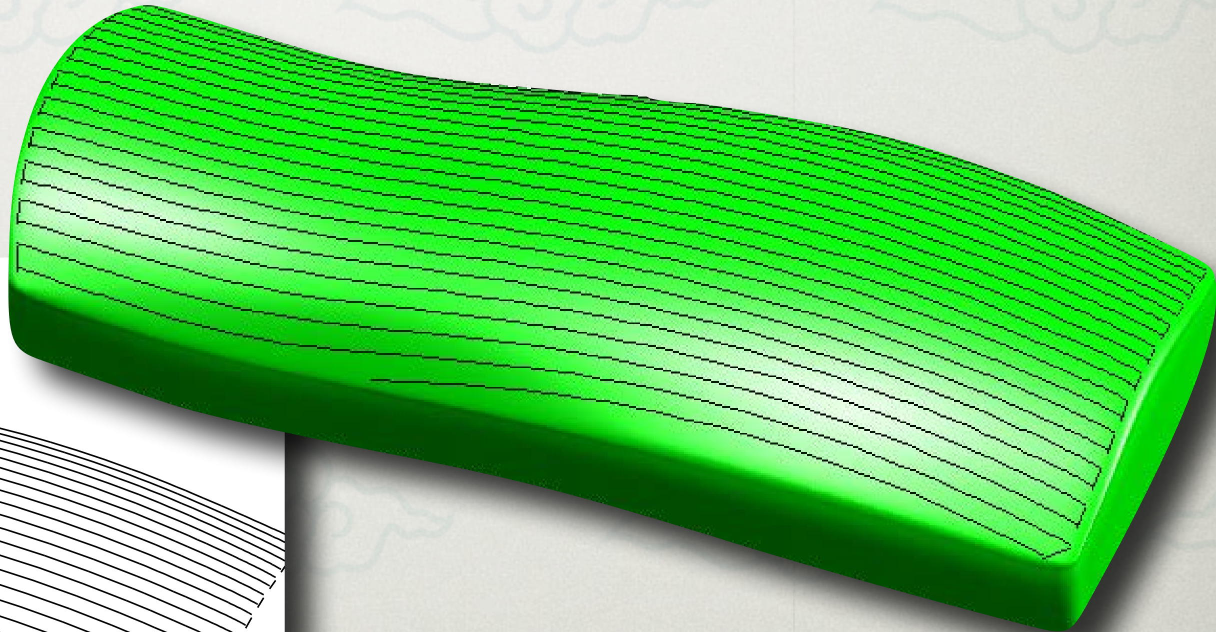

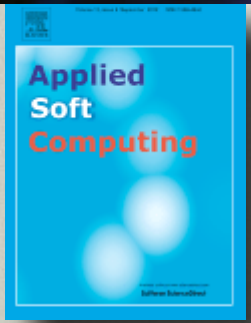

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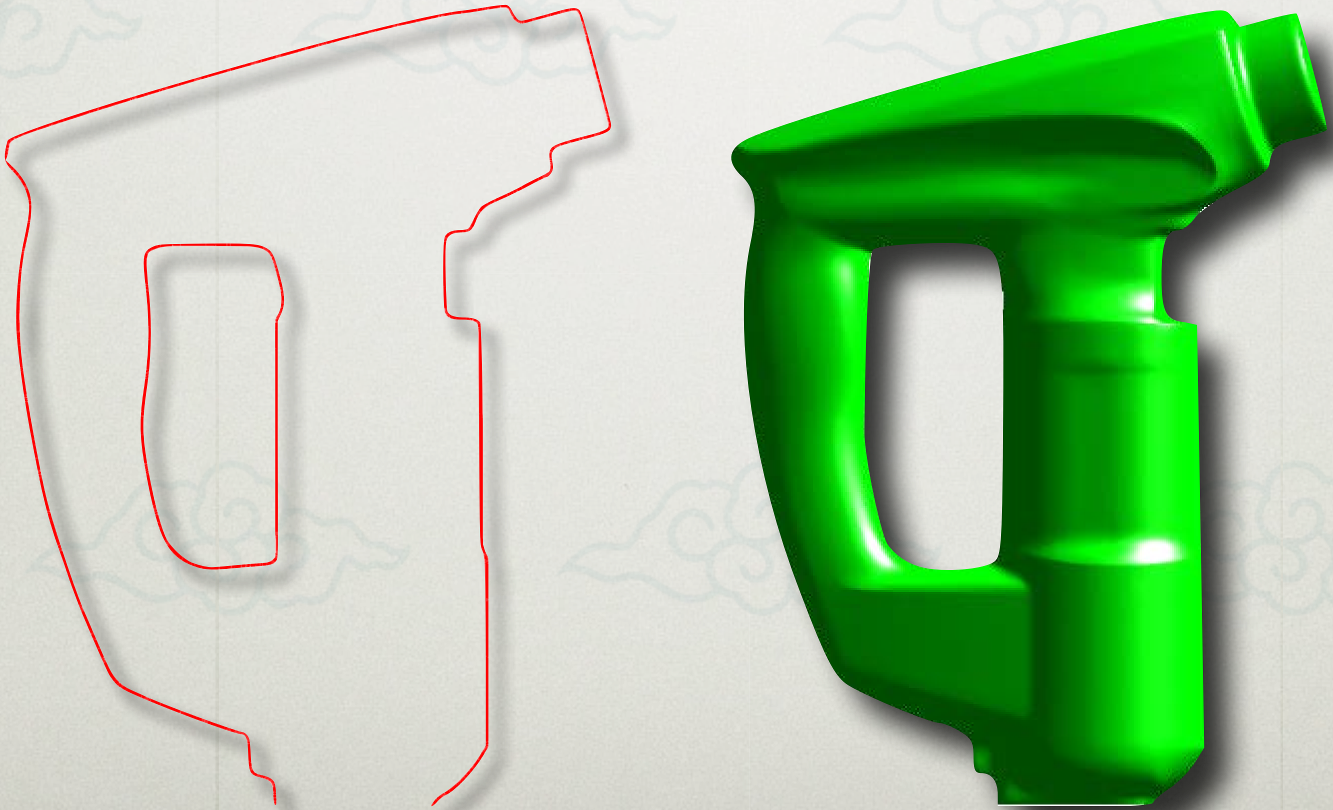
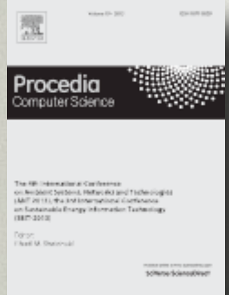
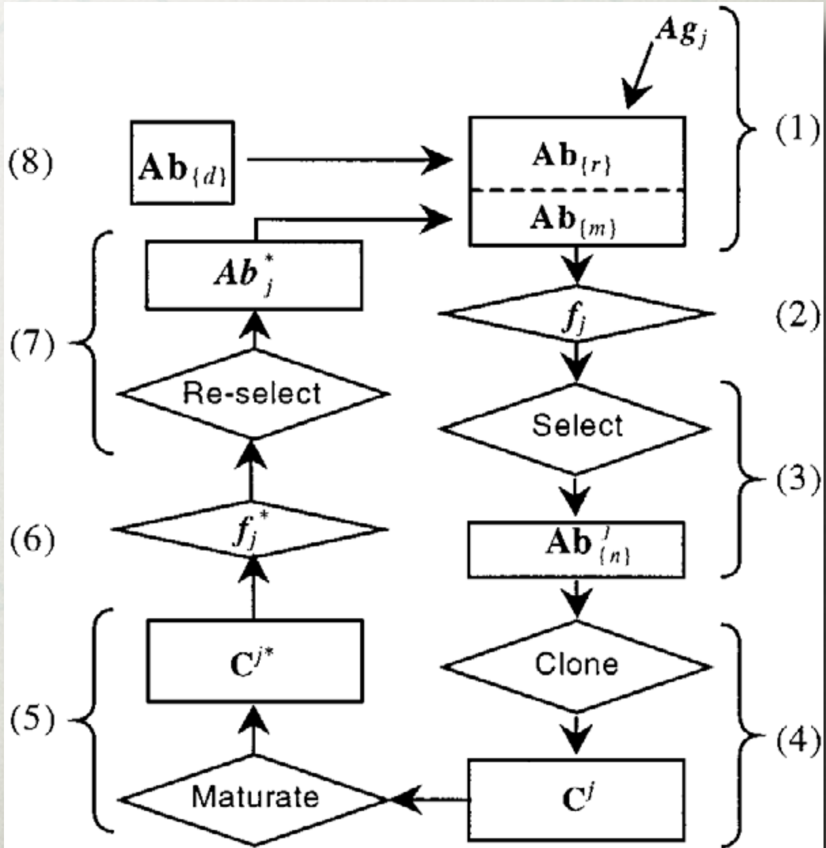
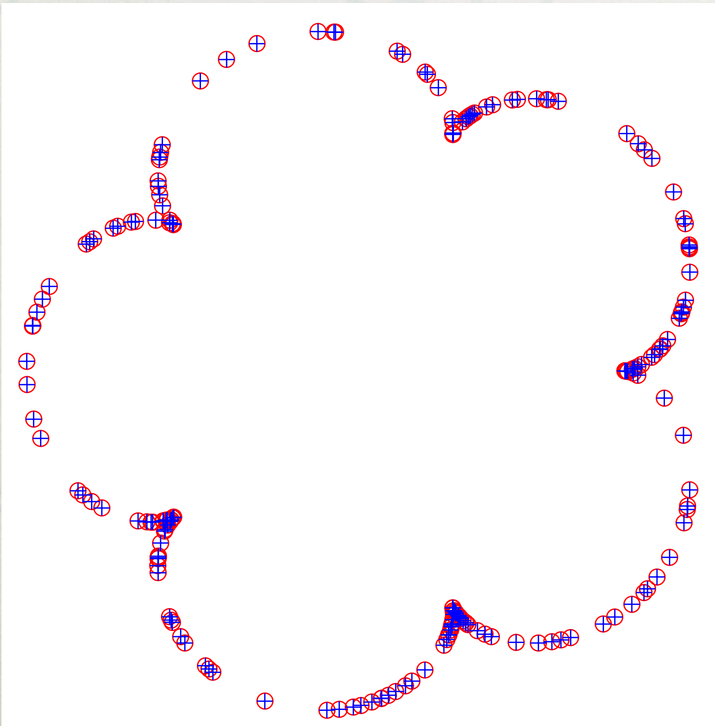


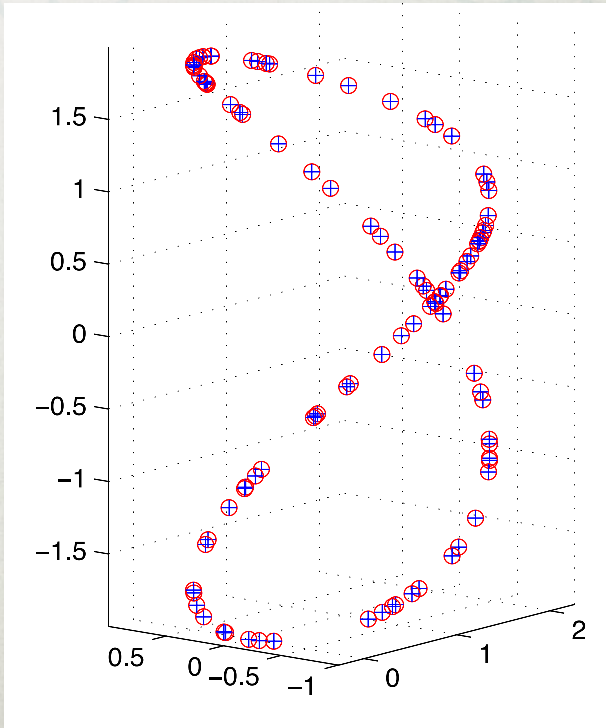


A. Gálvez, A. Iglesias, A. Avila: *"Immunological-based approach for accurate fitting of 3D noisy data points with Bézier surfaces"*. ICCS'2013 (CORE-A), 50-59 (2013)

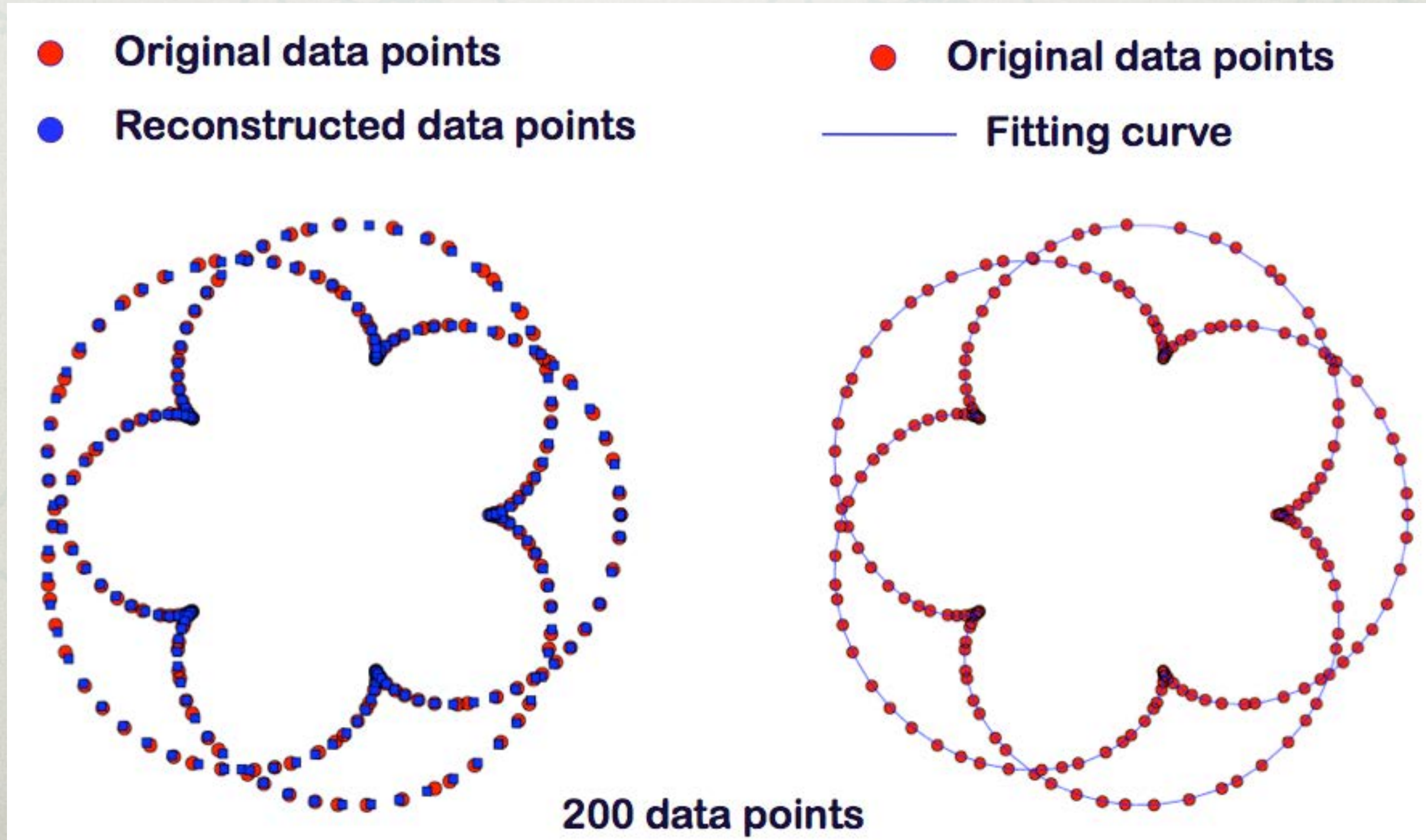


A. Gálvez, A. Iglesias, L. Cabellos: *"Tabu Search-Based Method for Bézier Curve Parameterization"*. Int. J. Software Eng. & Appl., Vol.7, Issue 5, 283-296 (2013)

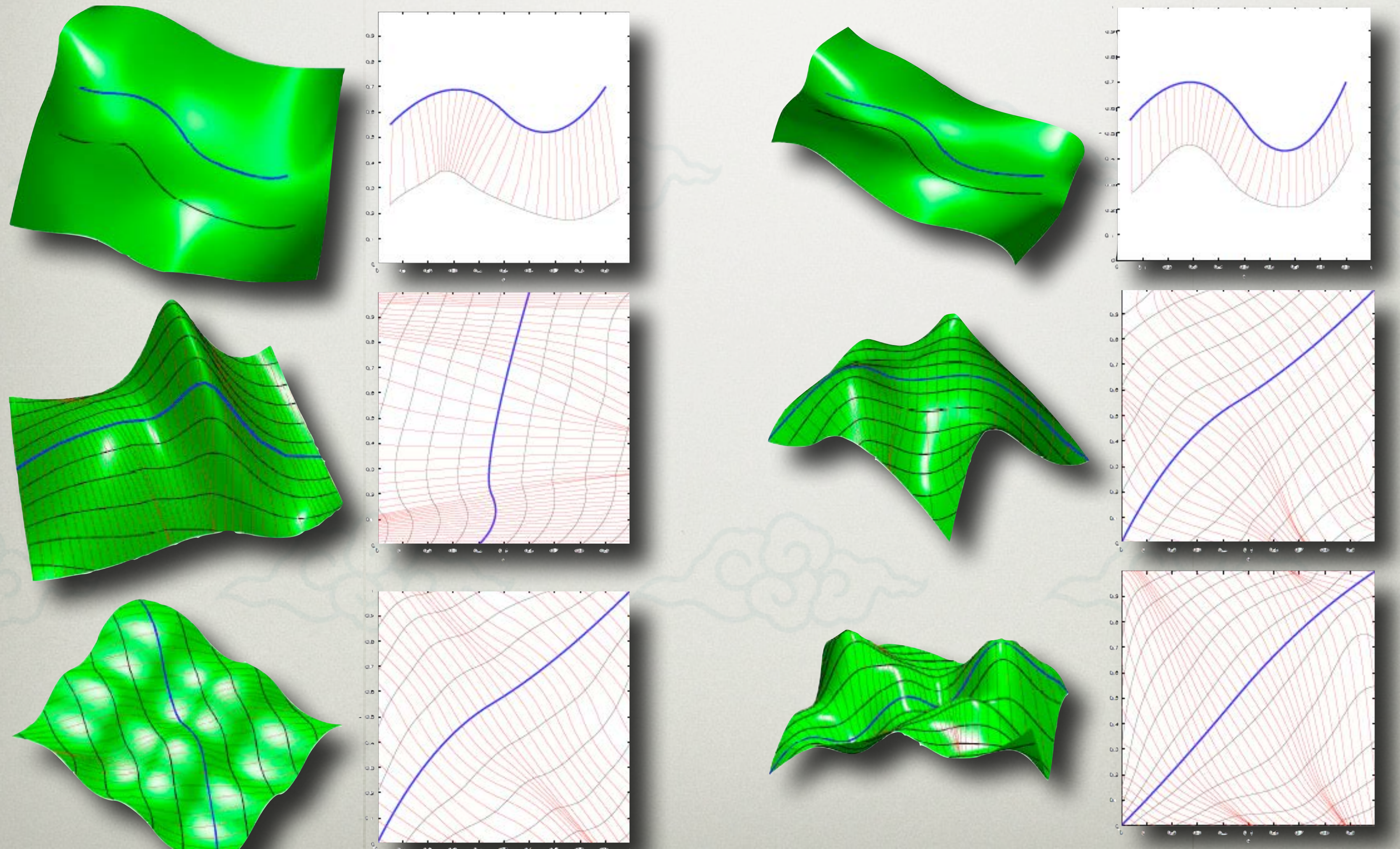




A. Gálvez, A. Iglesias, L. Cabellos: *"Firefly Algorithm for Explicit B-Spline Curve Fitting to Data Points"*. Journal of Applied Mathematics (I.F. 0.834) (2013)



