RBF Morph:
A simple set-up for complex workflows

Dr. Corrado Groth
Prof. Marco Evangelos Biancolini
University of Rome Tor Vergata
info@rbf-morph.com
biancolini@ing.uniroma2.it
corrado.groth@students.uniroma2.eu

Outline

- Morphing?
- RBF theory
- How it works
- Hands-on!

Morphing & Smoothing

- A mesh morpher is a tool capable to perform **mesh modifications**, in order to achieve arbitrary shape changes and related volume smoothing, without changing the mesh topology.
- In general a morphing operation can introduce a reduction of the **mesh quality**
- A **good** morpher has to minimize this effect, and maximize the possible shape modifications.
- If mesh quality is well preserved, then using the same mesh structure it's a **clear benefit** (remeshing introduces **noise**!).

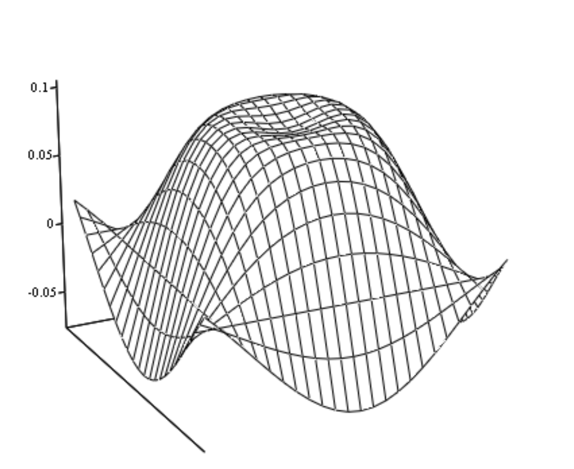
Mesh morphing with RBF

- A system of **radial functions** is used to **fit** a **solution** for the mesh movement/morphing, from a list of **source points** and their **displacements**.
- The RBF problem definition does not depend on the mesh
- Radial Basis Function interpolation is used to derive the displacement in **any location** in the space, each component of the displacement is interpolated:

$$\begin{cases} v_x = s_x(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^x \phi\left(\left\|\mathbf{x} - \mathbf{x}_{k_i}\right\|\right) + \beta_1^x + \beta_2^x x + \beta_3^x y + \beta_4^x z \\ v_y = s_y(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^y \phi\left(\left\|\mathbf{x} - \mathbf{x}_{k_i}\right\|\right) + \beta_1^y + \beta_2^y x + \beta_3^y y + \beta_4^y z \\ v_z = s_z(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^z \phi\left(\left\|\mathbf{x} - \mathbf{x}_{k_i}\right\|\right) + \beta_1^z + \beta_2^z x + \beta_3^z y + \beta_4^z z \end{cases}$$

RBF Theory

- A system of **radial functions** is used to **fit** a **solution** for the mesh movement/morphing, from a list of **source points** and their **displacements**. This approach is valid for both surface shape changes and volume mesh smoothing.
- The RBF problem definition does not depend on the mesh
- Radial Basis Function interpolation is used to derive the displacement in any location in the space, so it is also available in every grid node.
- An interpolation function composed by a radial basis and a polynomial is defined.



$$s(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i \phi(\|\mathbf{x} - \mathbf{x}_i\|) + h(\mathbf{x})$$

$$h(\mathbf{x}) = \beta + \beta_1 x + \beta_3 y + \beta_4 z$$

RBF Theory

- A radial basis fit exists if desired values are matched at source points with a null poly contribution
- The fit problem is associated with the solution of a linear system
- **M** is the interpolation matrix
- **P** is the constraint matrix
- **g** are the scalar values prescribed at source points
- γ and β are the fitting coefficients

