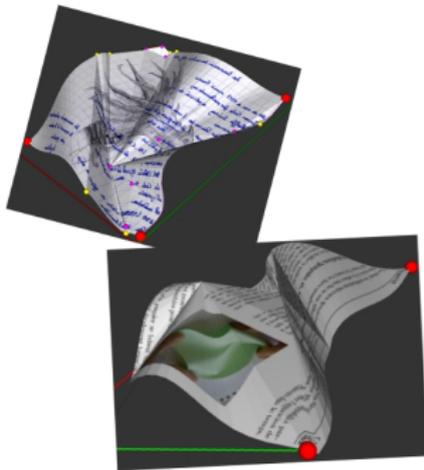


Animation et manipulation de papier froissé

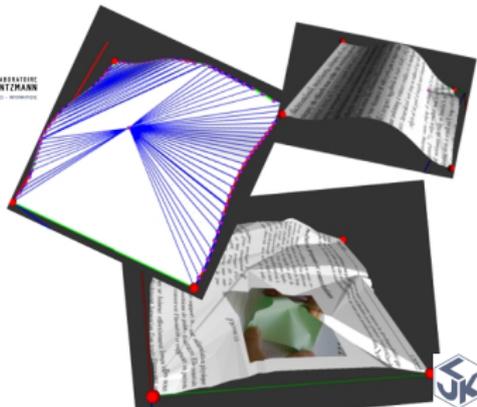
Camille Schreck

Encadrants :

Stefanie Hahmann (LJK-Inria/Imagine),
Damien Rohmer (CPE Lyon, Inria/Imagine)



Inria



14 *Novembre* 2013

Motivation

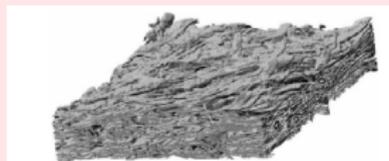
- Le papier : matériau très commun, mais peu représenté en informatique graphique.
- Pas d'outils.

→ Méthode pour modéliser et manipuler du papier interactivement.

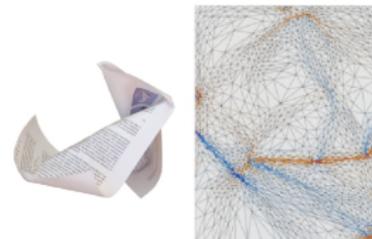
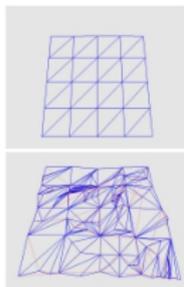


Difficultés

- Isométrie à un patron 2D
- Plis francs
- Plasticité



État de l'art : Approches physiques



Plaques minces

[Grinspun, Eurographics'03]
[Burgoon, C&A'06]

- + réalisme
- plis prédéfinis
- pas de plasticité

Maillage dynamique

[Zhang, CASA'09]

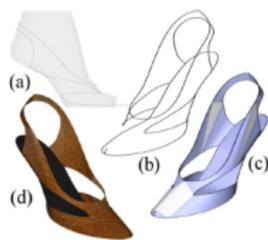
- + rapide
- plis le long des arêtes

[Narain, SIGGRAPH, 13]

- + très réaliste
- plis doivent s'adapter au maillage
- temps de calcul élevé



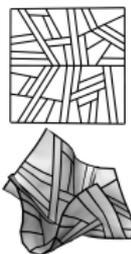
État de l'art : Approches géométriques



Synthèse de surface
développable

[Rose, SGP'07]
[Decaudin, CGF'06]

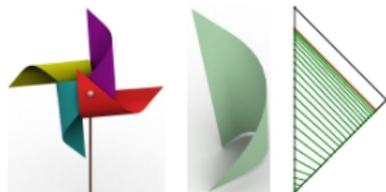
- + développabilité exacte
- surface lisse → pas de plis francs



Déformation de surface développable

[Rohmer, Eurographics'11] [Solomon, CGF'12]

- + plis francs
- pas de cohérence temporelle



- + développabilité exacte
- pli défini par utilisateur

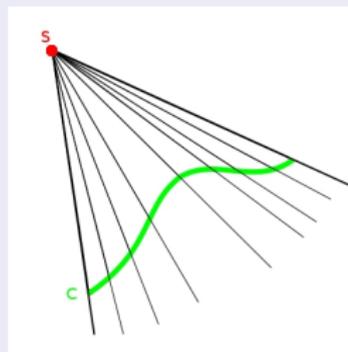
Surface développable

Définitions

- Peut être dépliée sur un plan sans déformation.
- si C^2 :
 - ▶ Surface réglée
 - ▶ Plan tangent constant le long d'une règle.
- Courbure de Gauss nulle en tout point.