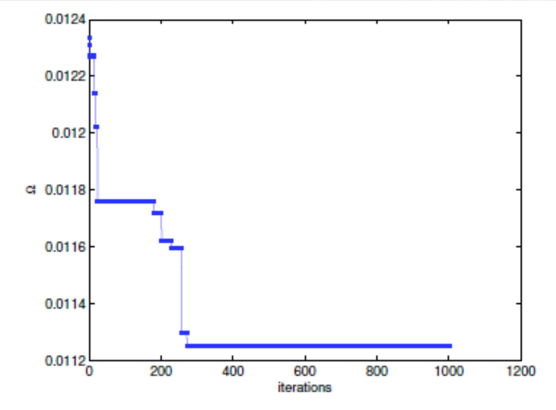
A. Iglesias, A. Gálvez: *"Computing parallel curves on parametric surfaces"*.
Applied Mathematical Modeling, (I.F. 5.0) Vol.38, 2398-2413 (2014)

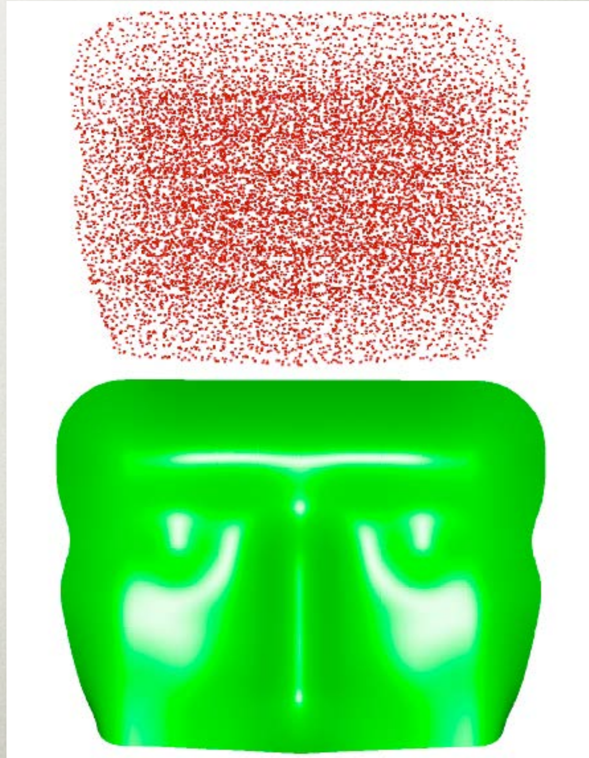


A. Gálvez, A. Iglesias: *"Firefly Algorithm for Explicit B-Spline Curve Fitting to Data Points"*. Mathematical Problems in Engineering (I.F. 1.383) (2013)

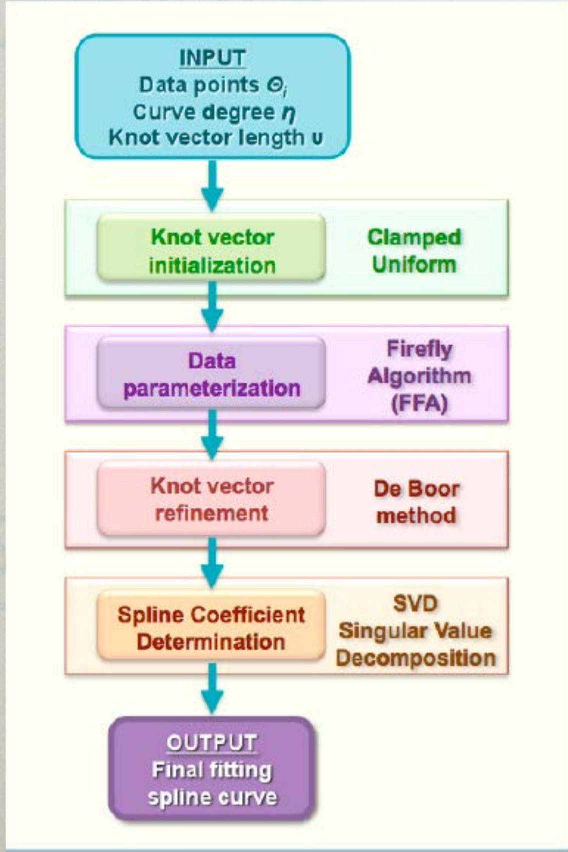
A. Gálvez, A. Iglesias, A. Avila, C. Otero, R. Arias, C. Manchado: *"Elitist Clonal Selection Algorithm for Optimal Choice of Free Knots in B-spline Data Fitting"*. Applied Soft Computing, (I.F. 8.7) (*sub. April 2013*)

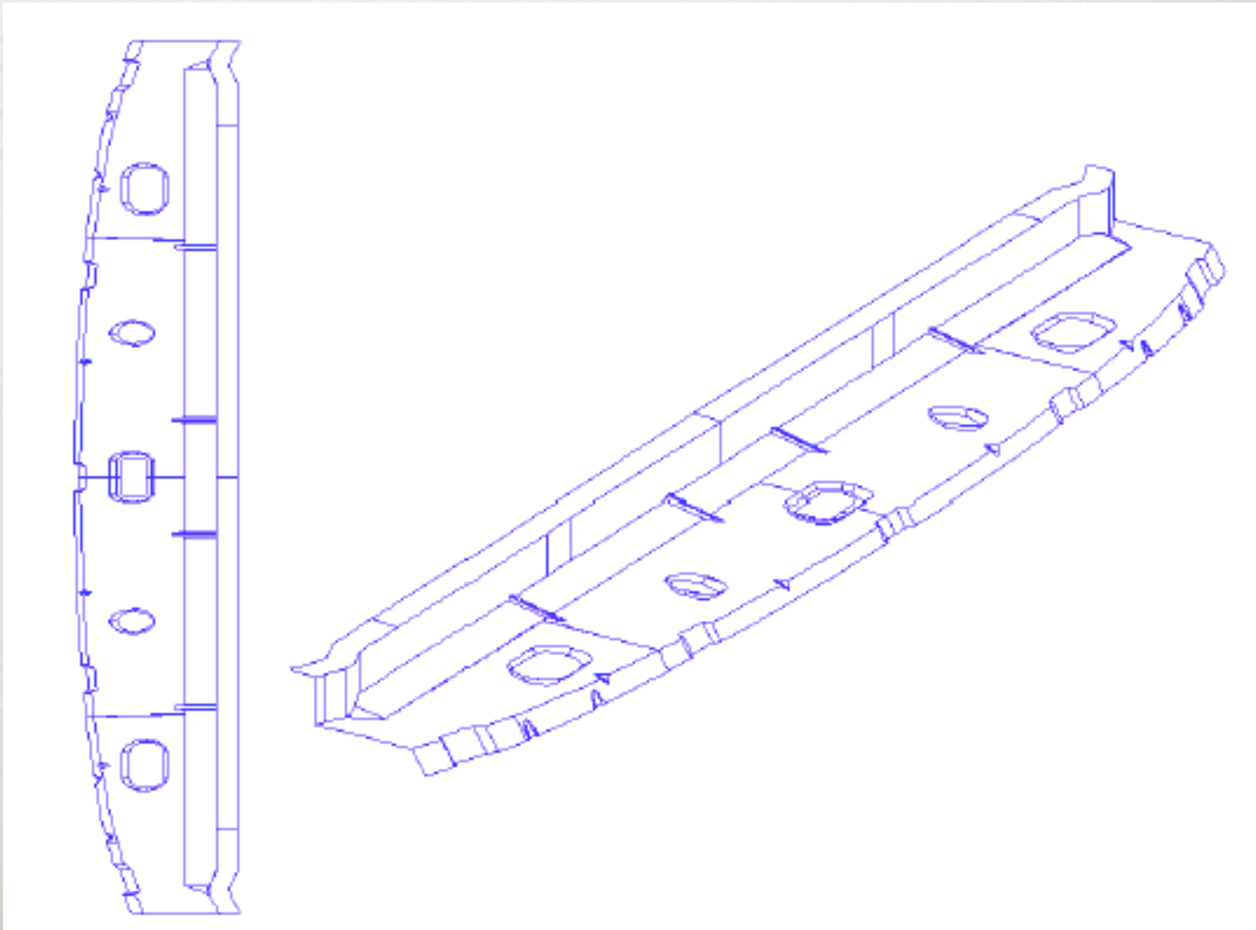
A. Gálvez, A. Iglesias: *"Hybrid Functional-Neural Approach for Surface Reconstruction"*. Mathematical Problems in Engineering (I.F. 1.383) (2014)



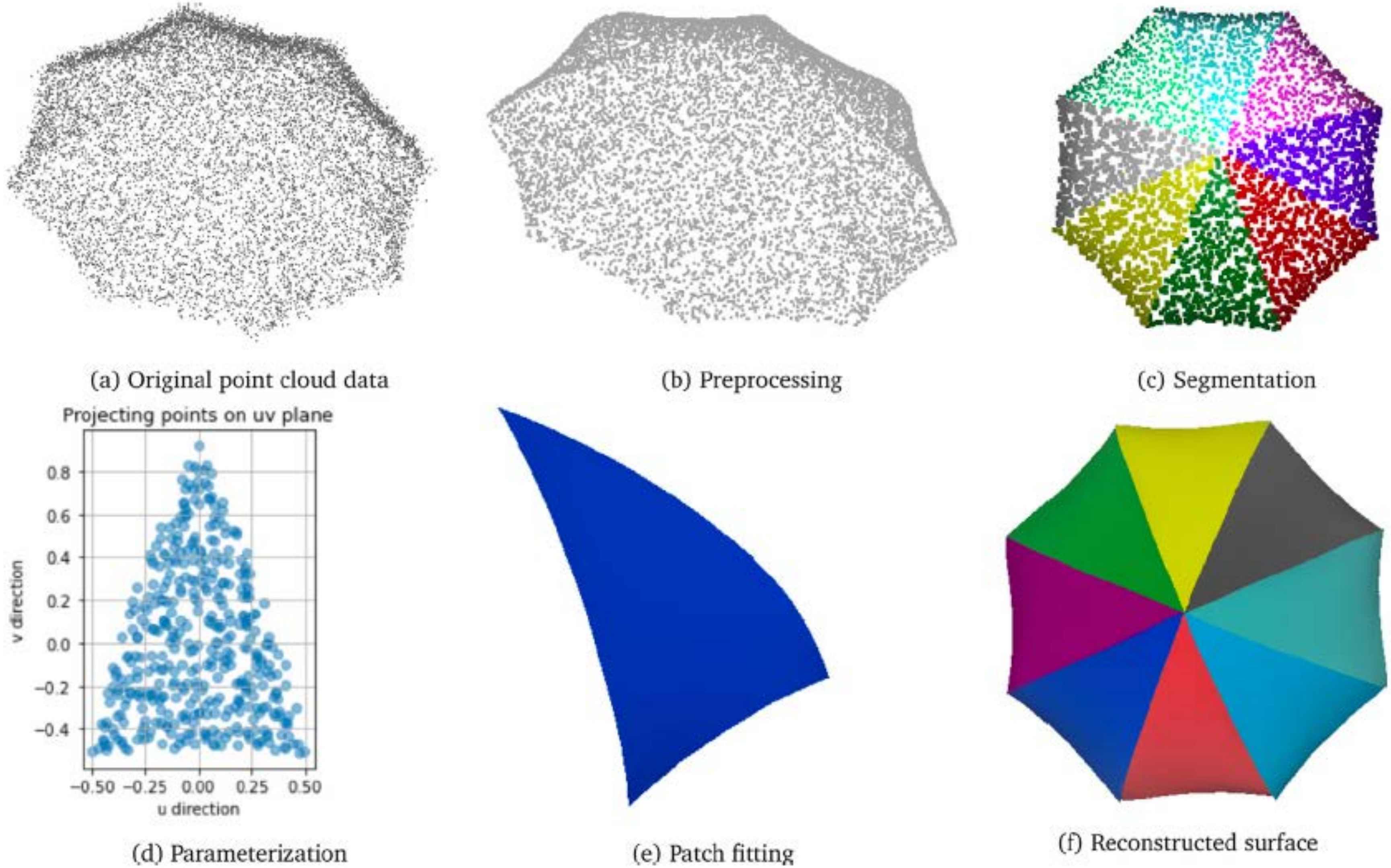


A. Gálvez, A. Iglesias: *“From Nonlinear Optimization to Convex Optimization Through Firefly Algorithm and Indirect Approach with Applications to CAD/CAM”*. The Scientific World Journal (I.F. 1.730) (2013)





Z Zhu, A Zheng, A Iglesias, S Wang, Y Xia, E Chaudhry, L You, J Zhang: *"PDE patch-based surface reconstruction from point clouds"*. Journal of Computational Science (I.F. 3.3), 61, Paper 101647 (2022).



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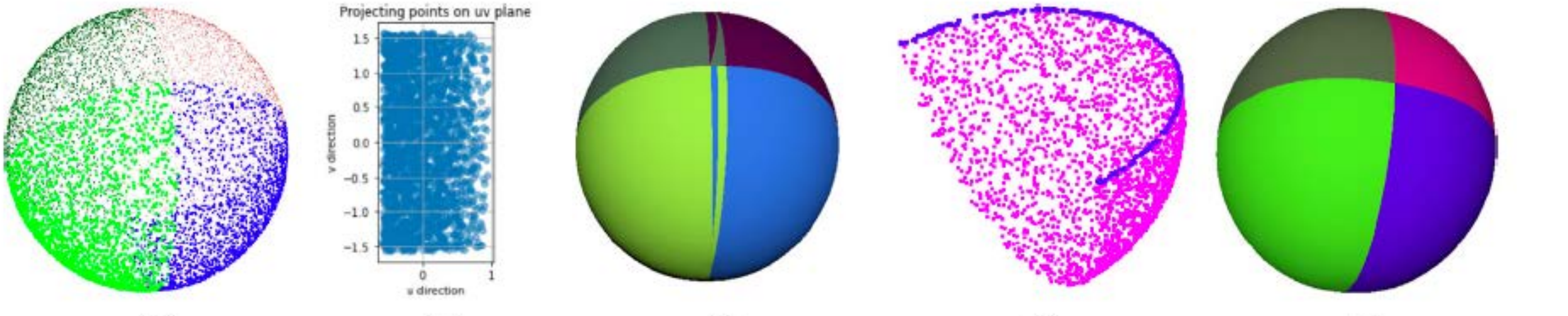
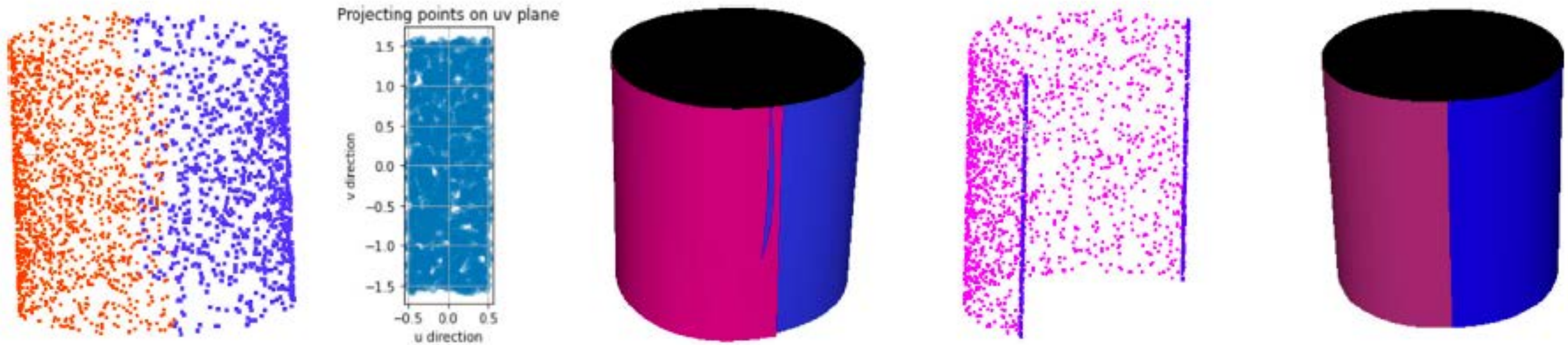


(a) (b) (c) (d) (e)