$$s(\mathbf{x}_{k_i}) = g(\mathbf{x}_{k_i}) \quad 1 \le i \le N$$

$$0 = \sum_{i=1}^{N} \gamma_i q(\mathbf{x}_{k_i})$$

$$\begin{pmatrix} \mathbf{M} & \mathbf{P} \\ \mathbf{P}^{\mathrm{T}} & \mathbf{0} \end{pmatrix} \begin{pmatrix} \boldsymbol{\gamma} \\ \boldsymbol{\beta} \end{pmatrix} = \begin{pmatrix} \mathbf{g} \\ \mathbf{0} \end{pmatrix}$$

$$M_{ij} = \phi\left(\left\| \mathbf{x}_{k_i} - \mathbf{x}_{k_j} \right\|\right) \quad 1 \le i \quad j \le N$$

$$\mathbf{P} = \begin{pmatrix} 1 & x_{k_1}^0 & y_{k_1}^0 & z_{k_1}^0 \\ 1 & x_{k_2}^0 & y_{k_2}^0 & z_{k_2}^0 \\ \vdots & \vdots & \vdots & \vdots \\ 1 & x_{k_N}^0 & y_{k_N}^0 & z_{k_N}^0 \end{pmatrix}$$

RBF Theory

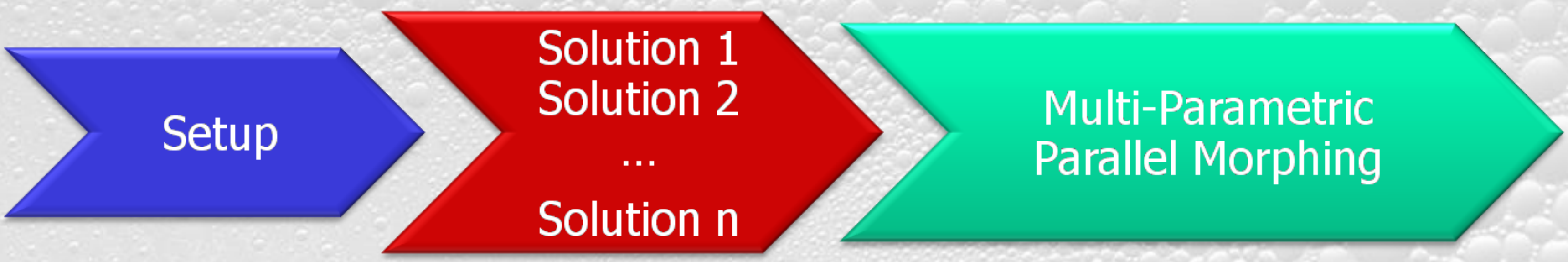
- The radial function can be fully or compactly supported. The bi-harmonic kernel fully supported gives the best results for smoothing.
- For the smoothing problem each component of the displacement prescribed at the source points is interpolated as a single scalar field.

Radial Basis Function	$\phi(r)$
Spline type (R_n)	$\lvert r\rvert^n$, n odd
Thin plate spline (TPS_n)	$\lvert r\rvert^n \log\lvert r\rvert$, n even
Multiquadric(MQ)	$\sqrt{1+r^2}$
Inverse multiquadric (IMQ)	$\dfrac{1}{\sqrt{1+r^2}}$
Inverse quadratic (IQ)	$\dfrac{1}{1+r^2}$
Gaussian (GS)	e^{-r^2}

$$\begin{cases} v_x = s_x(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^x \phi\left(\left\|\mathbf{x}-\mathbf{x}_{k_i}\right\|\right) + \beta_1^x + \beta_2^x x + \beta_3^x y + \beta_4^x z \\ v_y = s_y(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^y \phi\left(\left\|\mathbf{x}-\mathbf{x}_{k_i}\right\|\right) + \beta_1^y + \beta_2^y x + \beta_3^y y + \beta_4^y z \\ v_z = s_z(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^z \phi\left(\left\|\mathbf{x}-\mathbf{x}_{k_i}\right\|\right) + \beta_1^z + \beta_2^z x + \beta_3^z y + \beta_4^z z \end{cases}$$