Surfaces C^2 -développables

- Composées de portions de:
 - ▶ plans
 - ▶ cylindres
 - ▶ cônes
 - ▶ développées tangentielles.
- Cas particulier : cônes généralisés



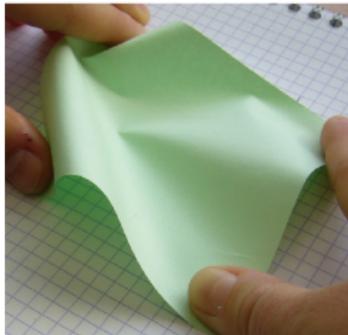
Notre approche

Principe

- Gestion explicite des singularités.
- Surface s'appuyant sur ces points.

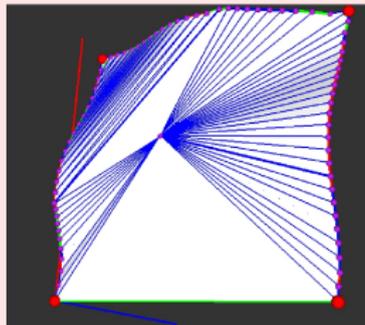
Cas particulier :

- doigts sur les coins
- doigts se déplacent dans un plan.



Contributions

- **Approche mixte :**
géométrique/physique
- **Gestion réaliste des points singuliers**
- **Maillage optimal :**
adapté aux plis et points singuliers



Sommaire

- 1 Une approche mixte pour la modélisation du papier
- 2 Analyse et déformation de la surface
- 3 Simulation physique
- 4 Validation et résultats
- 5 Limitations et perspectives

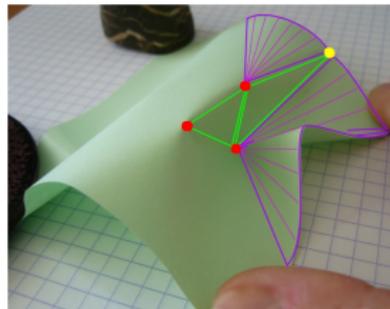
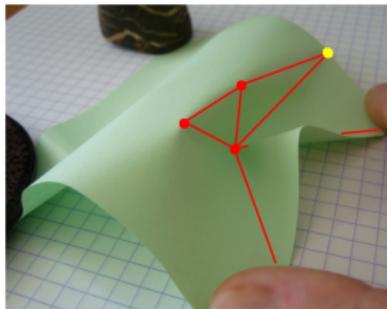


Index

- 1 Une approche mixte pour la modélisation du papier
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Une approche mixte pour la modélisation du papier



Papier froissé.

- point singulier
- point de contour

— partie plus rigide entre des points singuliers

Approximation de la surface par des cônes généralisés.

- △ zone plane
- △ cône généralisé



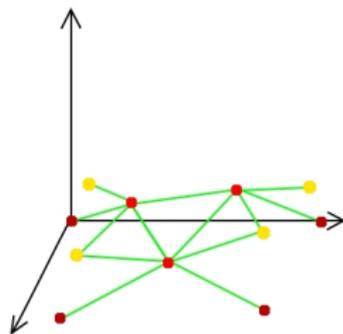
Algorithme

Initialisation

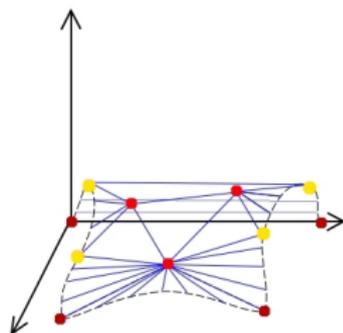
Triangulation des points représentant les doigts.