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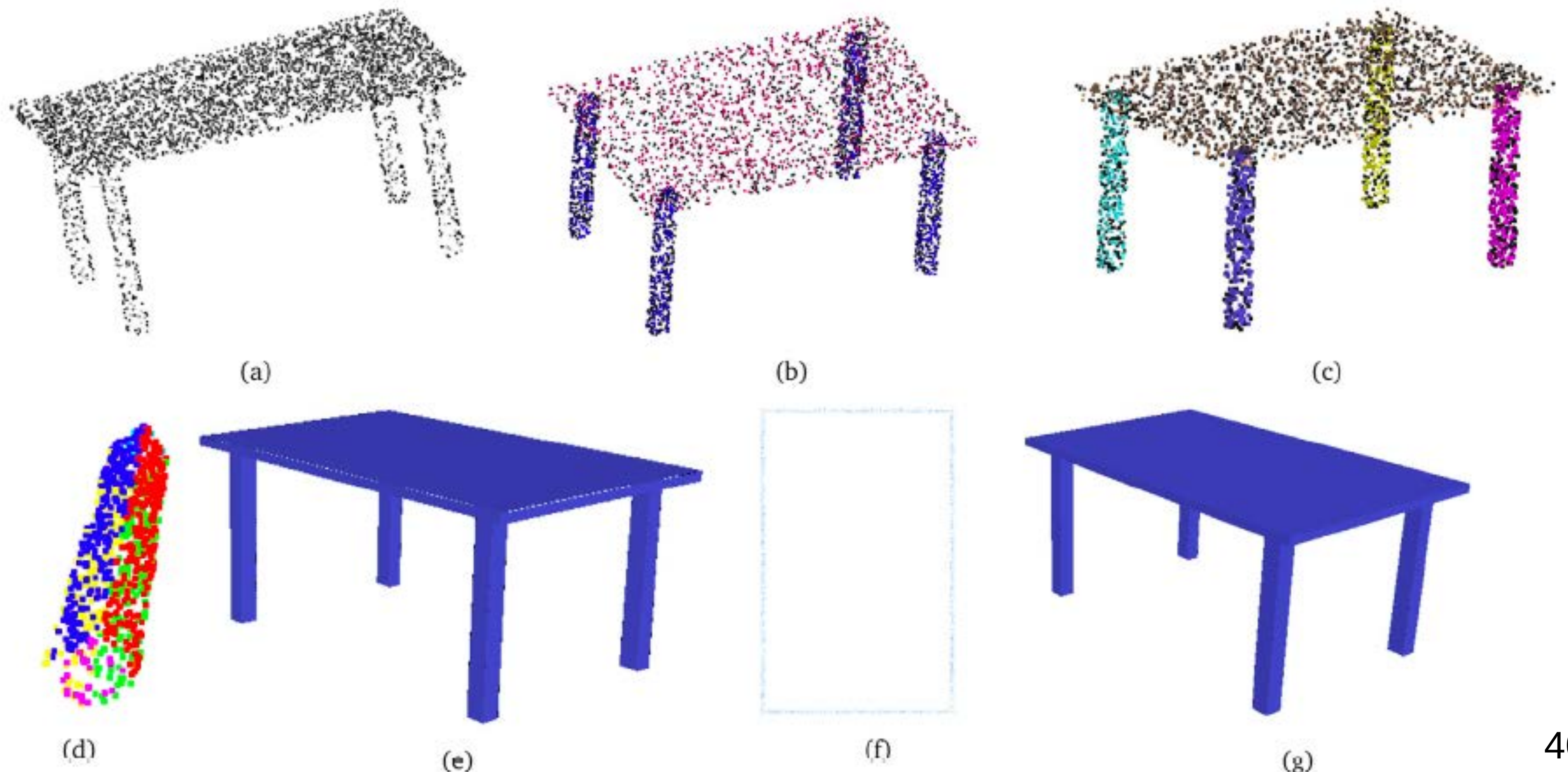

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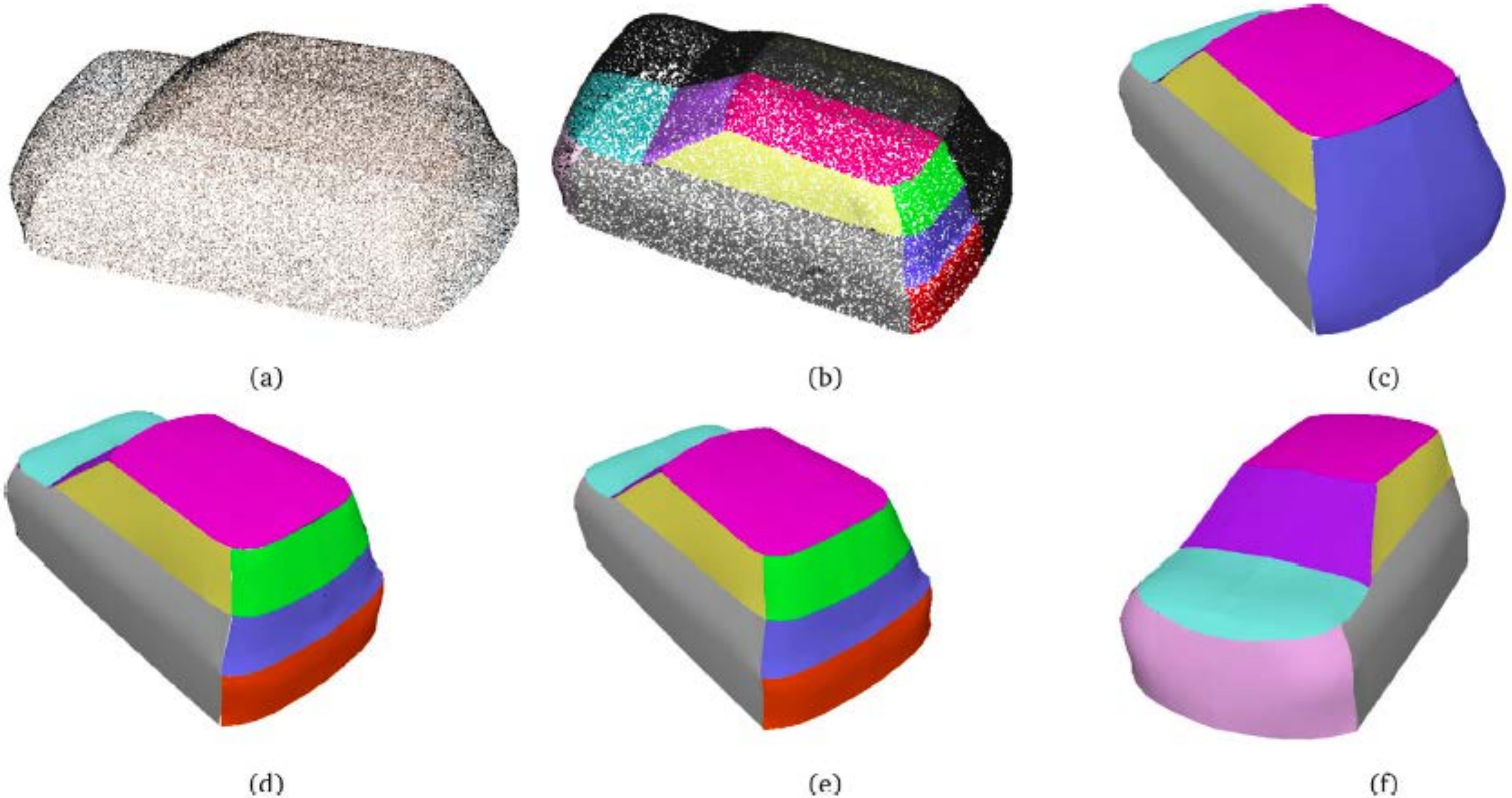
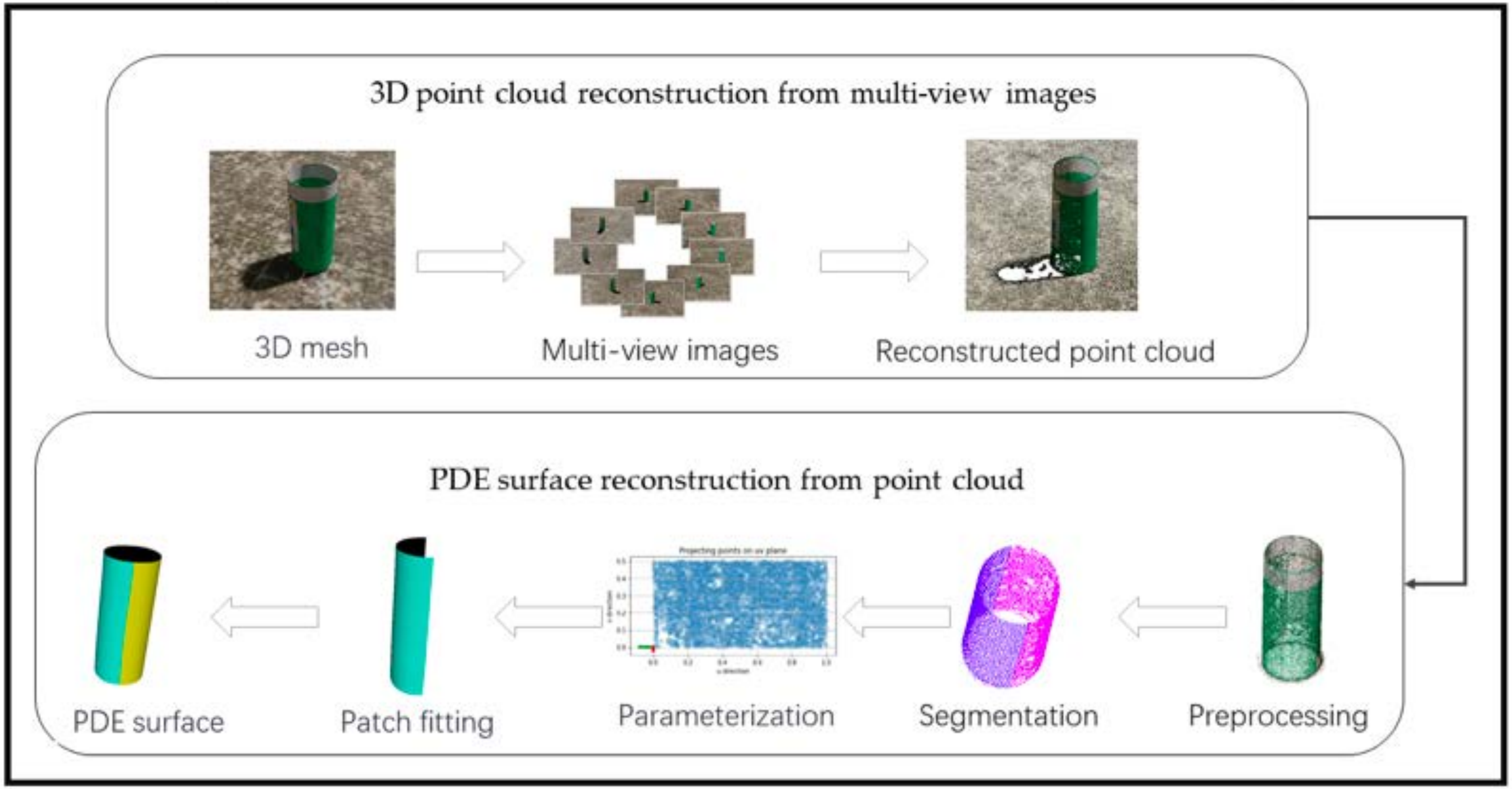


Zhu Z., Iglesias A., Zhou L., You L., Zhang J.J.: *"PDE-Based 3D Surface Reconstruction from Multi-View 2D Images".* Mathematics (I.F. 2.4), 10(4), Paper 542 (2022).

Pipeline of PDE-surface reconstruction from multi-view images



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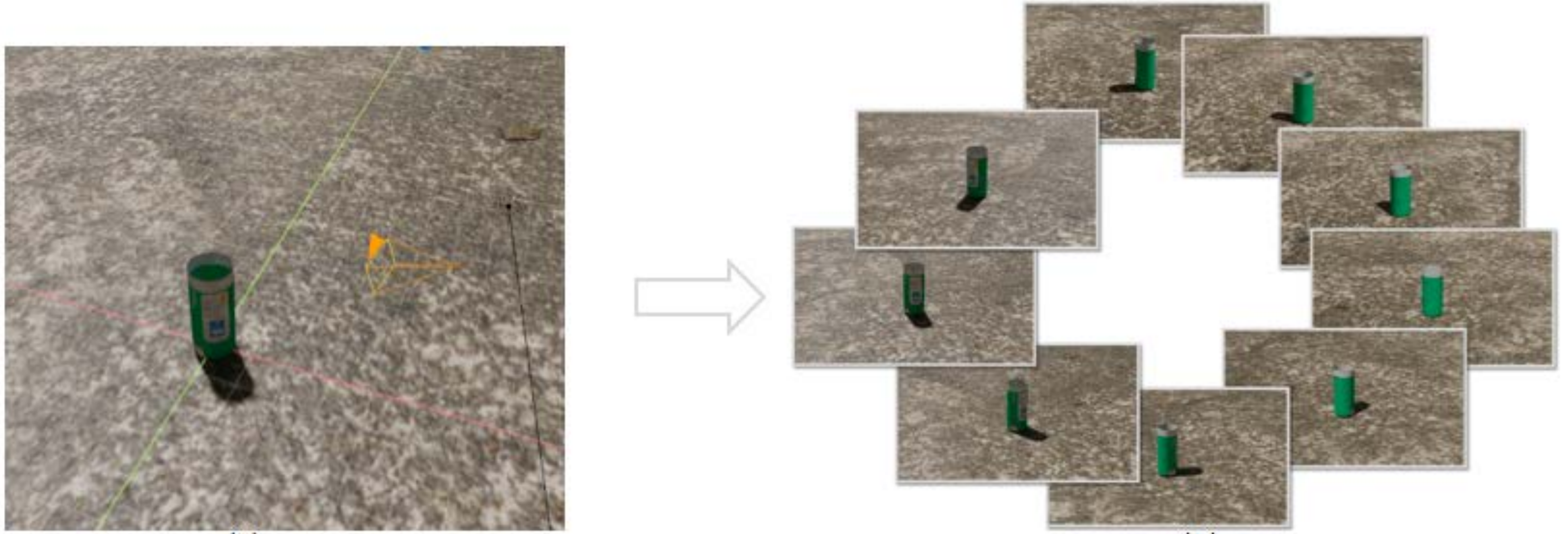

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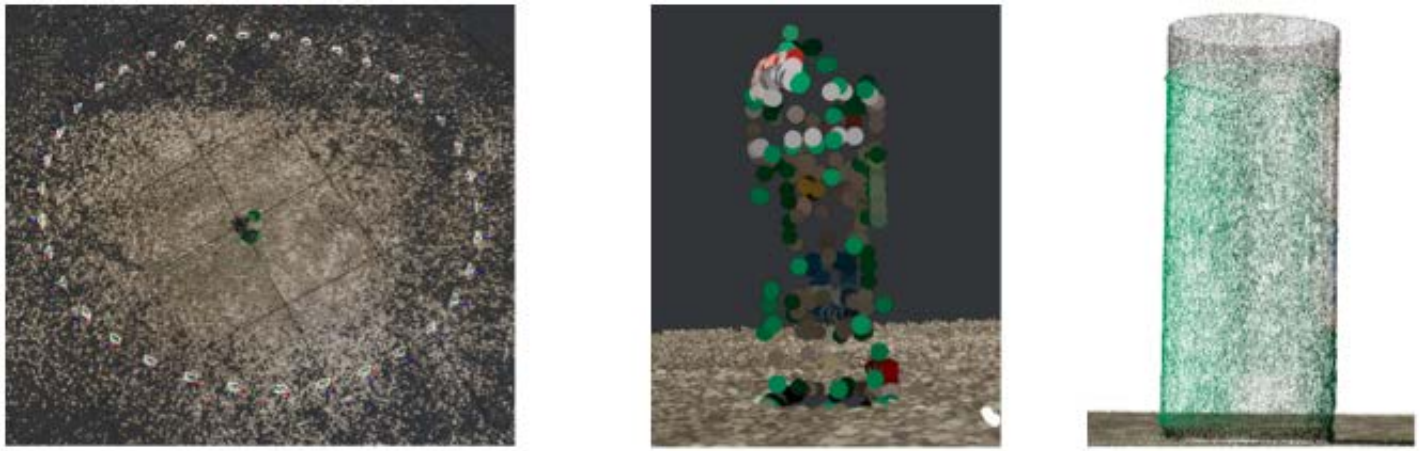

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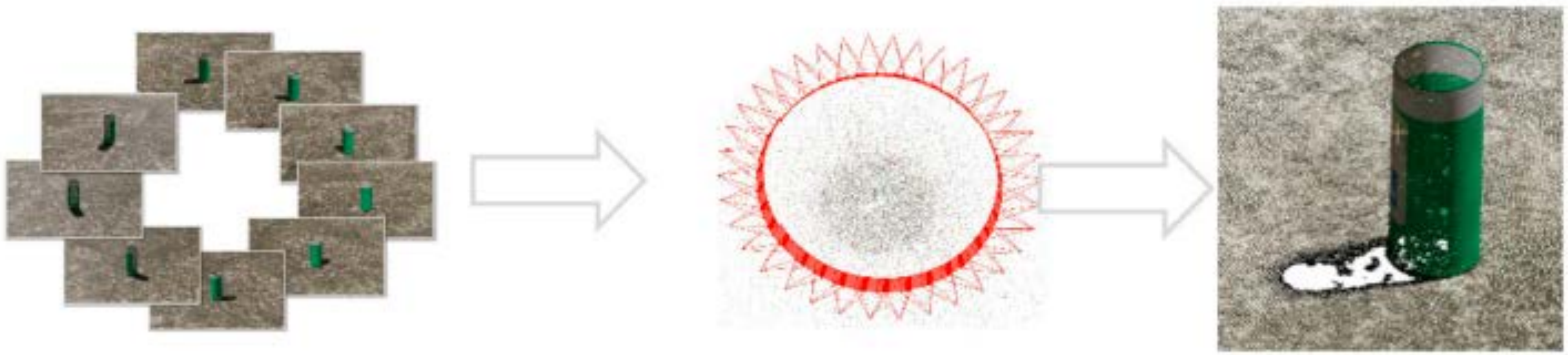

