MERLIN-Frac: An Efficient Computational Approach To Origami Fracture Mechanics

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MERLIN software (Liu K, Paulino GH.) [1]

- Reduced order model (ROM) composed by **"bar-and-hinge" elements**
- Bars elements are assumed under nonlinear Odgen hyperelastic model
- Elastic hinges are divided into bending and folding element types

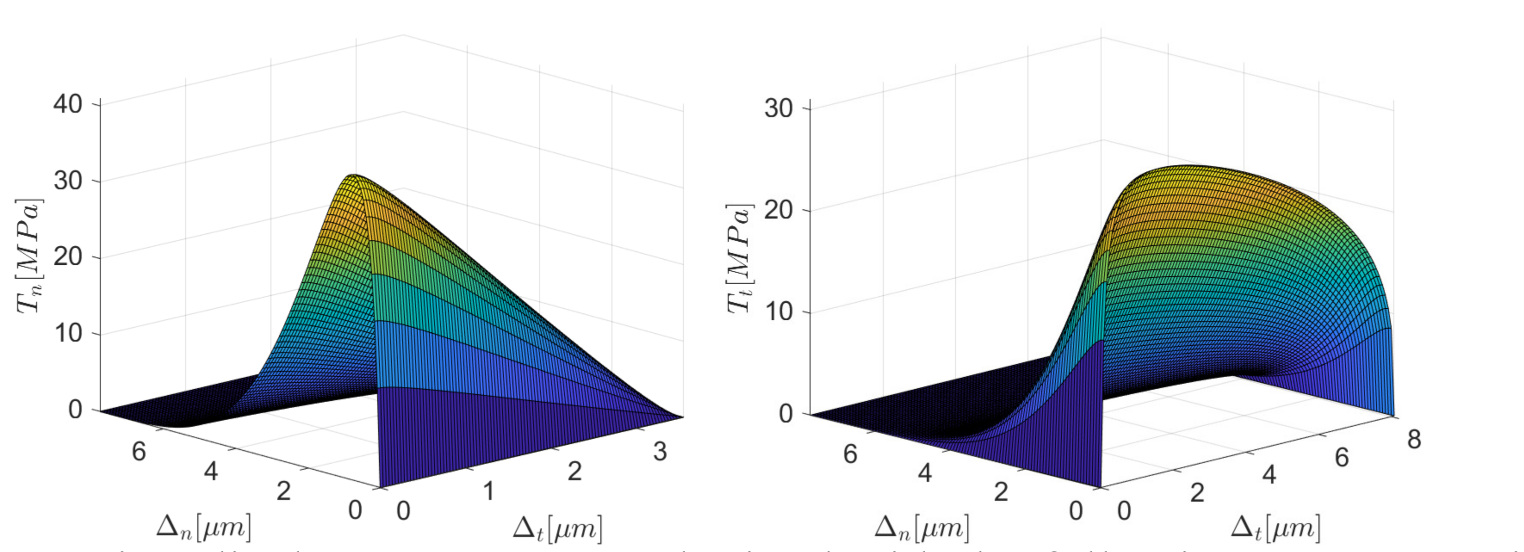
PPR (Park K, Paulino GH, Roesler JR.) [3]

- **Cohesive zone model** (CZM)
- Polynomial potential based model
- 3D displacement formulation