Boucle d'animation

- Màj et résolution du système physique rigide
→ position 3D points de fracture et contour
- Pour chaque triangle :
 - ▶ si non compressé :
surface plane.
 - ▶ si compressé dans une direction :
morceaux de cône généralisé.
 - ▶ si compressé dans deux directions :
ajout d'un point de fracture,
subdivision de la surface.
- Création dynamique du maillage



Système rigide.



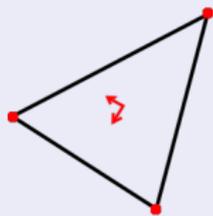
Surface formée de cônes généralisés

Index

- 1 Une approche mixte pour la modélisation du papier
- 2 Analyse et déformation de la surface**
- 3 Simulation physique
- 4 Validation et résultats
- 5 Limitations et perspectives



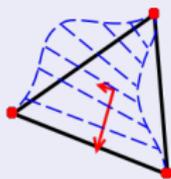
Détection de la compression



Triangle non
comprimé.



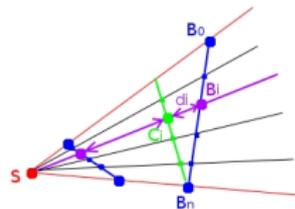
Triangle comprimé
dans une direction.



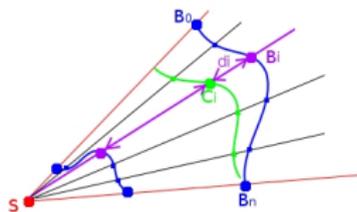
Création d'un nouveau
cône généralisé.

Construction des cônes généralisés

2D :



3D :



Pour $i = 1 \dots n - 1$:

En 2D :

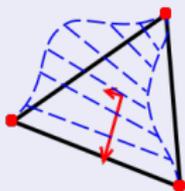
B_i = intersection entre le bord
et la règle passant par C_i

$$d_i = \|\vec{C_i B_i}\|$$

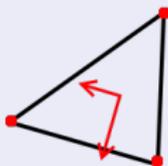
En 3D :

$$B_i = C_i + d_i \times \frac{\vec{S C_i}}{\|\vec{S C_i}\|}$$

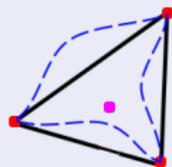
Insertion de points singuliers



Triangle comprimé
dans une direction.



Triangle comprimé
dans deux directions

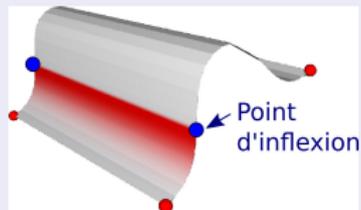


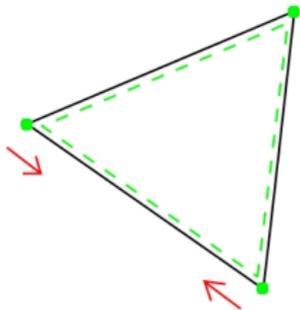
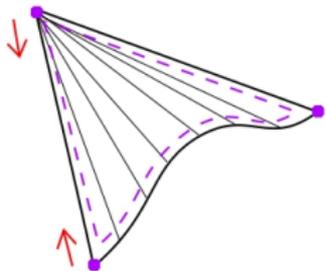
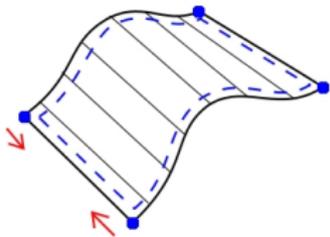
Apparition d'un point
singulier.