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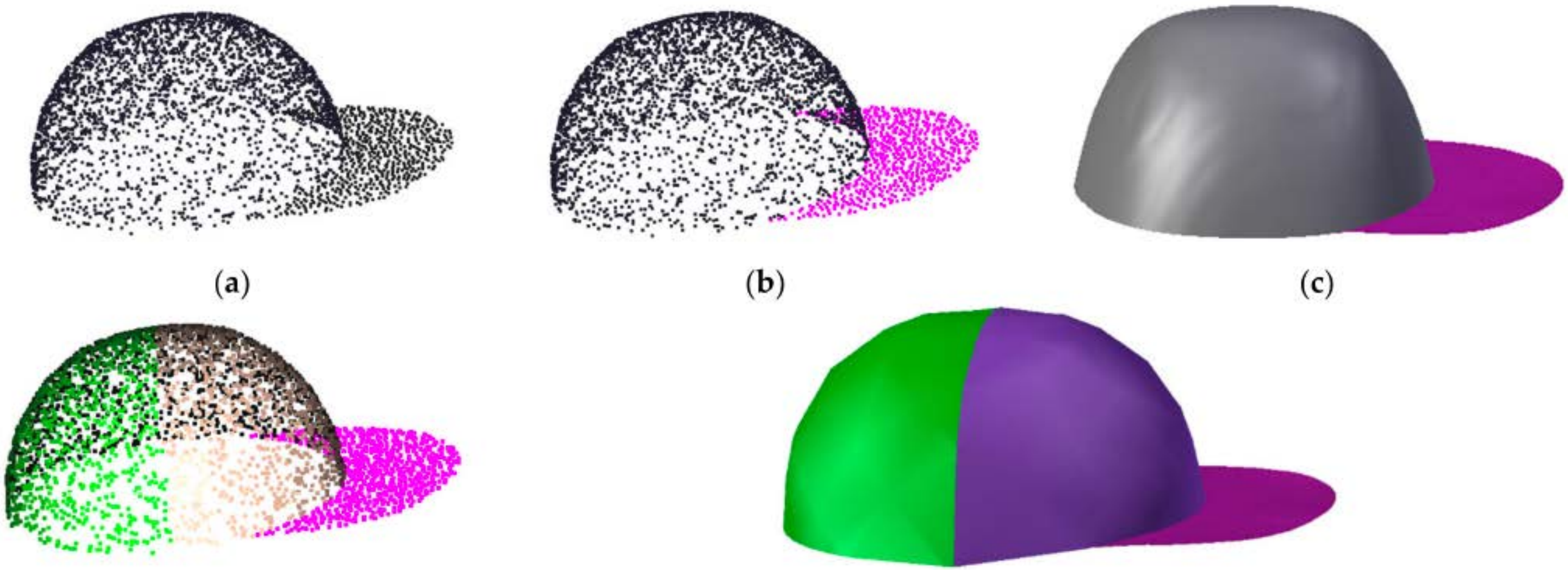
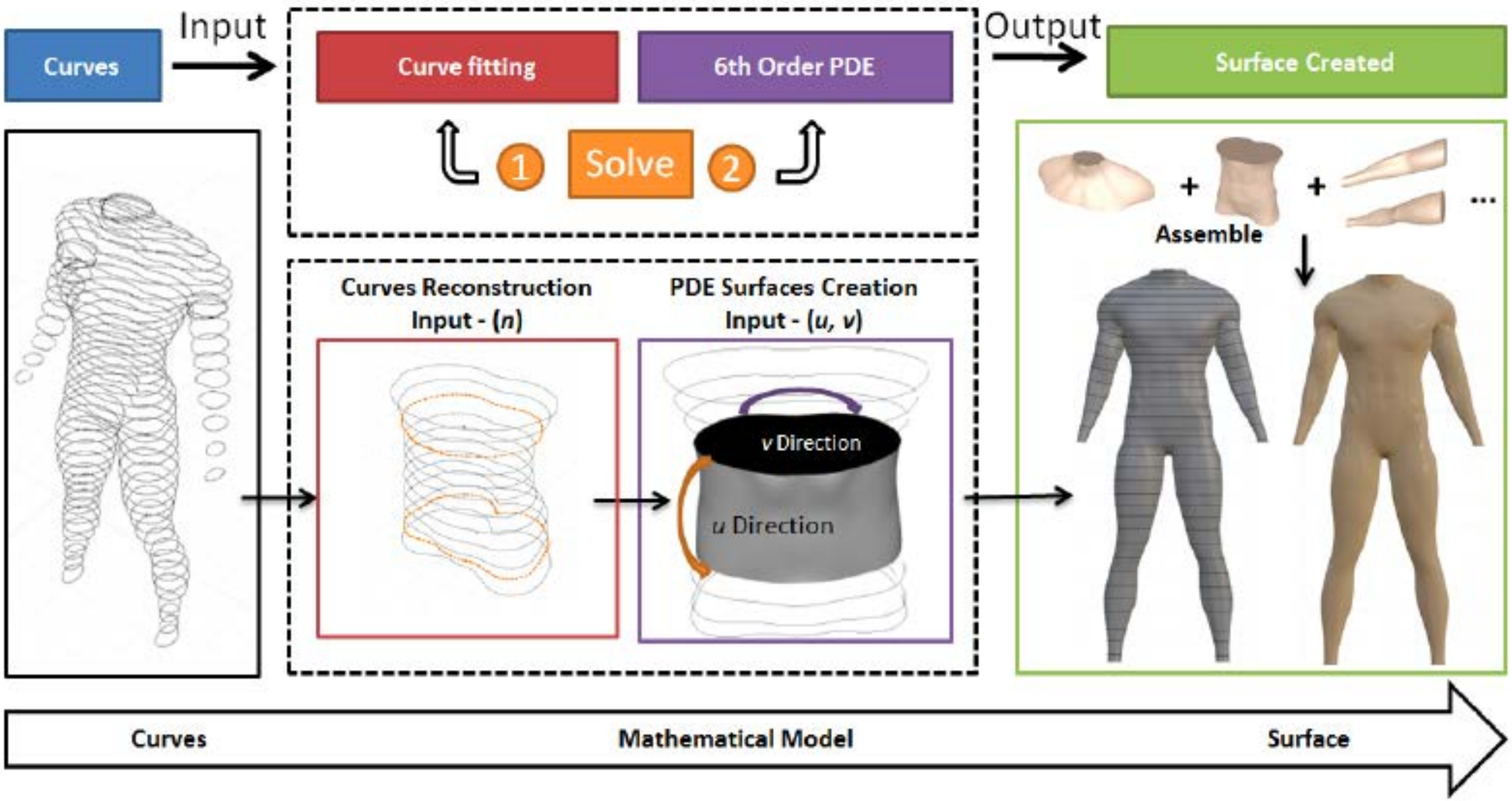


(a) (b) (c)

(d) (e)

H. Fu, S. Bian, O. Li, J. Macey, A. Iglesias, E. Chaudhry, L. You, J.J. Zhang: *"3D Modelling with C^2 Continuous PDE Surface Patches"*. Mathematics (I.F. 2.4), 10(3), Paper 319 (2022).



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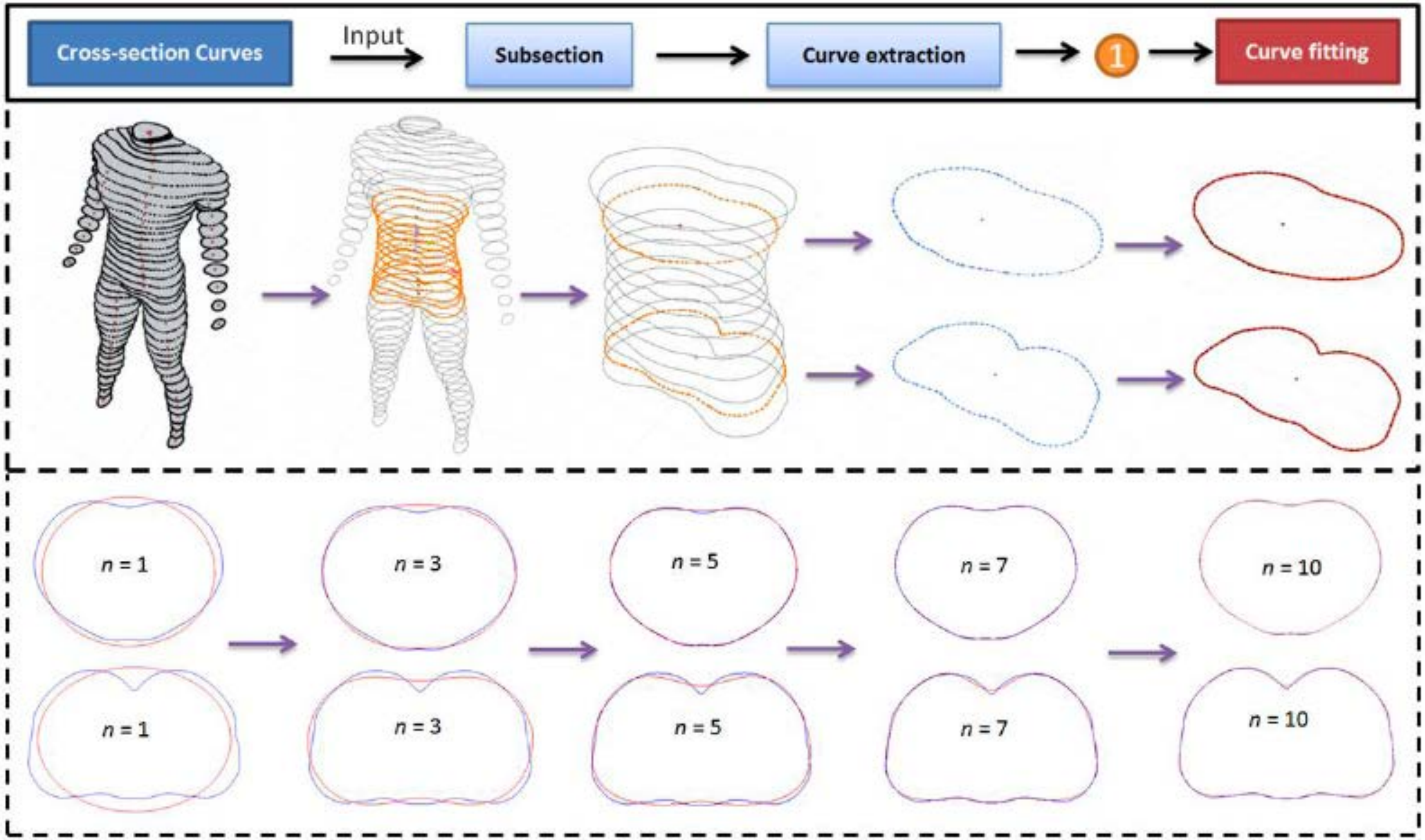

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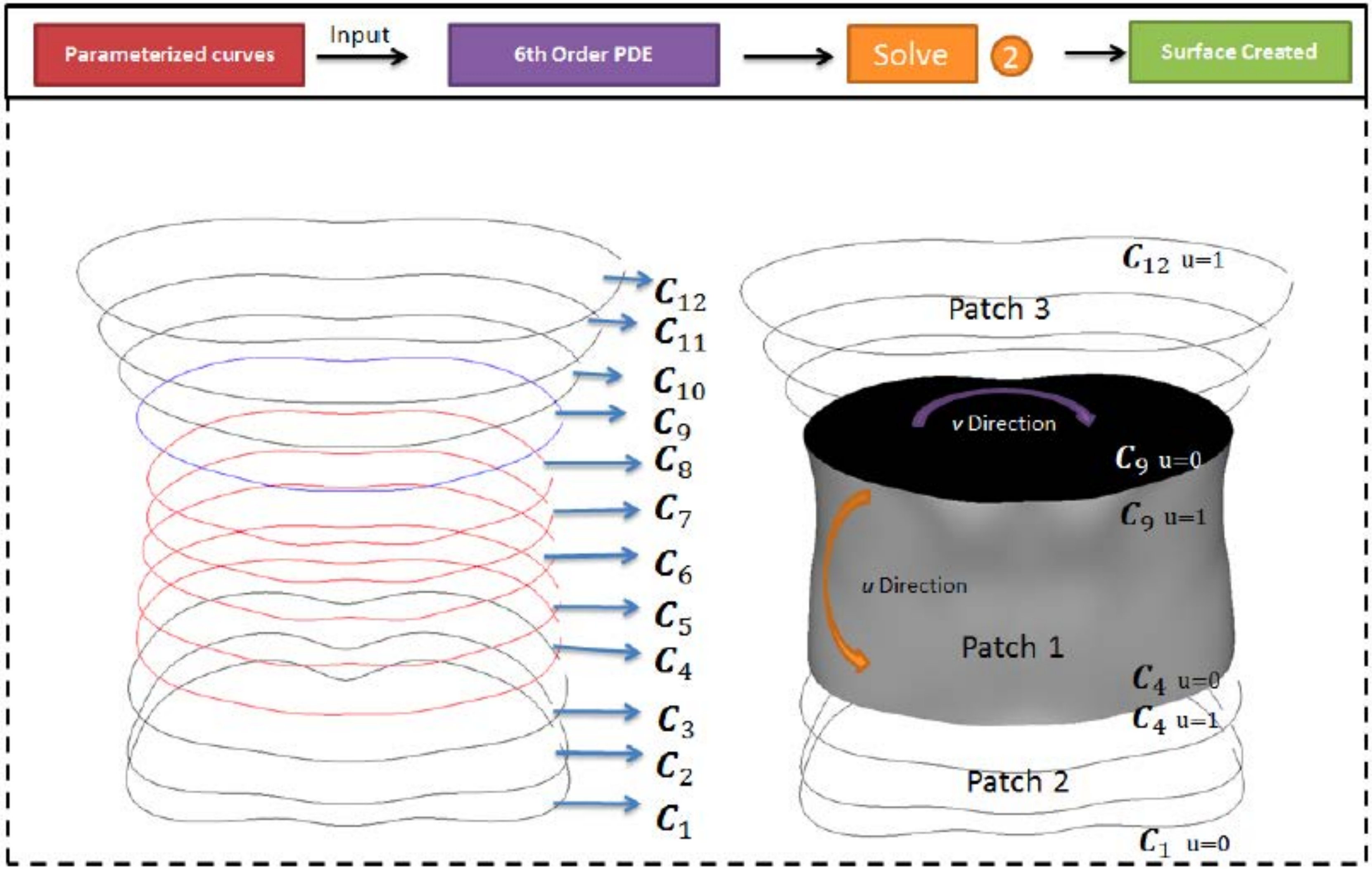

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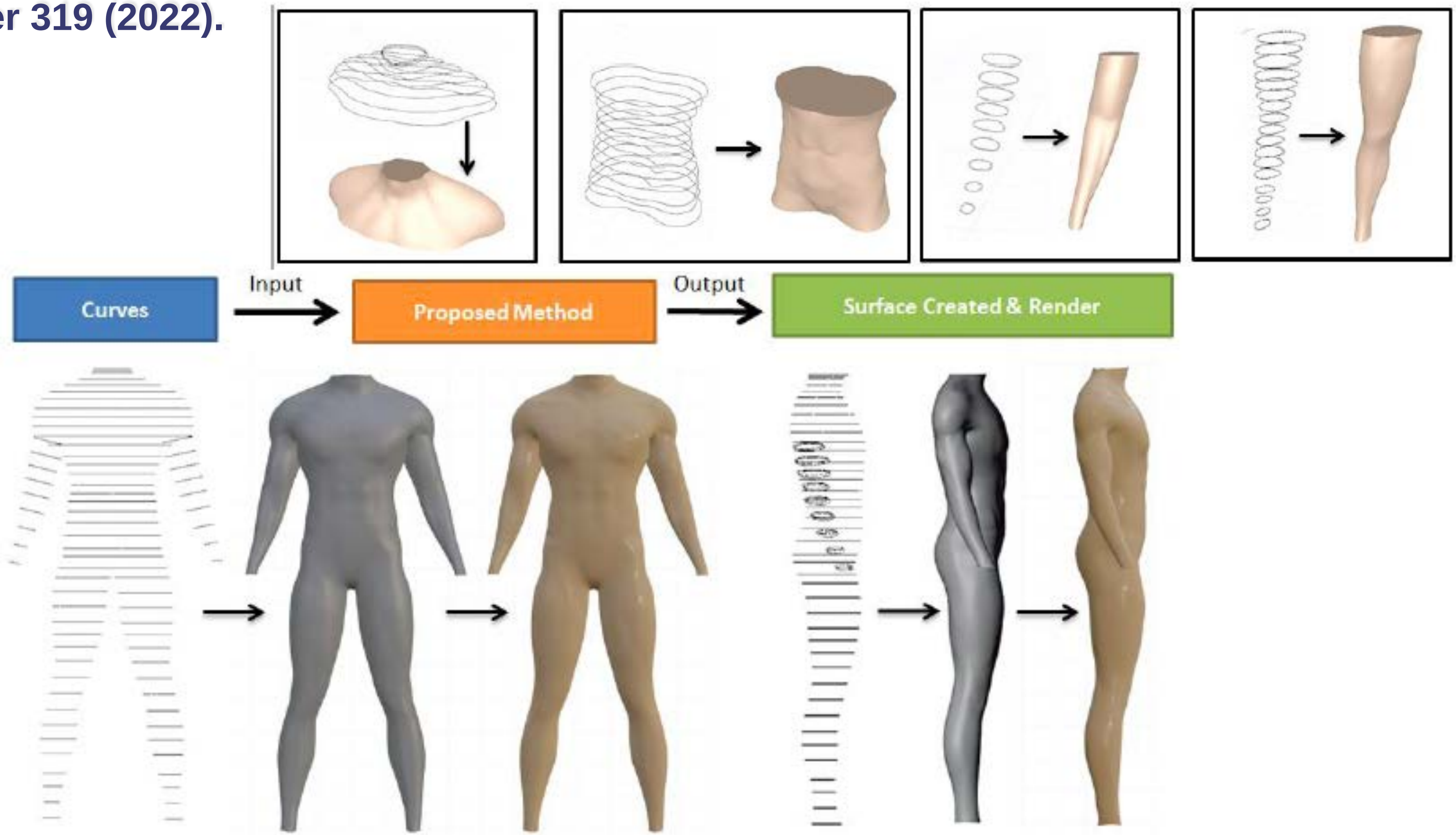