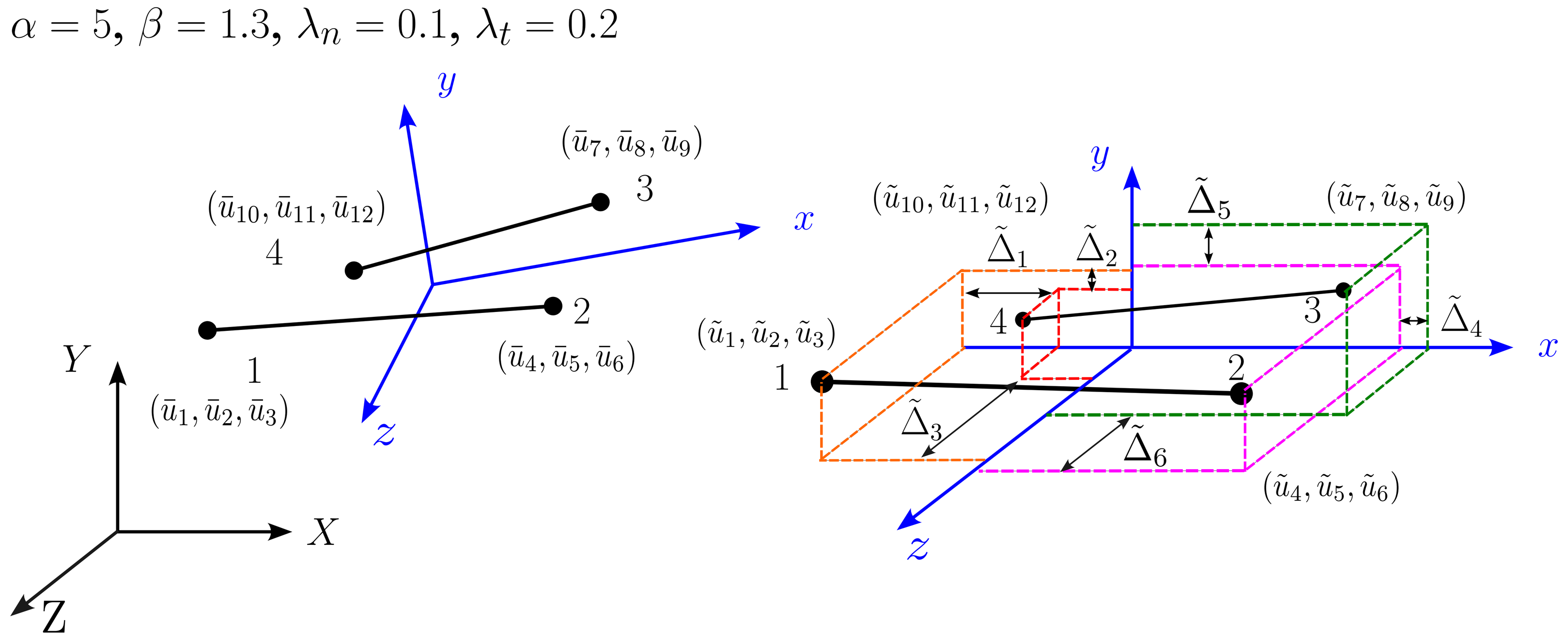
$$\Psi(\Delta_n,\Delta_t) = min(\phi_n,\phi_t) + \left[\Gamma_n\left(1-\frac{\Delta_n}{\delta_n}\right)^{\alpha}\left(\frac{m}{\alpha}+\frac{\Delta_n}{\delta_n}\right)^{m} + <\phi_n-\phi_t>\right]\cdot \cdot\left[\Gamma_t\left(1-\frac{|\Delta_t|}{\delta_t}\right)^{\alpha}\left(\frac{n}{\beta}+\frac{|\Delta_t|}{\delta_t}\right)^{m} + <\phi_t-\phi_n>\right]$$

Traction vector components:

$$T_t(\Delta_n,\Delta_t) = \frac{\partial\Psi(\Delta_n,\Delta_t)}{\partial\Delta_t} \quad , \quad T_n(\Delta_n,\Delta_t) = \frac{\partial\Psi(\Delta_n,\Delta_t)}{\partial\Delta_n}$$