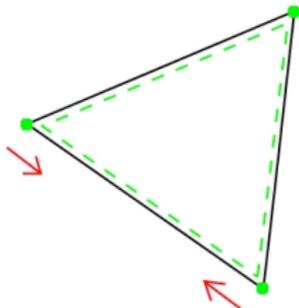
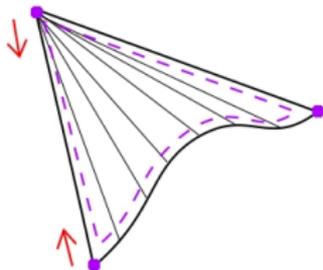
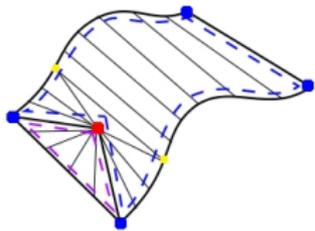
Position d'un point singulier

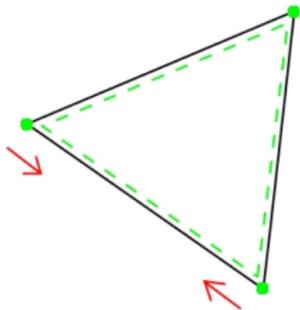
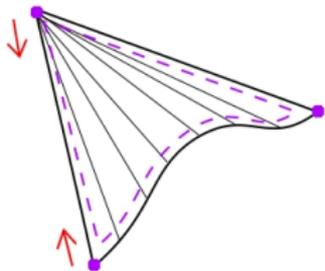
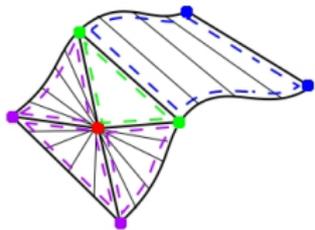
La probabilité qu'un point de fracture apparaisse à une position dépend :

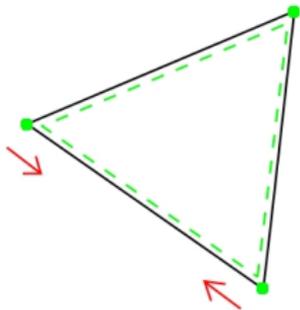
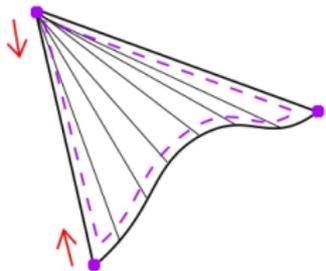
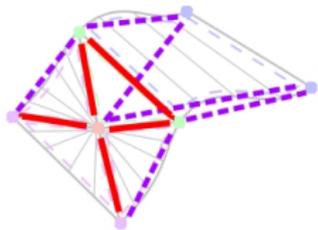
- des fibres du papier : texture 2D
- de $p = e^{-\frac{d^2}{\sigma^2}}$
 d = distance à la ligne d'inflexion.

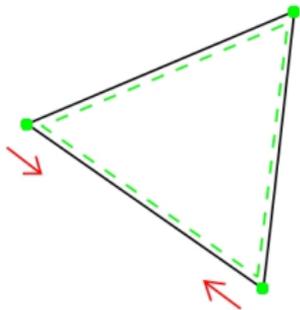
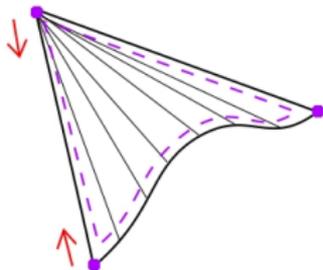
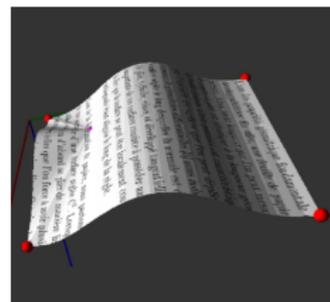
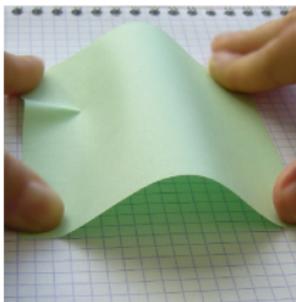
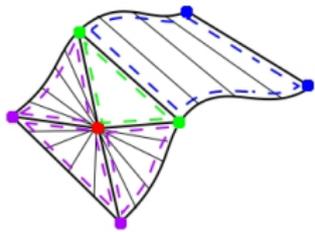