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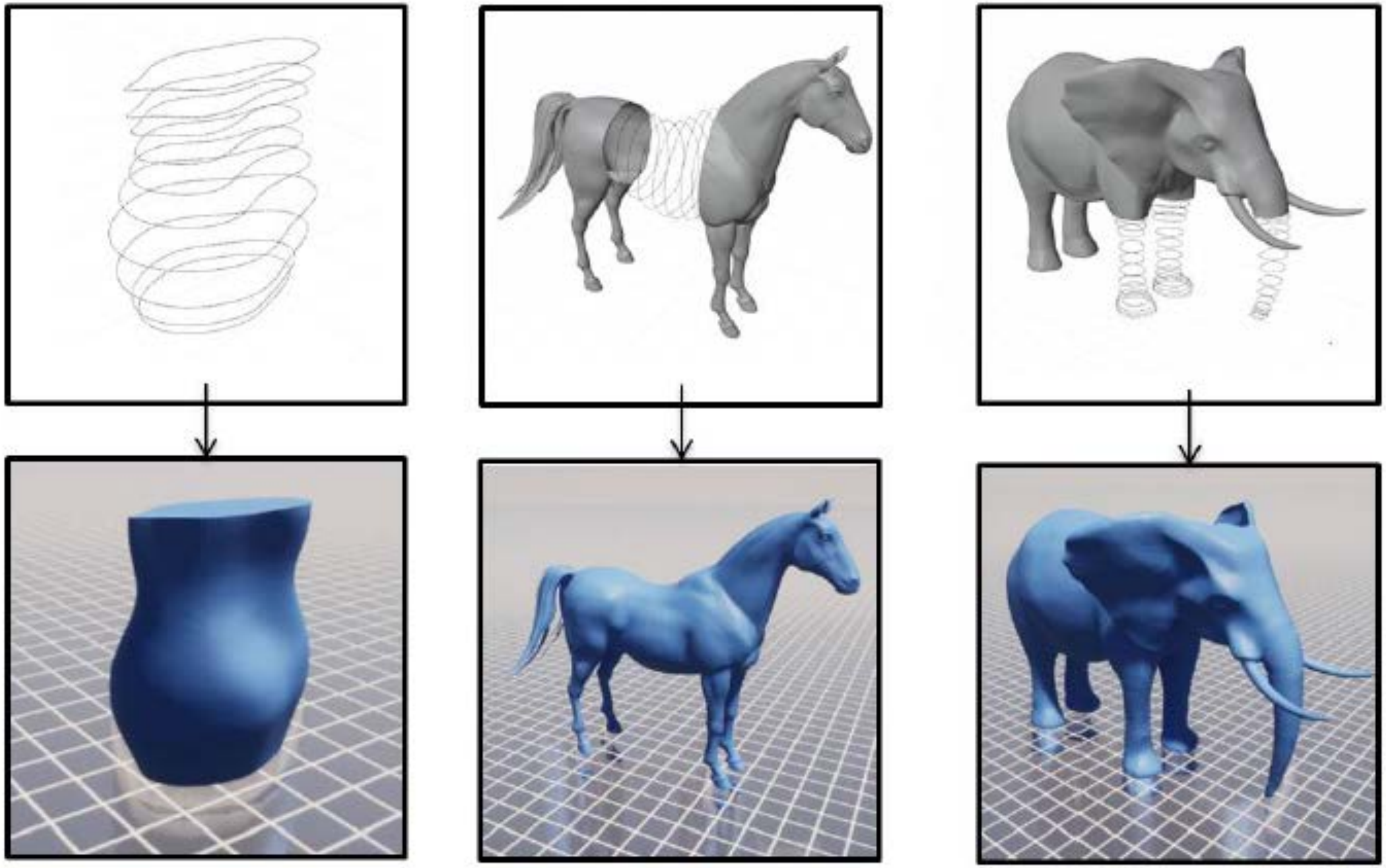
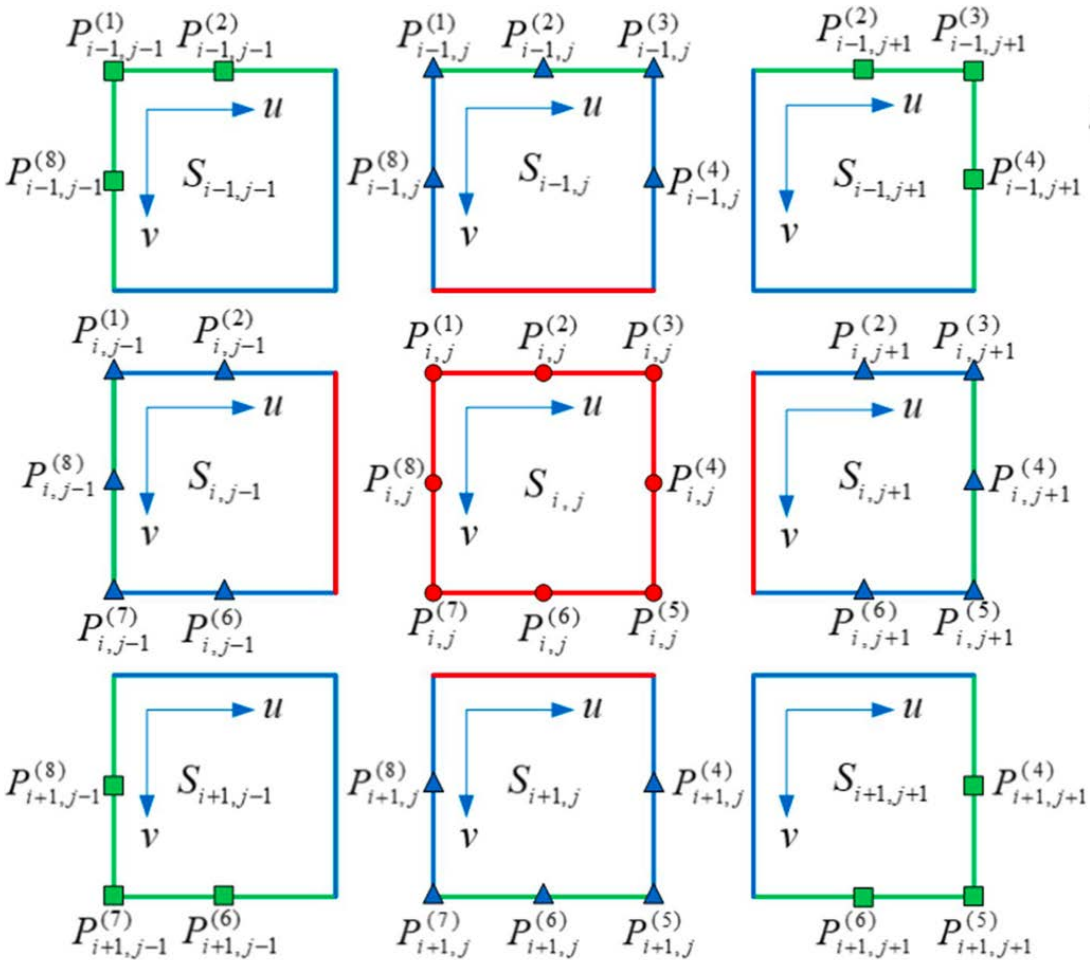
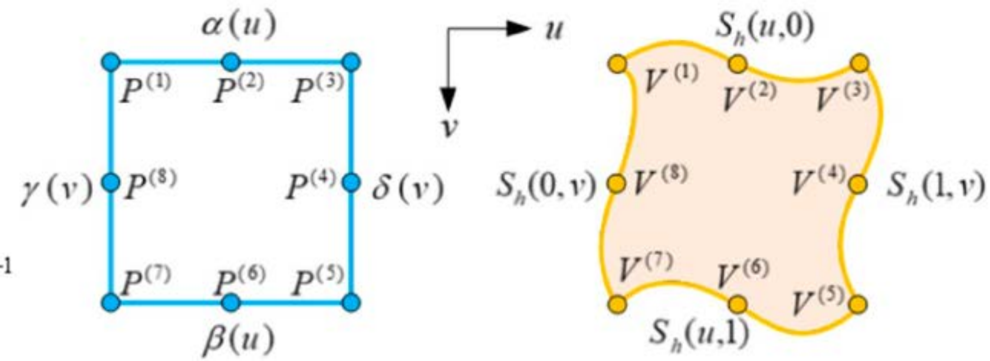
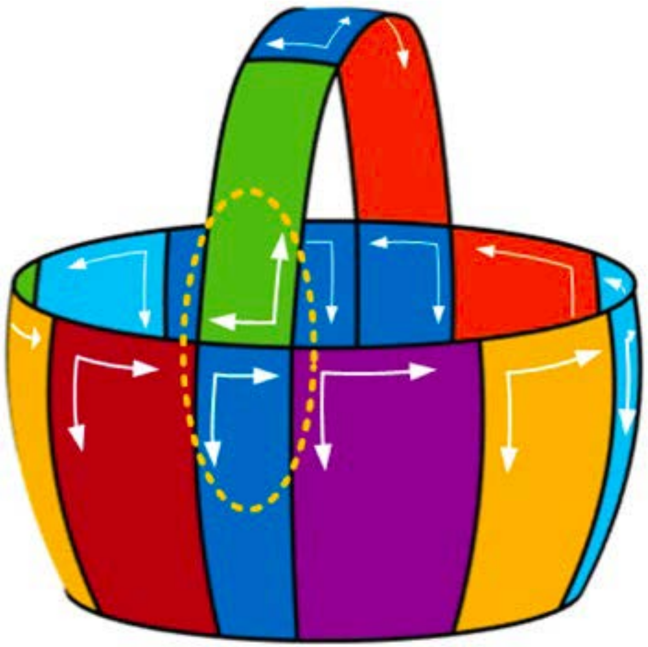


S. Wang, Y. Xia, L. You, H. Ugail, A. Carriazo, A. Iglesias, J.J. Zhang: "Interactive PDE patch-based surface modeling from vertex-frames". **Engineering with Computers** **(I.F. 8.7)**, Vol. 38, pp. 4367-4382 (2022).





(a)
(b)



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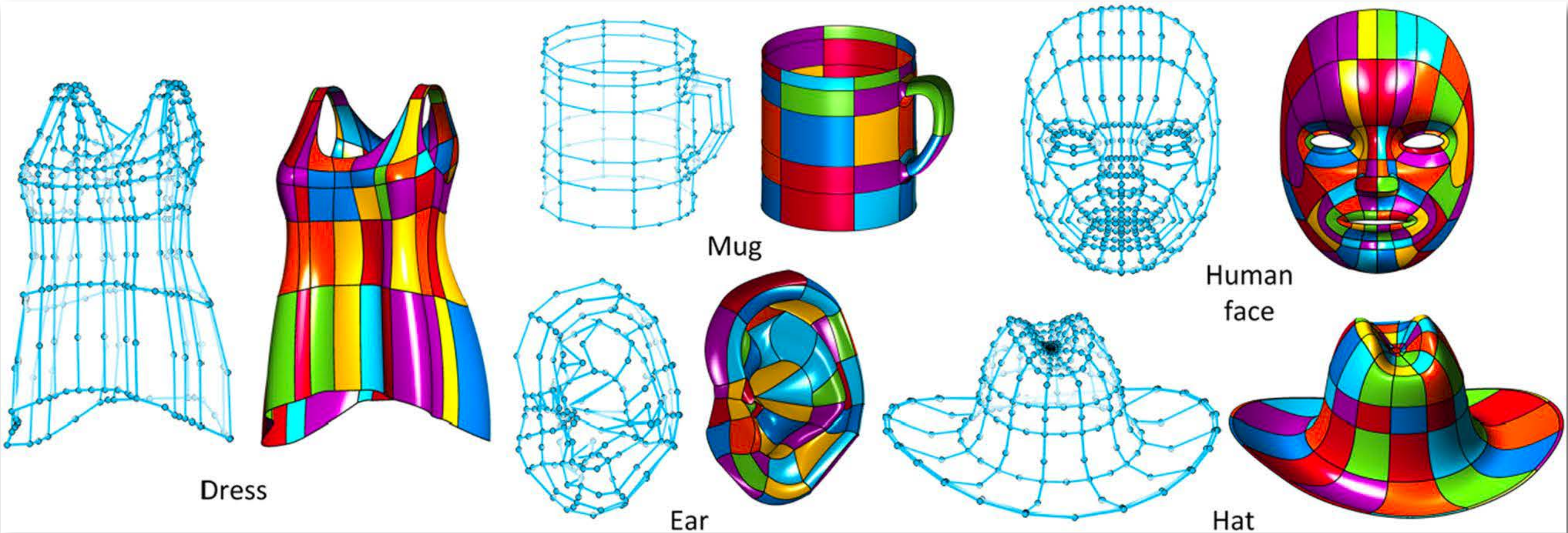

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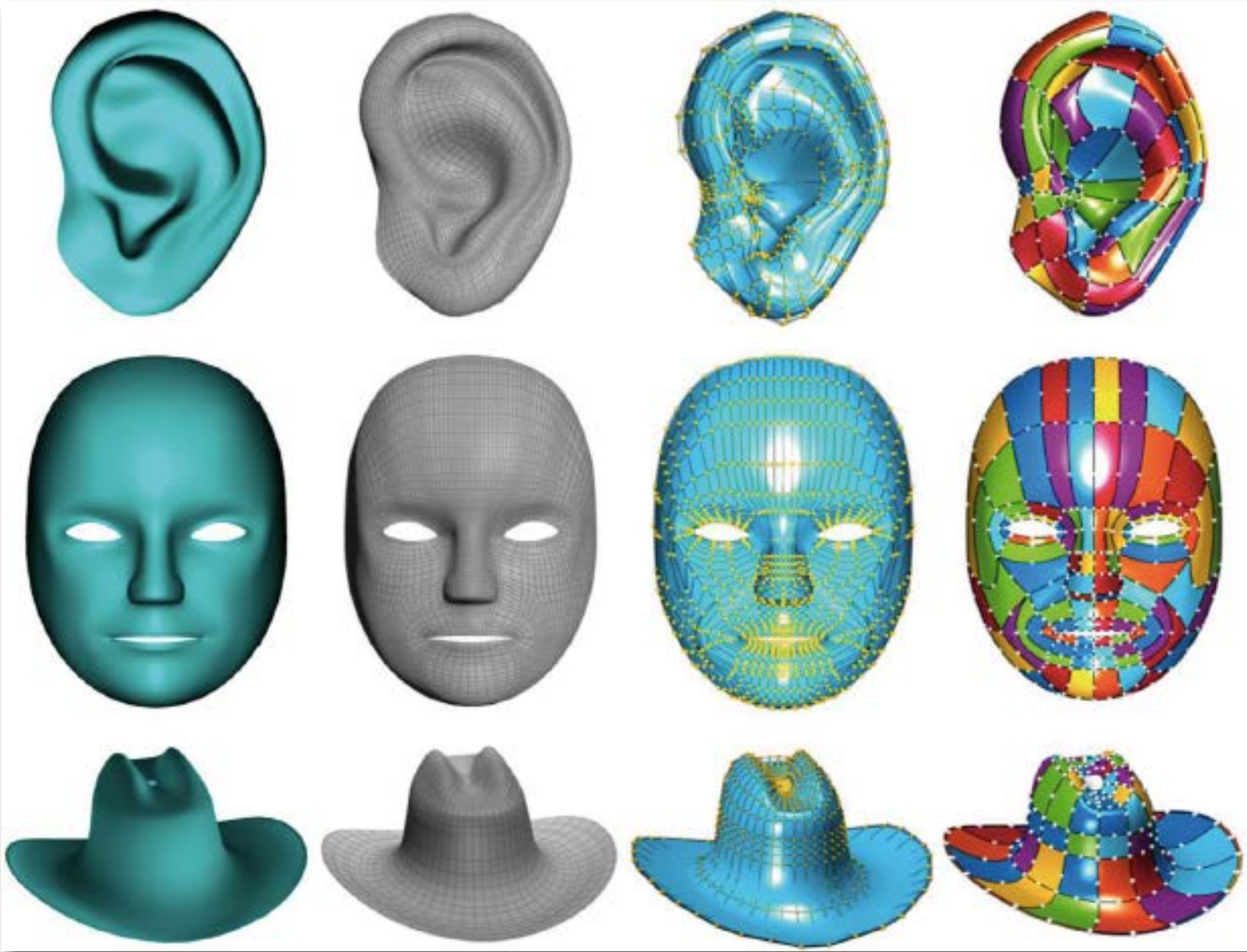
	Vertices or control points		
	PO	NU	Ours
Dress	2996	1020	362
Mug	1275	460	168
Ear	1862	498	174
Hat	2256	900	312
Face	3701	963	336



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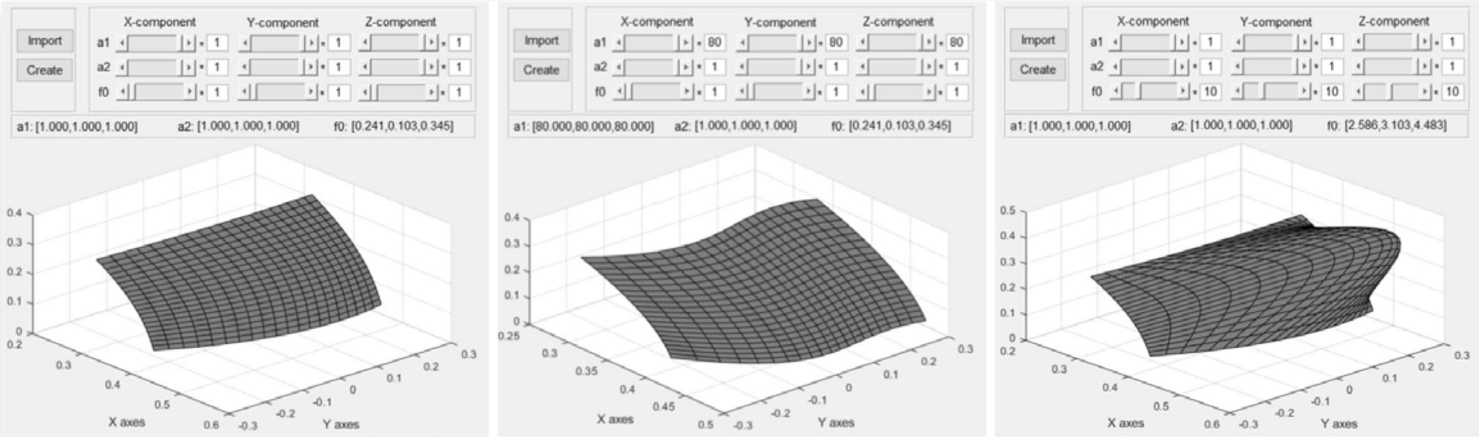