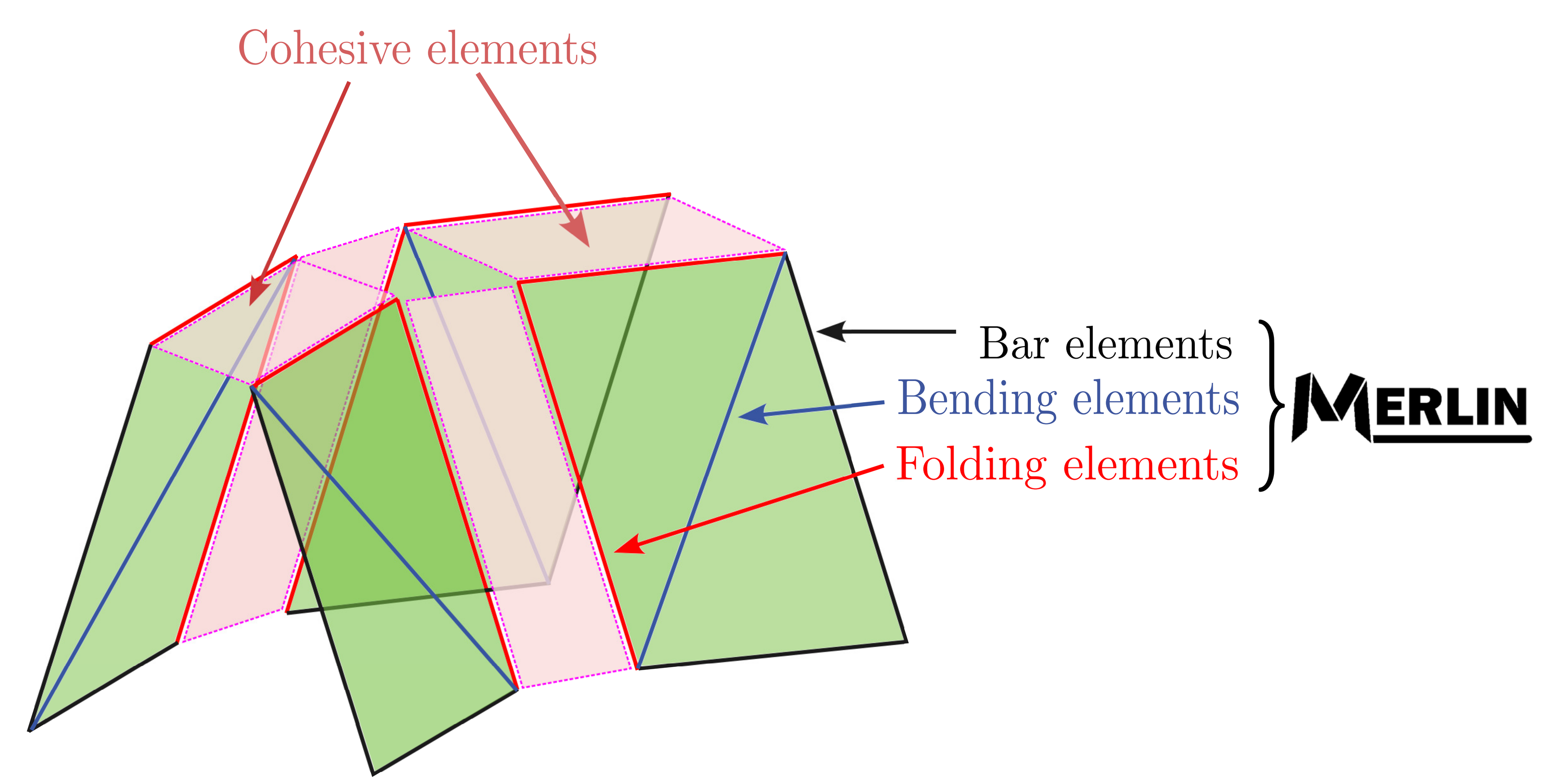
Traction-displacement curves obtained with the following parameters in traction vector $\phi_n = 100N/m$, $\phi_t = 200N/m$, $\sigma_{max} = 40MPa$, $\tau_{max} = 30MPa$, $\alpha = 5$, $\beta = 1.3$, $\lambda_n = 0.1$, $\lambda_t = 0.2$



Global coordinates converted into local coordinate systems.

MERLIN-Frac (MERLIN and PRR combined)

- **Creases fracture** (mountain or valley)
- Combination in a single procedure is not straightforward since additional considerations arise