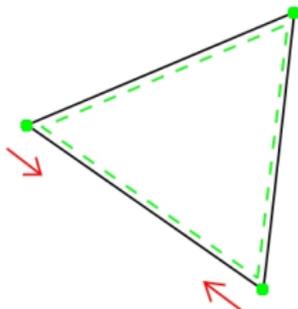
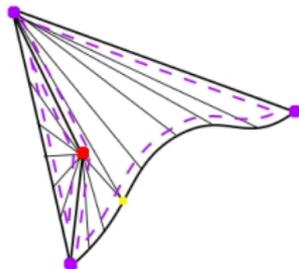
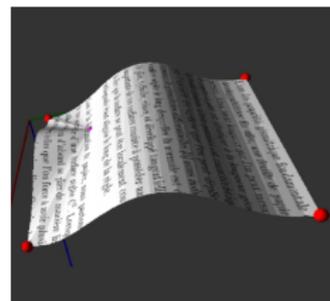
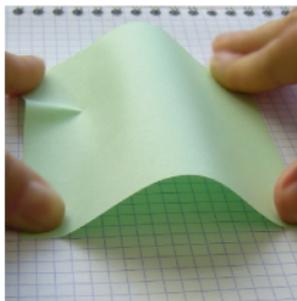
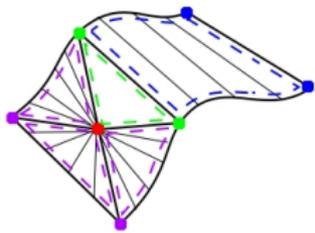


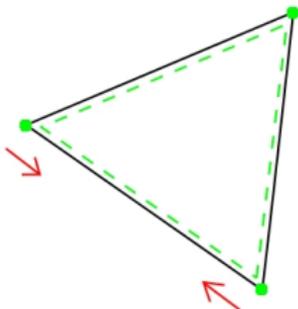
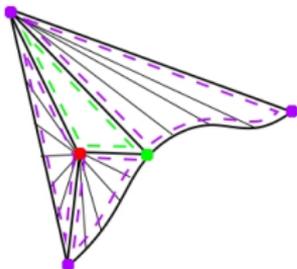
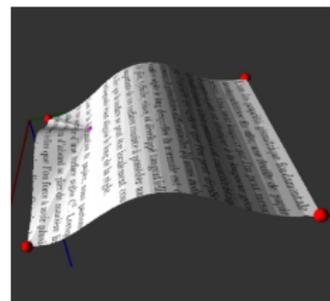
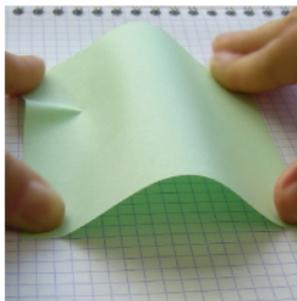
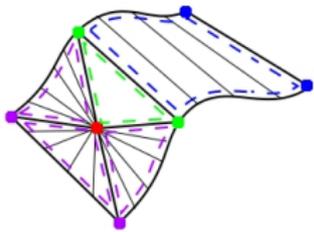


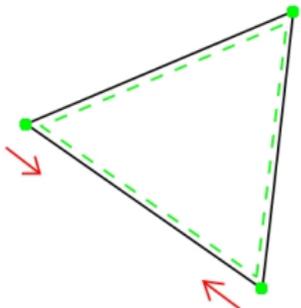
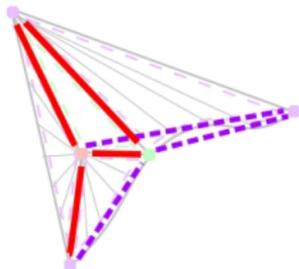
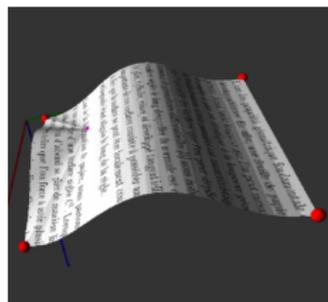
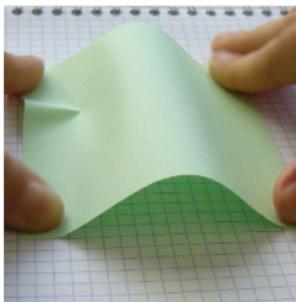
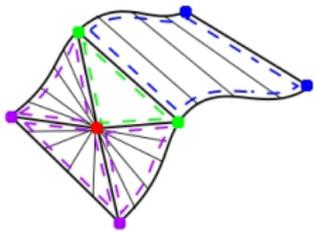