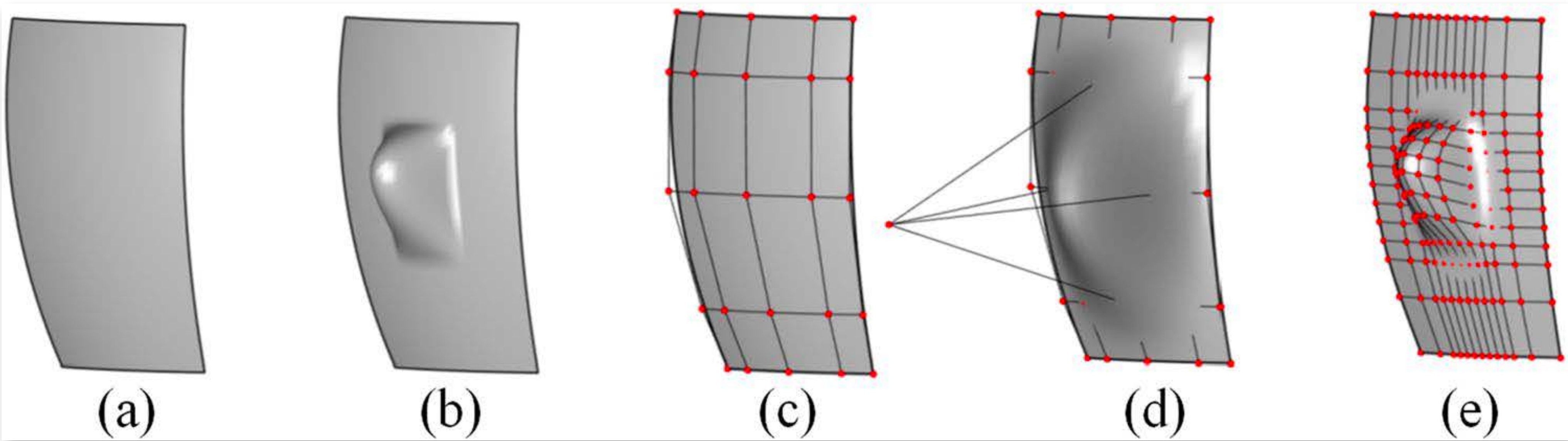

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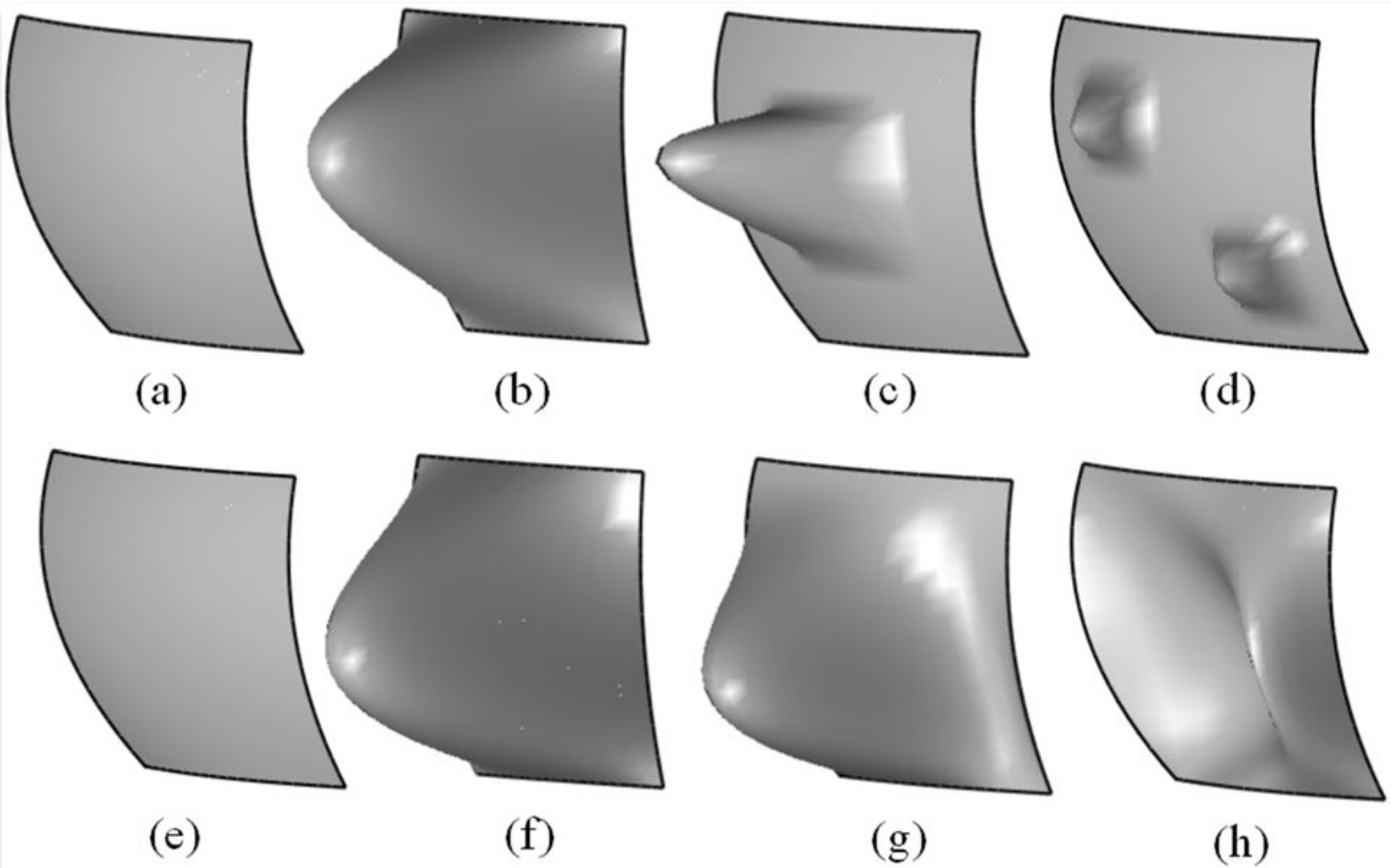

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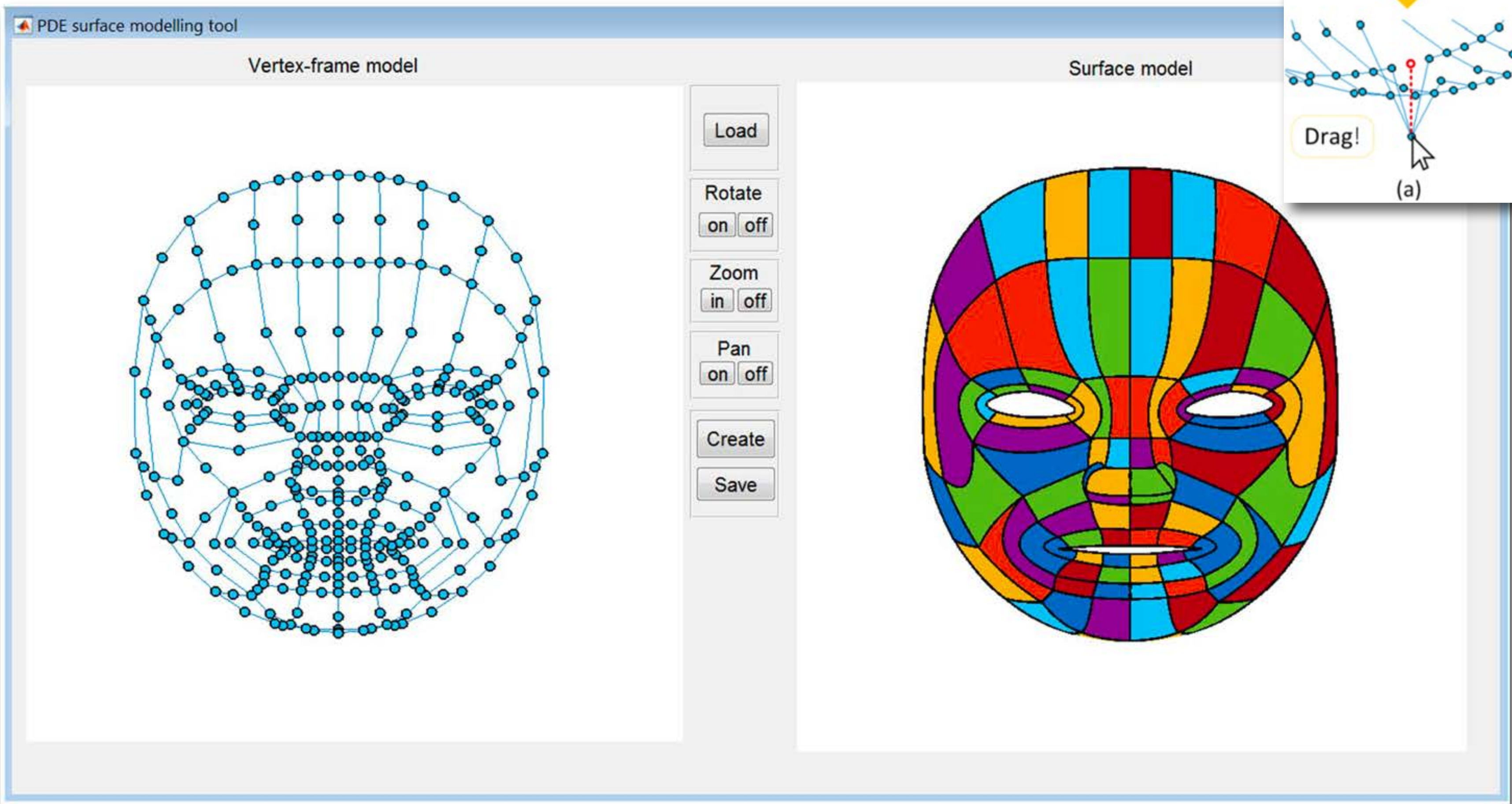

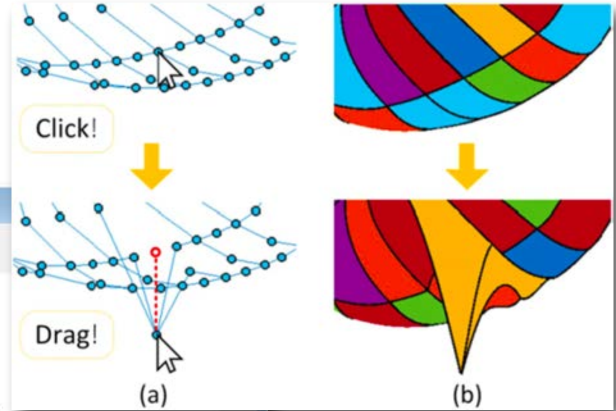

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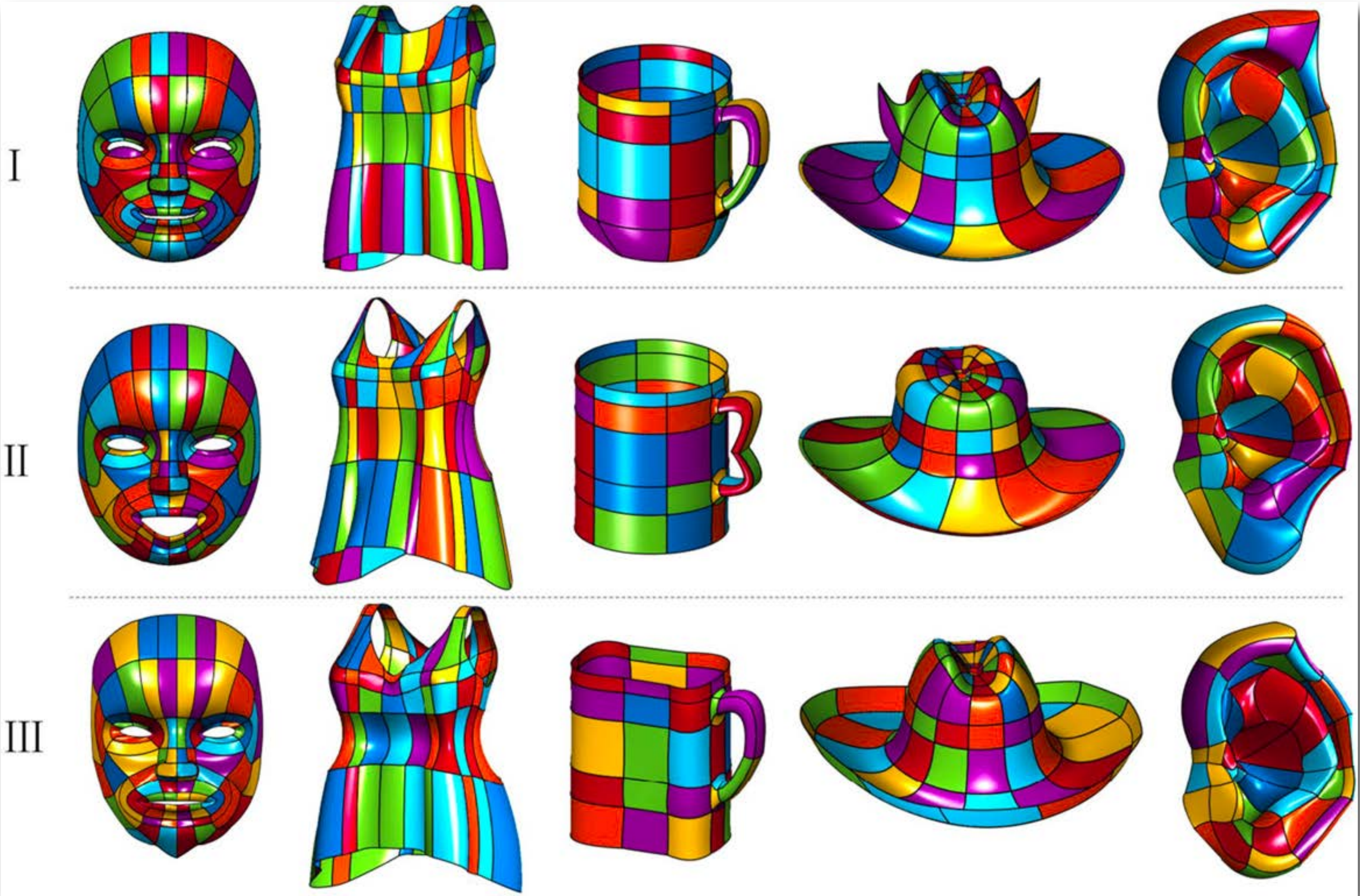
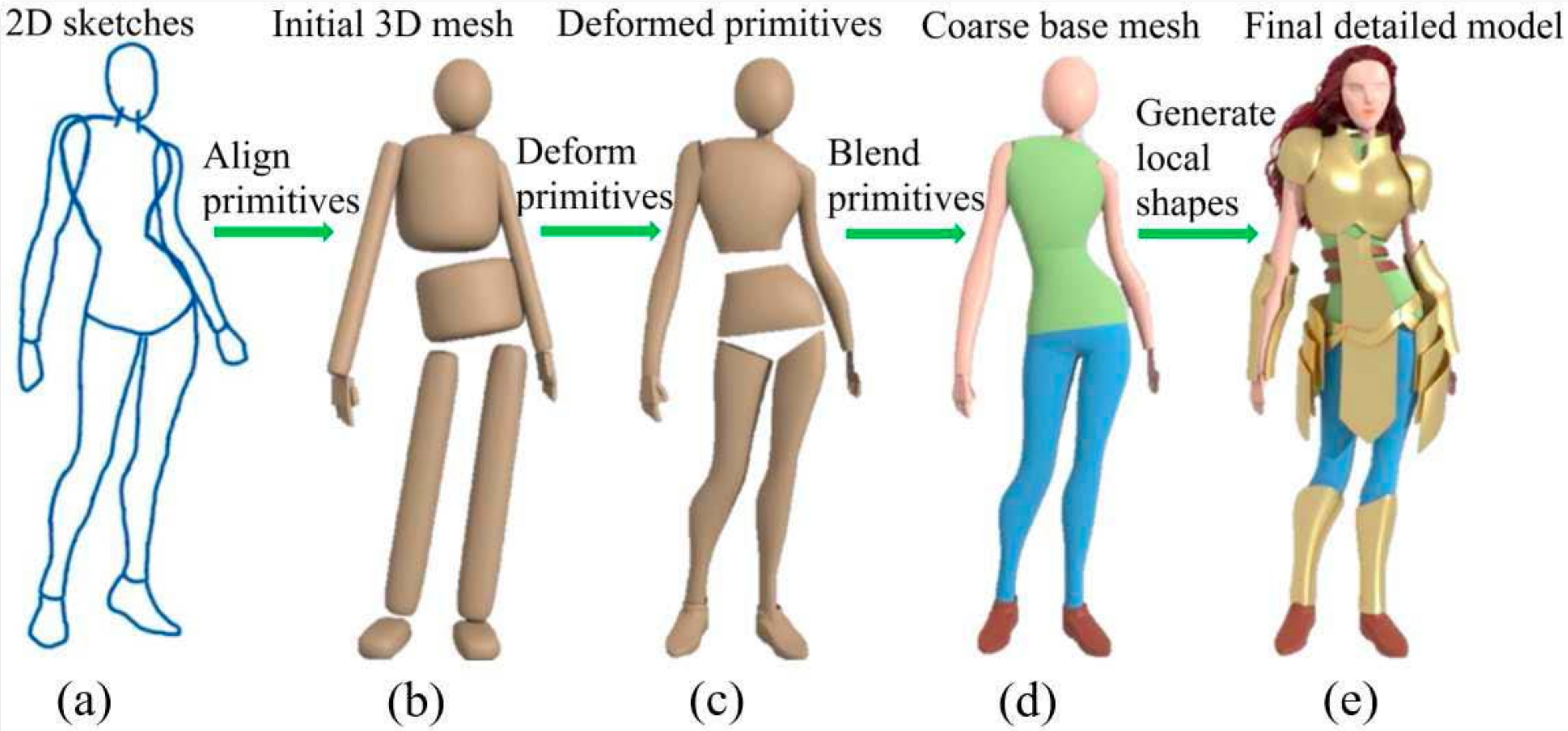


O. Li, H. Fu, S. Bian, X. Yang, X. Jin, A. Iglesias, A. Noreika, L. You, J.J. Zhang: "Character Modeling with Sketches and ODE-Based Shape Creation". Numerical Mathematics: Theory, Methods and Applications, (I.F. 1.3) Vol. 16, pp. 720-751 (2023).