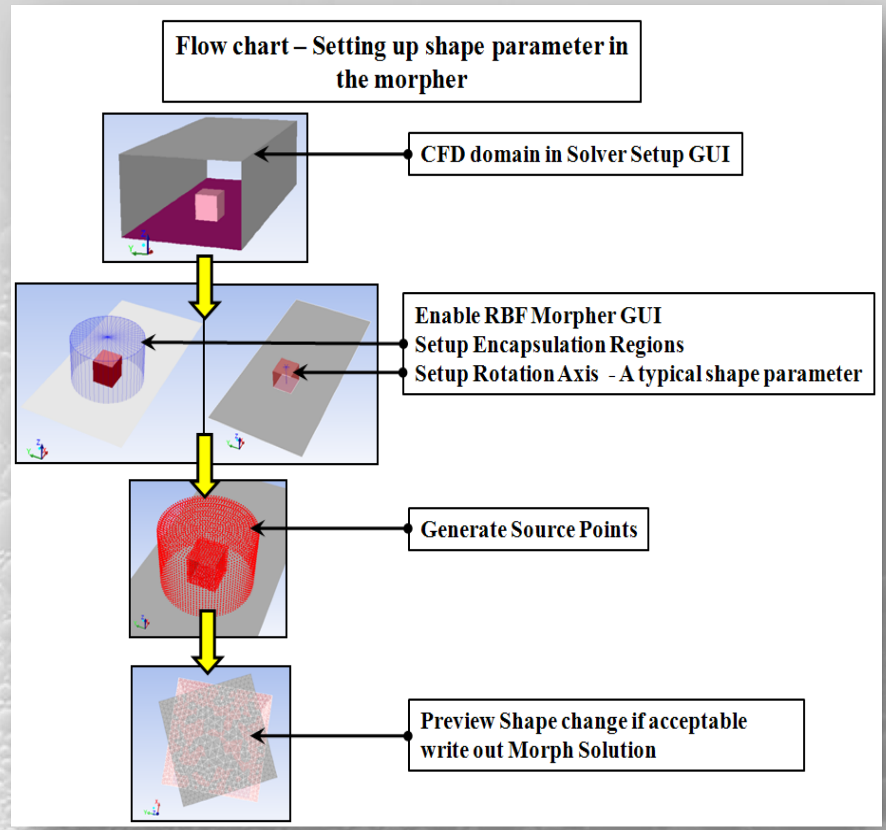
How it Works: the work-flow

- *RBF Morph* basically requires three different steps:
- **Step 1 setup** and definition of the problem (source points and displacements).
- **Step 2 fitting** of the RBF system (write out .rbf + .sol).
- **Step 3 [SERIAL or PARALLEL] morphing** of the surface and volume mesh (available also in the **CFD solution stage** it requires only baseline mesh and .rbf + .sol files).



How it Works: the problem setup

- The problem must describe correctly the **desired changes** and must **preserve exactly** the fixed part of the mesh.
- The prescription of the **source points** and their displacements fully defines the *RBF Morph* problem.
- Each problem and its fit define a mesh **modifier** or a **shape parameter**.



How it Works:
Fluent parallel morphing

- **Interactive** update using the GUI **Multi-Sol** panel and the Morph/Undo commands.
- **Interactive** update using **sequential morphing** by the TUI command `(rbf-smorph)`.
- **Batch** update using the **single morphing** command `(rbf-morph)` in a journal file (the RBF Morph DOE tool allows to easily set-up a run).
- **Batch** update using several **sequential morphing** commands in a journal file.
- Link shape amplifications to **Fluent custom parameters** driven by **Workbench** (better if using **DesignXplorer**).
- More options (transient, FSI, modeFRONTIER, batch RBF fit …)

Hands-on!

Muito obrigado pela vossa atenção!

Dr. Corrado Groth
Prof. Marco Evangelos Biancolini

E-mail: info@rbf-morph.com
Web: www.rbf-morph.com

Goo.gl/1svYd

linkedin.com/company/rbf-morph

Twitter.com/RBFMorph

youtube.com/user/RbfMorph