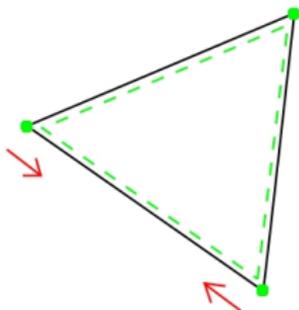
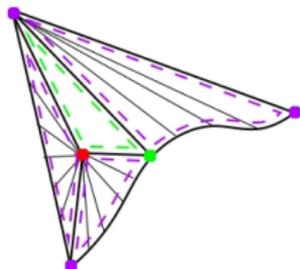
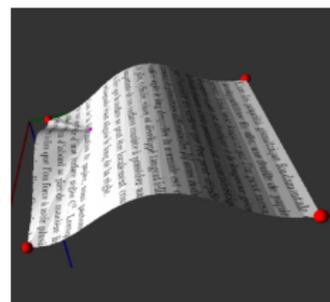
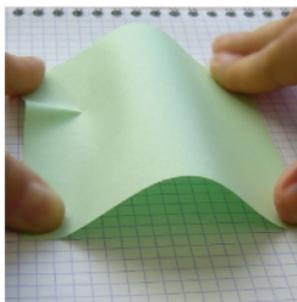
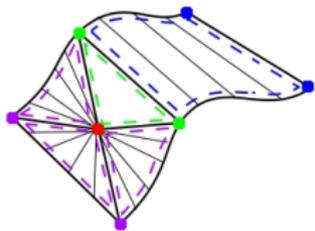


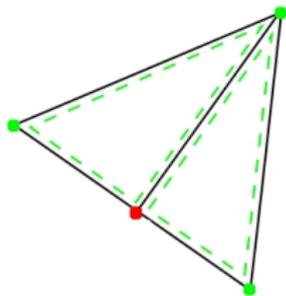
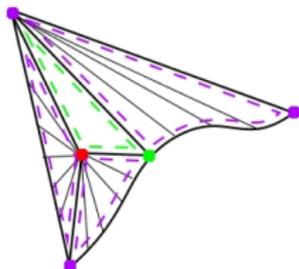
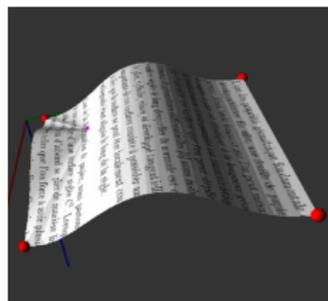
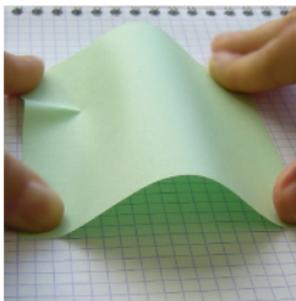
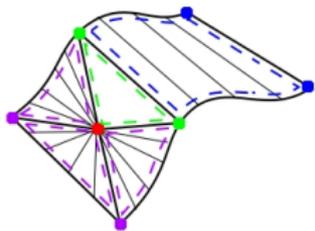