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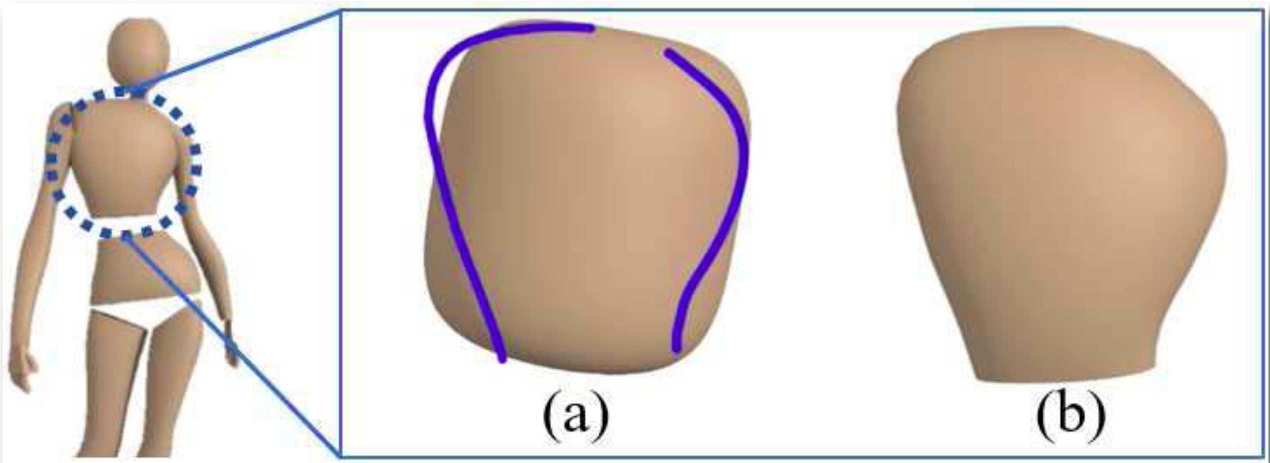

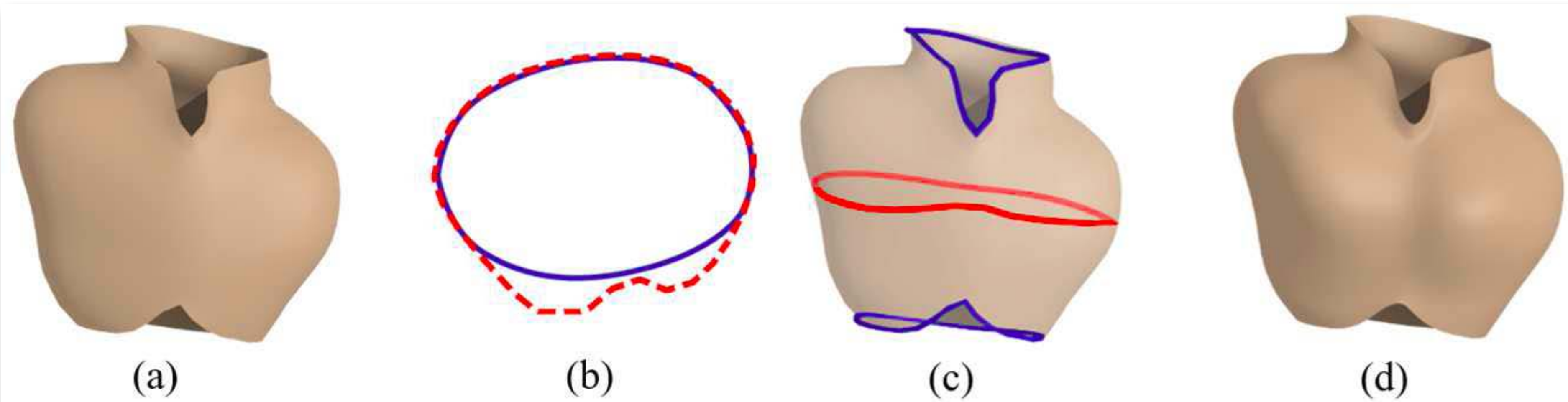

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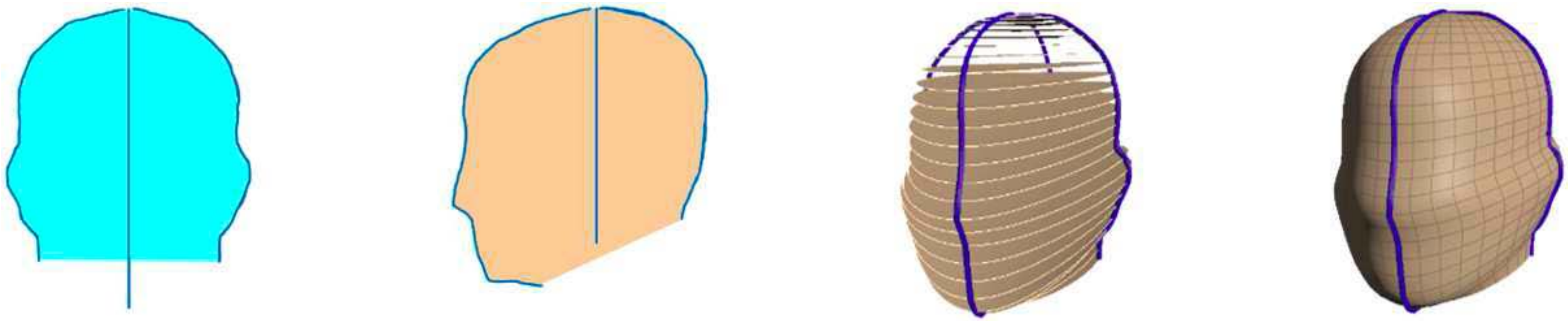
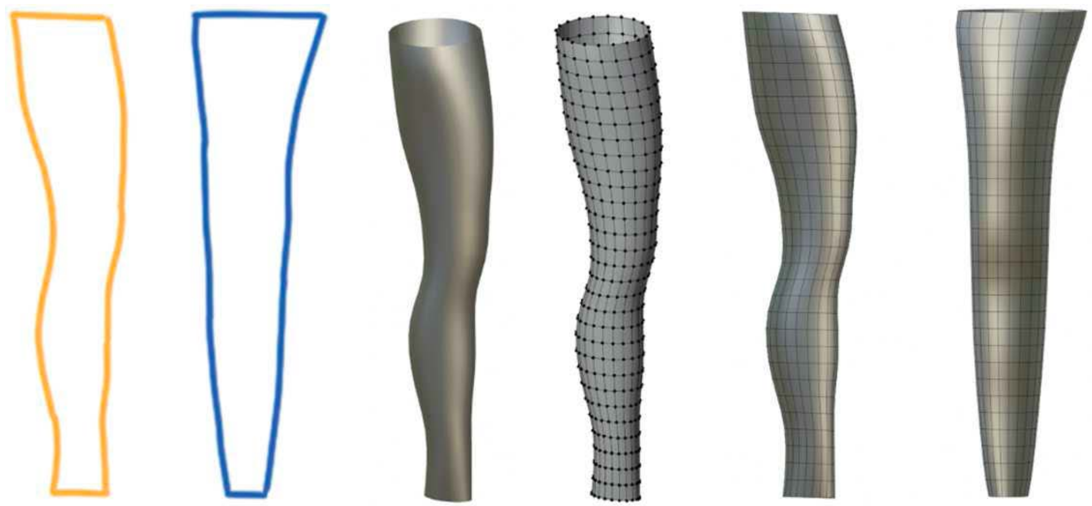

(a) (b) (c) (d)


(a) (b) (c)


(a) (b) (c) (d) (e) (f)

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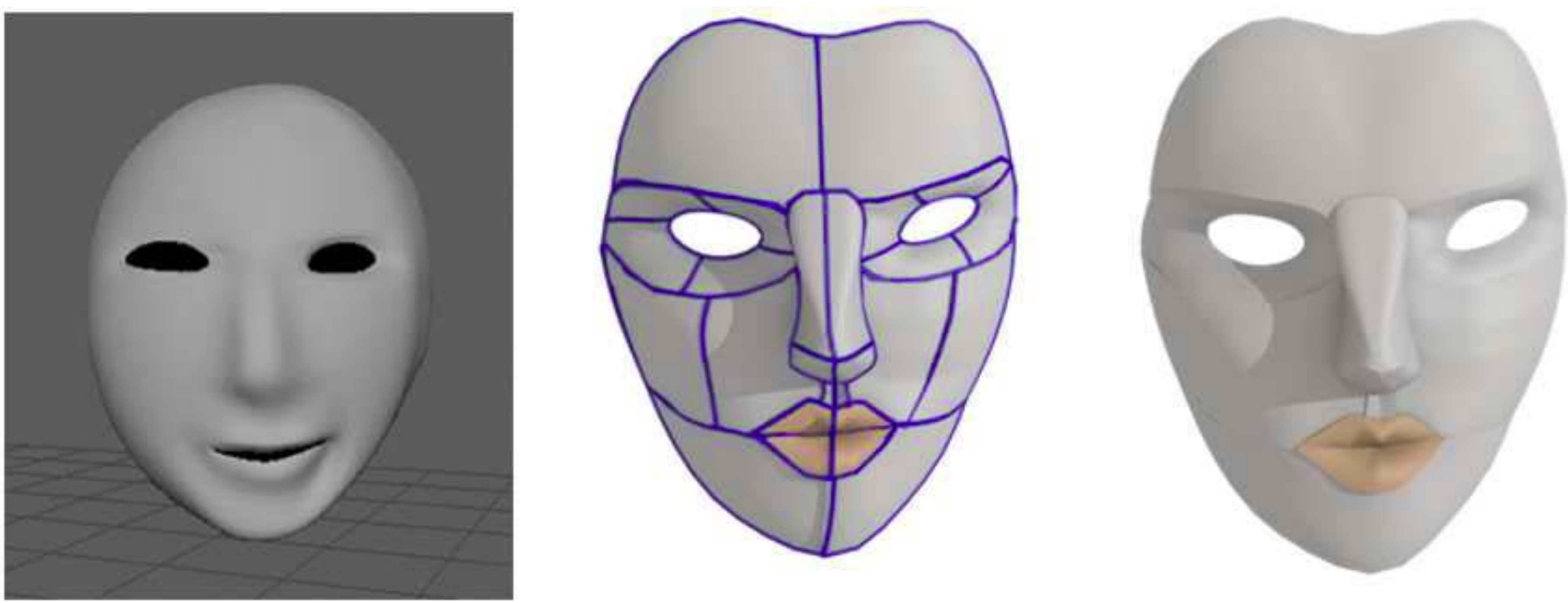
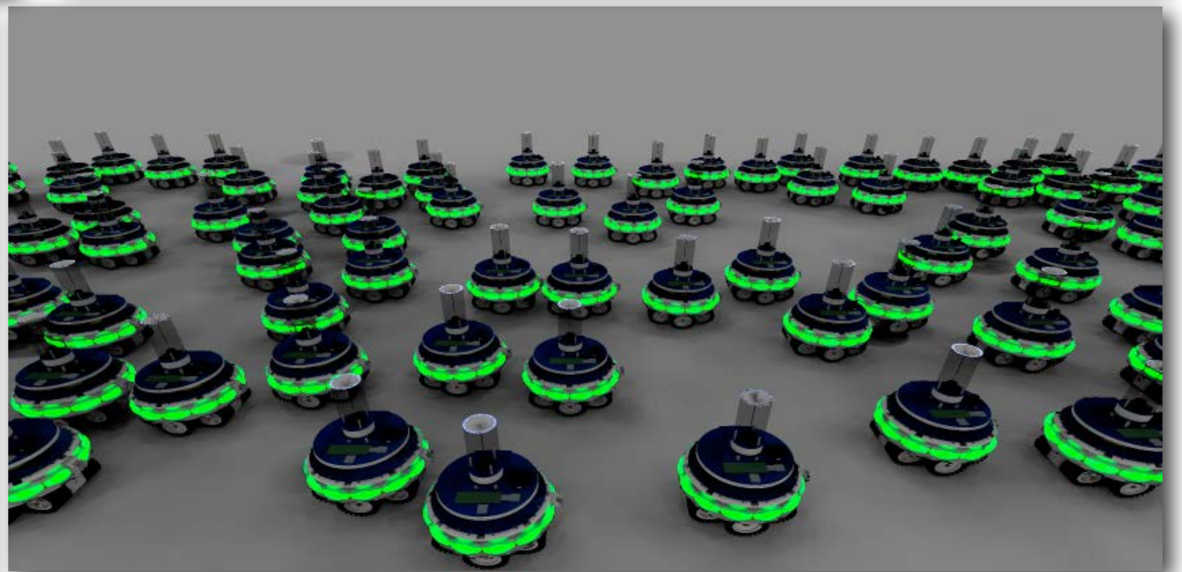


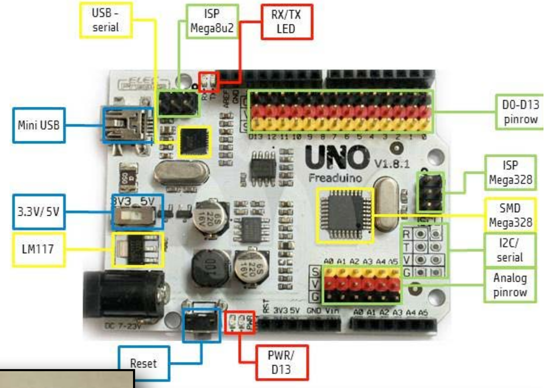
(a) (b) (c)

O. Li, H. Fu, S. Bian, X. Yang, X. Jin, A. Iglesias, A. Noreika, L. You, J.J. Zhang: "Character Modeling with Sketches and ODE-Based Shape Creation". Numerical Mathematics: Theory, Methods and Applications, (I.F. 1.3) Vol. 16, pp. 720-751 (2023).

Swarm Robotics



P. Suárez, A. Iglesias, A. Gálvez: "Make robots be bats: specializing robotic swarms to the Bat algorithm". **Swarm and Evolutionary Computation**, (I.F. 10) Vol. 44, pp. 113-129 (2019).



Main components:

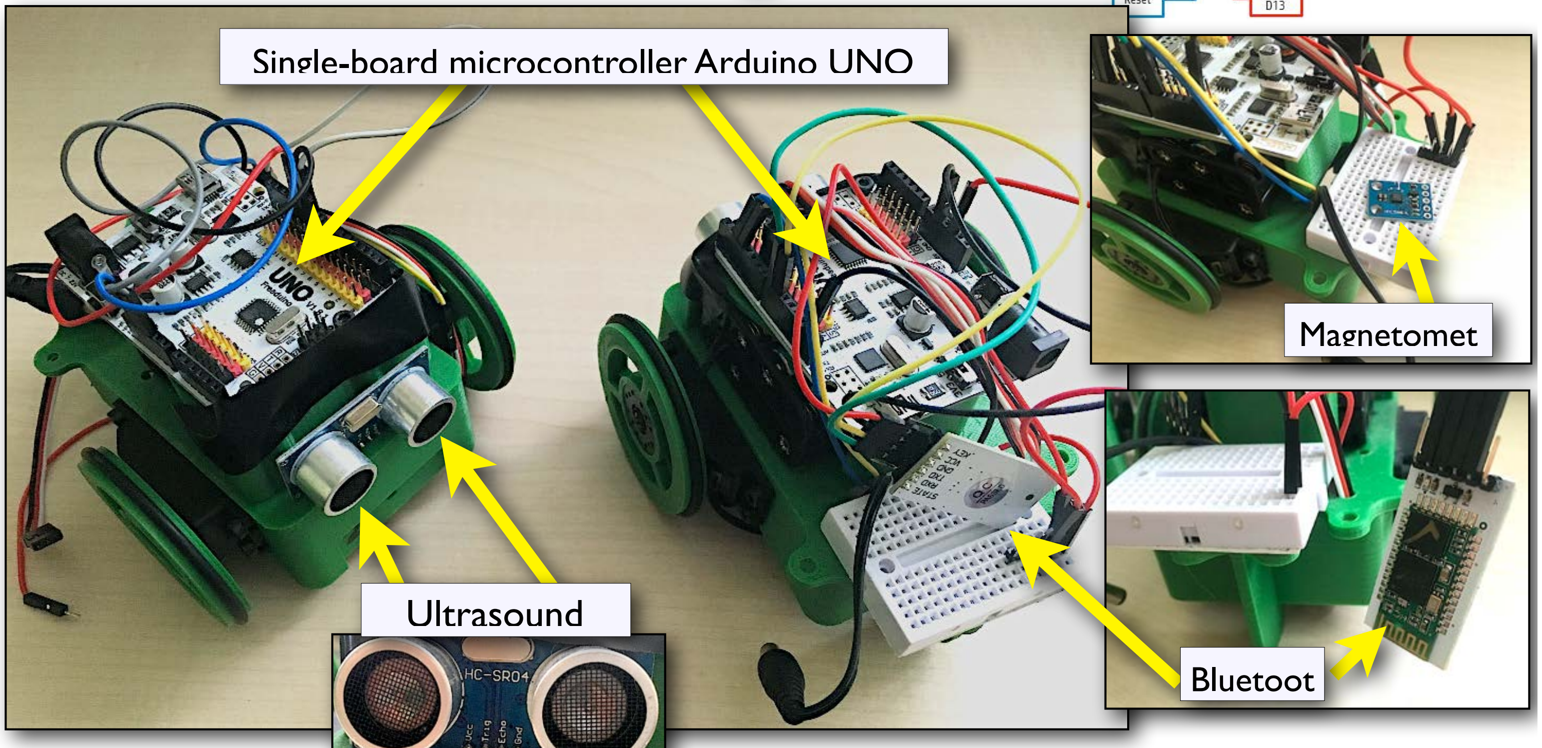
single-board micro-controller

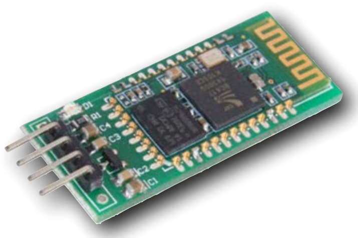
(small, affordable, reasonable computing power)