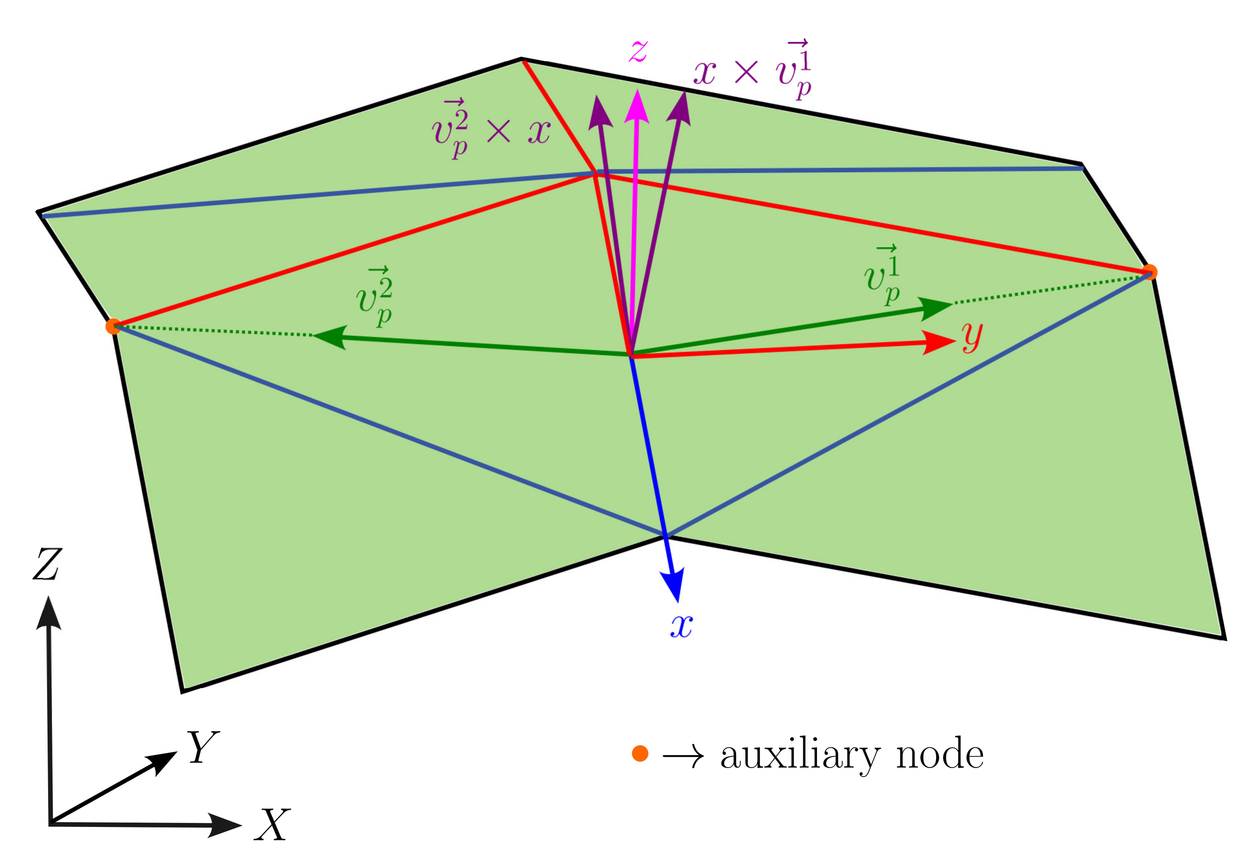
P-refinement

- **Hermitian basis functions** are used to interpolate element displacement gaps (without extra nodes additions)

$$N_1 = \frac{1}{4}\cdot(2.0-3\xi+\xi^3),\quad N_2 = \frac{1}{4}\cdot(2.0+3\xi-\xi^3)$$

Rotation

- In 3D analysis the normal vector is not uniquely defined
- Auxiliary nodes can be chosen for establishing an unique local coordinate system