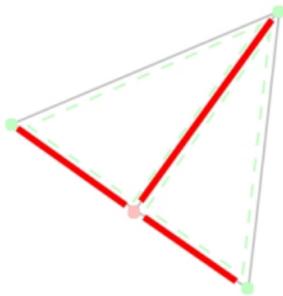
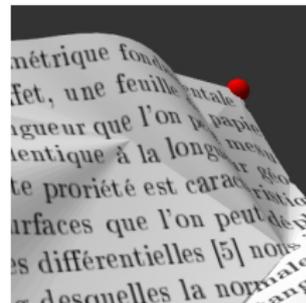
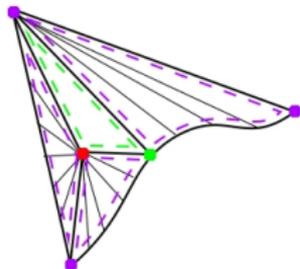
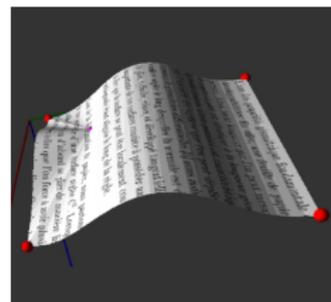
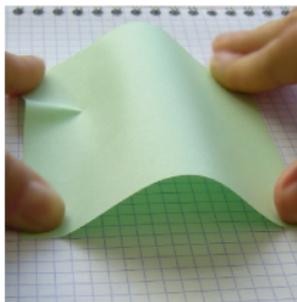
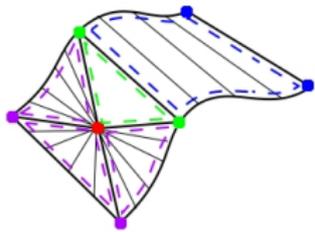


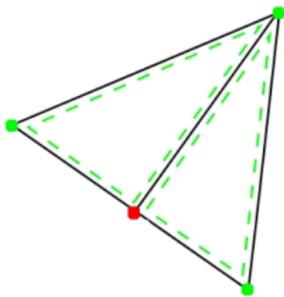
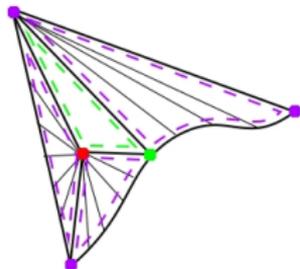
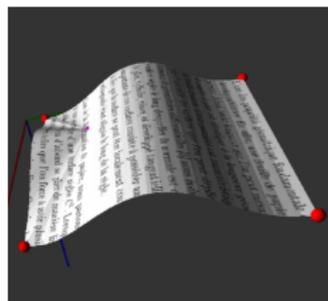
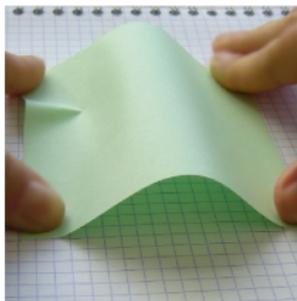
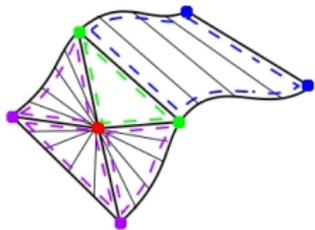












Index

- 1 Une approche mixte pour la modélisation du papier
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Un système masse-ressort pour simuler des éléments rigides

Deux cas où est utilisée la simulation physique

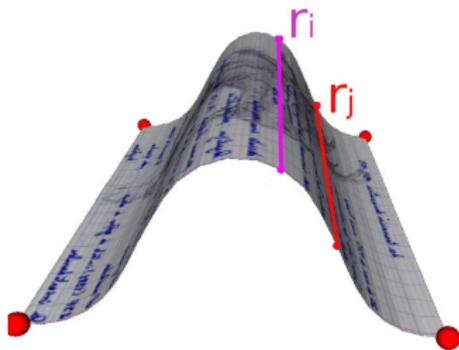
- Éléments rigides entre les points de fracture et de contour : ressorts créés au fur et à mesure.
- Relaxation de cône : ressorts le long des règles de bords courbés.