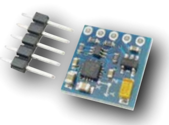
ultrasound sensors
collision avoidance

magnetometers
global spatial orientation

bluetooth cards
wireless communication
data exchange







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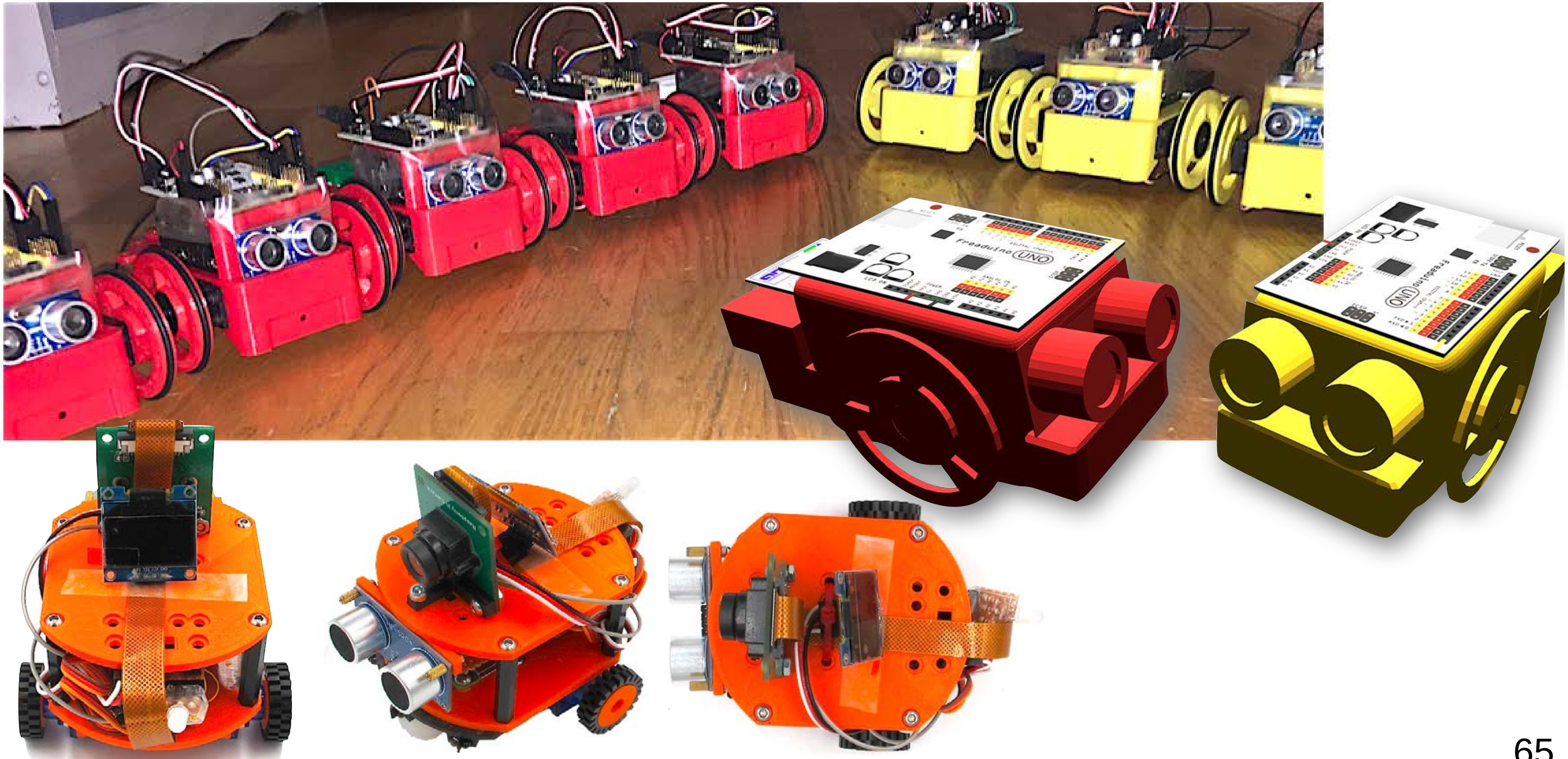
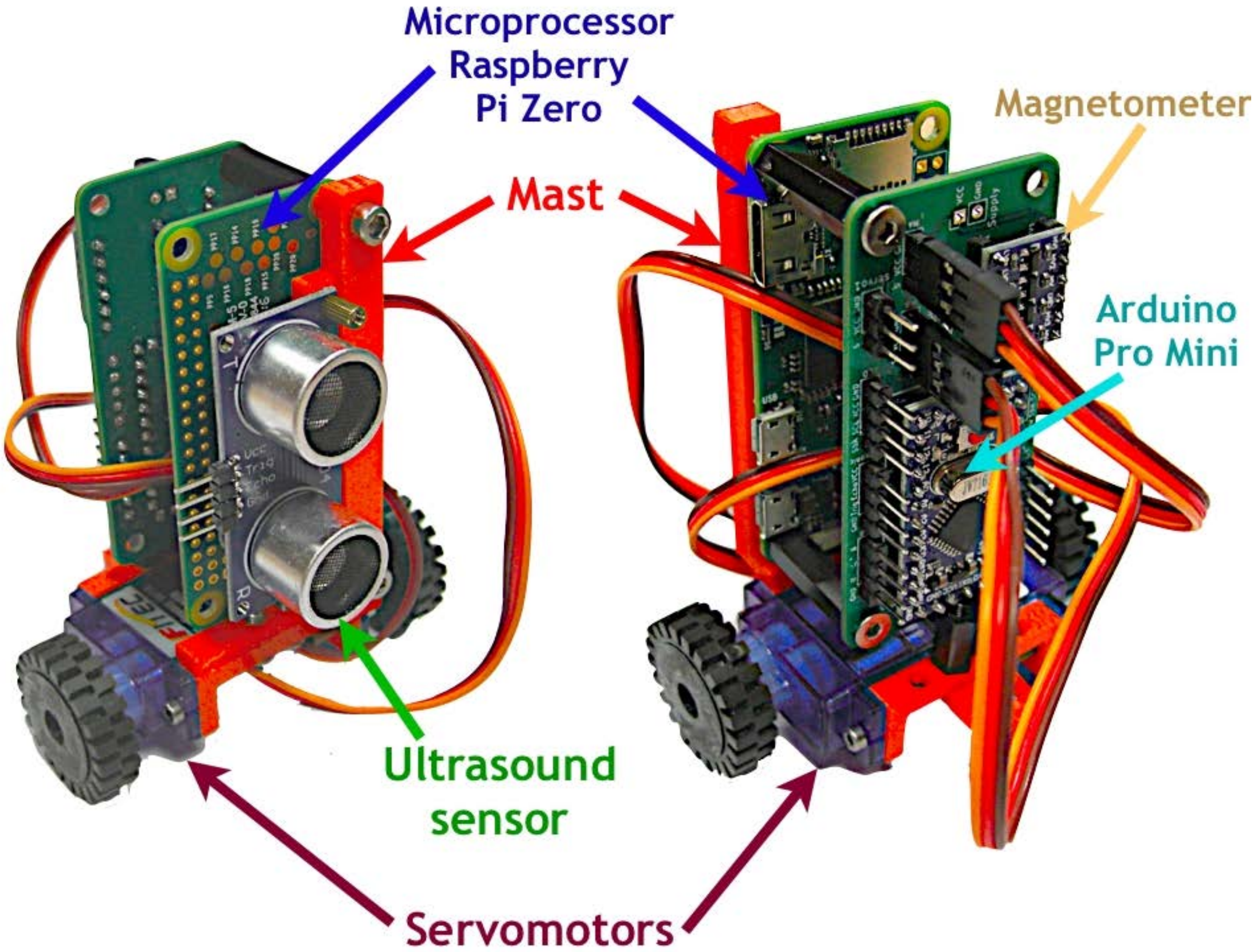
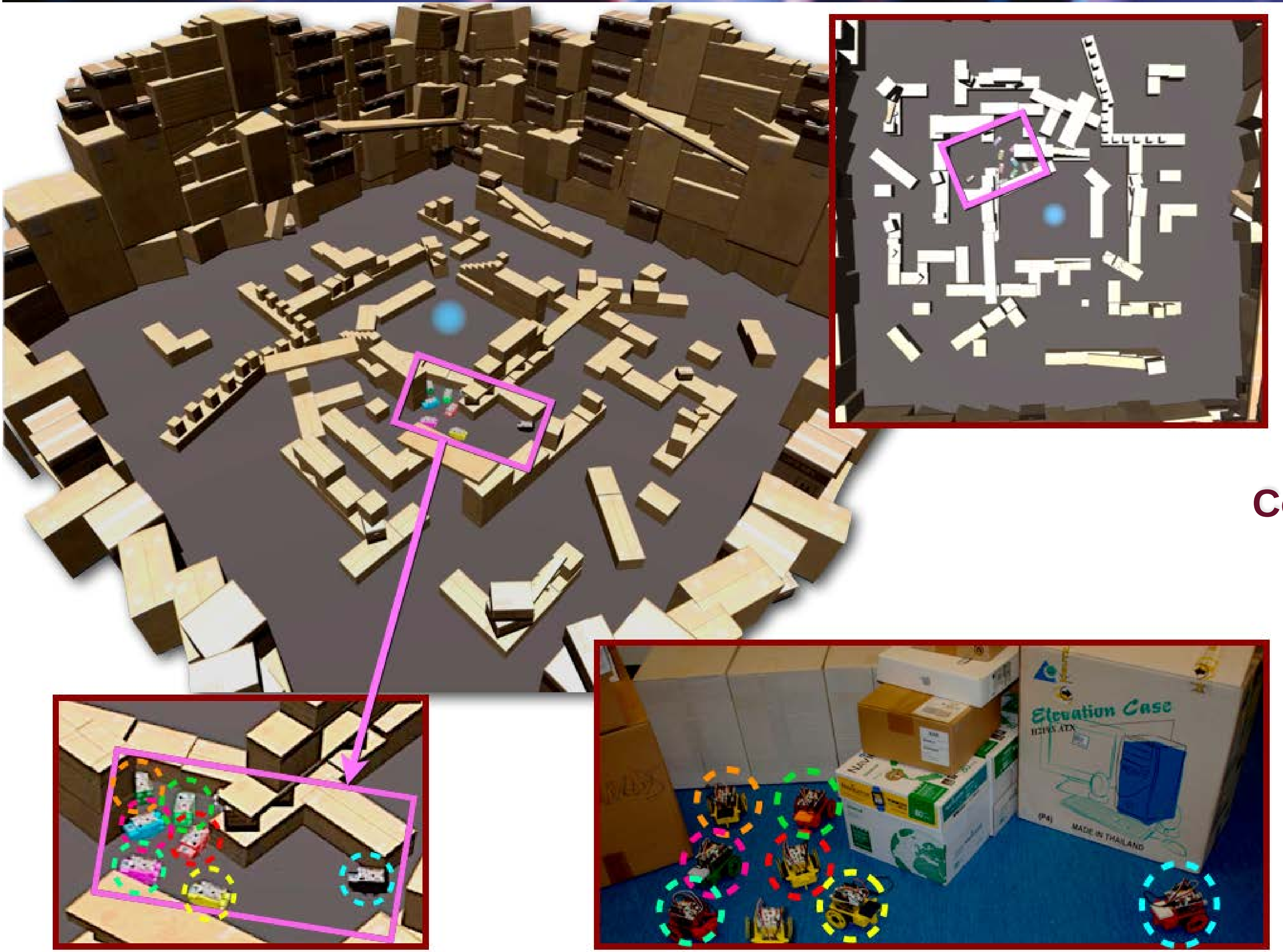



Microprocessor
Raspberry
Pi Zero
Magnetometer
Mast
Arduino
Pro Mini
Ultrasound
sensor
Servomotors

P. Suárez, A. Iglesias, A. Gálvez: "Make robots be bats: specializing robotic swarms to the Bat algorithm". Swarm and Evolutionary Computation, (I.F. 10) Vol. 44, pp. 113-129 (2019).



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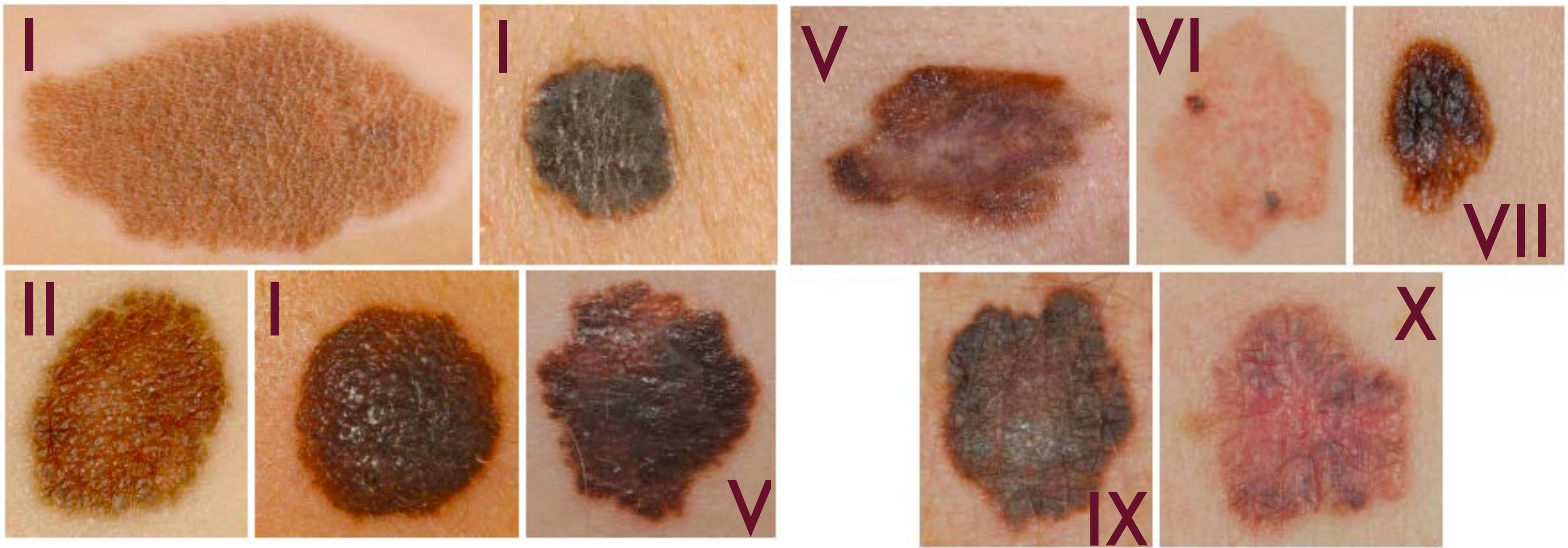
If you go to the website of this paper, you will find six videos available as supplementary material.

Link: https://www.sciencedirect.com/science/article/pii/S2210650217306338

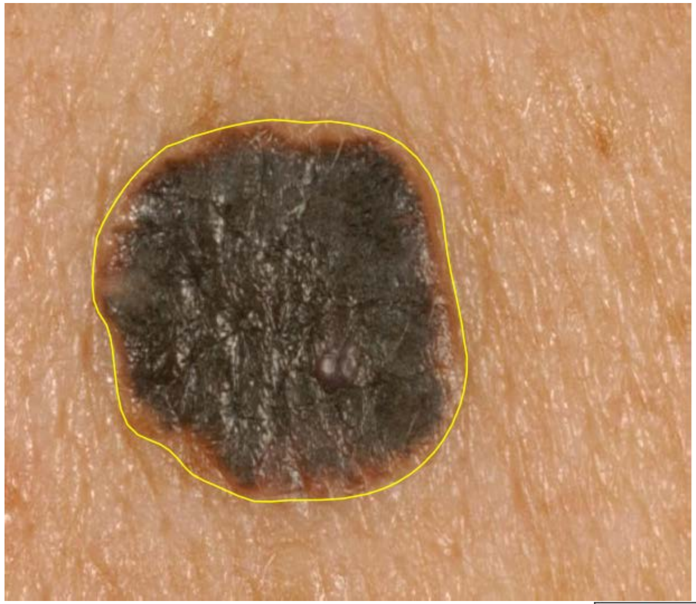
A Gálvez, A Iglesias: Memetic improved cuckoo search algorithm for automatic B-spline border approximation of cutaneous melanoma from macroscopic medical images. Advanced Engineering Informatics, (I.F. 8.8) Vol. 43, Paper 101005 (2020).

Malignant melanoma is the most frequent and most dangerous type of skin cancer (3.1 million cases with 60,000 deaths in 2015 worldwide)

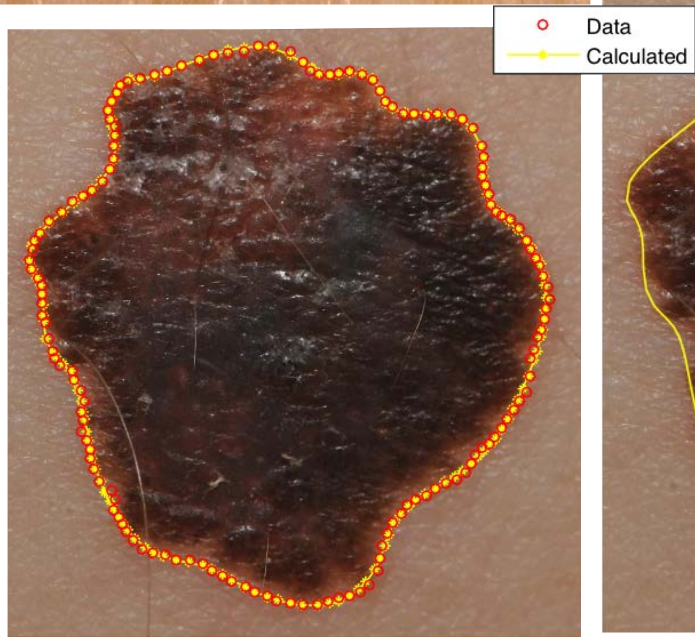
Can you tell me which ones of the next images do correspond to benign and malignat skin lesions?



Example I



Example II



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Conclusions

- In this talk, I revised the potential role of AI and PDE for the problem of shape reconstruction from heterogeneous data sources (point clouds, multi-view images, cross-sections, vertex frames, mixed inputs).
- This kind of complex & ambitious problems are more suitable for an international and mutidisciplinary approach. This problem has been addressed in the European Union project PDE-GIR (2018-2023).
- The developed methods have been applied to several challenging problems in computer design & manufacturing, computer graphics & animation, robotics, medical imaging, image processing, and others.
- The results are promising and show the potential of this technology towards its application to several academic, business and industrial fields.

Future Research

A critical limitation is that some problems still require some manual intervention at some steps of the process (i.e., sketch modeling medical imaging).

AI is the key to develop automatic procedures for model selections and other operations. The ability of AI systems to learn (from data, by examples) can help to fully automate the processes.

We aim at extending the technology developed in this project to other important applied problems in several fields.

Also, international cooperation is increasingly important in this area. We are open to potential collaborations with research and business stakeholders.

More info at:

PDE-GIR Portal

P∂E-GIR

Home | Project | Partners | Latest News | CGIPAI 2022 | Publications | Contact

pde-gir.com

ICACSE2023 Scopus

UNIVERSITI MALAYSIA SABAH UMS

DLSU De La Salle University

16th - 17th December 2023,
De La Salle University, Manila, Philippine (Hybrid Conference)

End of the talk

Thank you very much for for your attention

Acknowledgements

ICACSE 2024 Chairs & Organizers

European Commission

Marie Skłodowska--Curie Actions

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