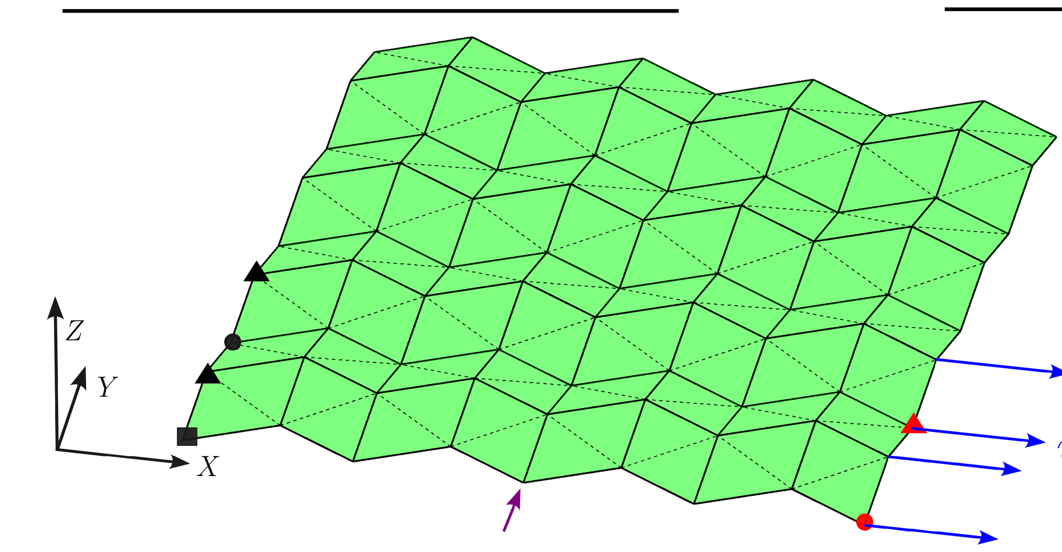


Sampling example

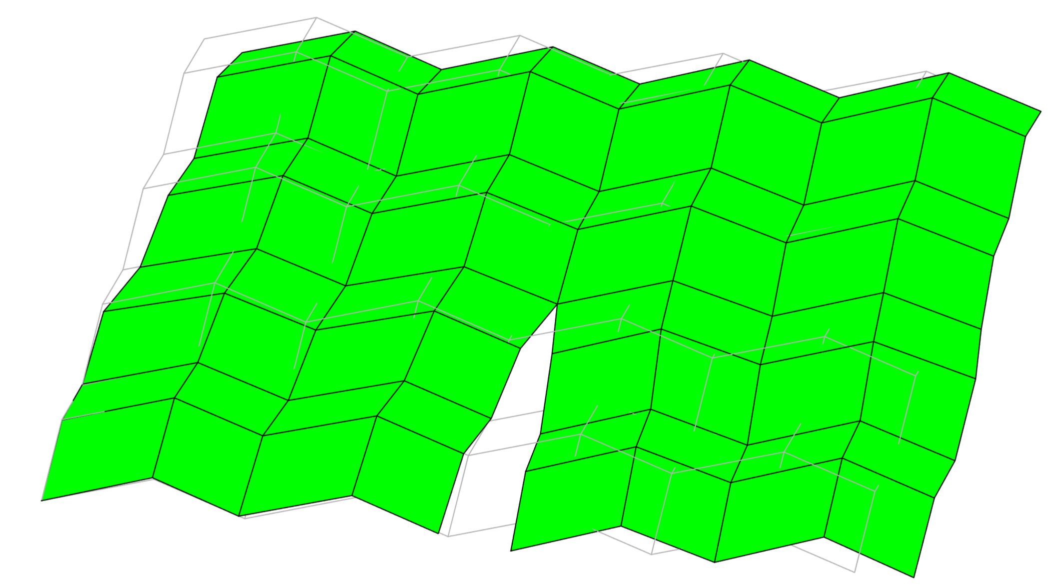
- 4×4 Miura-Ori tessellation model with prescribed displacement
- Solution with an incremental-iterative Newton-Raphson scheme

Merlin Variables	Value
a	$2m$
b	$2m$
θ	60°
E_0	$1GPa$
α_1	5.0
α_2	1.0
k_f	$100N/m$
k_b	$10MN/m$
A_{bar}	$1cm^2$

PPR Variables	Value
ϕ_n	$500N/m$
ϕ_t	$500N/m$
σ_{max}	$0.01MPa$
τ_{max}	$0.01MPa$
α	3.0
β	3.0
λ_n	0.02
λ_t	0.02
th	$0.0254m$



Legend	Fixed Displ.
■	$X-Y-Z$
●	$X-Z$
● (red)	$Y-Z$
▲	X
▲ (red)	Z



Miura-Ori tessellation results for $\bar{u} = 1.0m$

References

[1] Paulino GH. Liu K. Nonlinear mechanics of non-rigid origami: an efficient computational approach. *Proc. R. Soc. A*, 473, 2017.

[2] Paulino GH. Park K. Computational implementation of the ppr potential-based cohesive model in abaqus: Educational perspective. *Engineering Fracture Mechanics*, 93:239–262, 2012.

[3] Roesler JR. Park K, Paulino GH. A unified potential-based cohesive model of mixed-mode fracture. *J Mech Phys Solids*, 57(6):891–908, 2009.