Forces

- Élongation
- Courbure
- Cisaillement

- **Rigidité d'un ressort r_i le long d'une règle**

$$k_i = k_{regle} \times \text{courbure}_i$$



$$\begin{aligned} |\text{courbure}_i - \pi| &> |\text{courbure}_j - \pi| \\ \rightarrow k_i &> k_j \end{aligned}$$

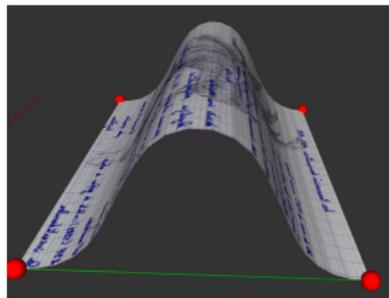


Index

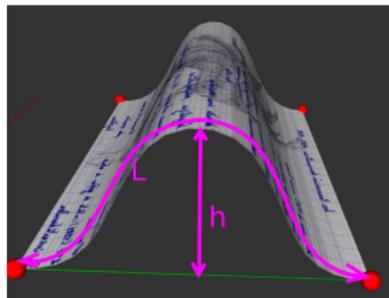
- 1 Une approche mixte pour la modélisation du papier
- 2 Analyse et déformation de la surface
- 3 Simulation physique
- 4 Validation et résultats**
- 5 Limitations et perspectives



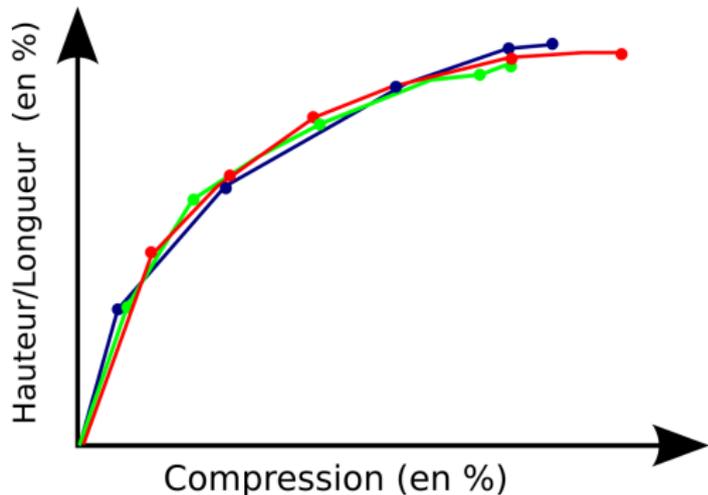
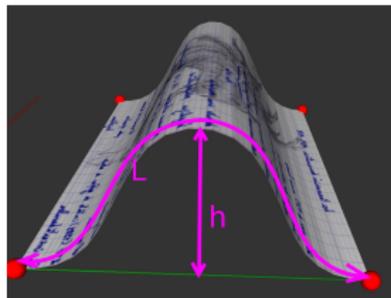
Validation des courbes



Validation des courbes



Validation des courbes



Hauteur/longueur de la courbe (h/L) en fonction de la compression.

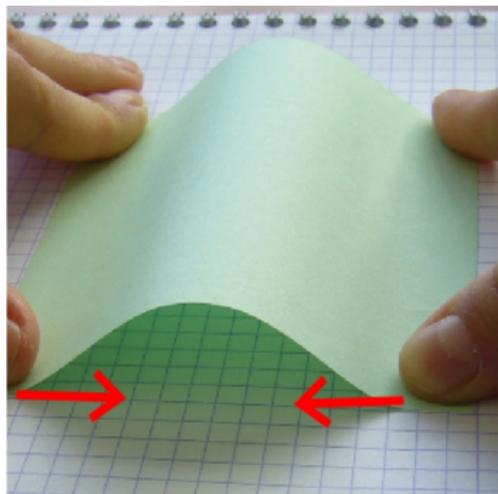
— modélisation

— papier d'imprimante 90 g/m^2

— papier à carreaux 70 g/m^2



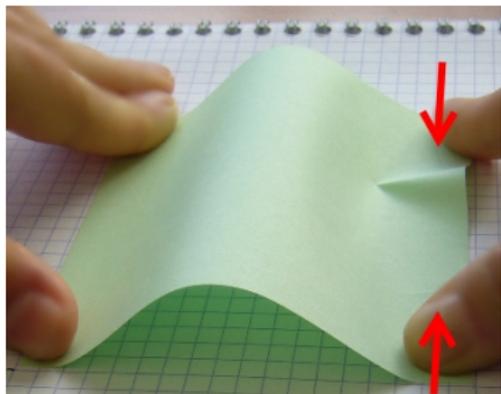
Validation de la position des points de fracture



Compression de la feuille



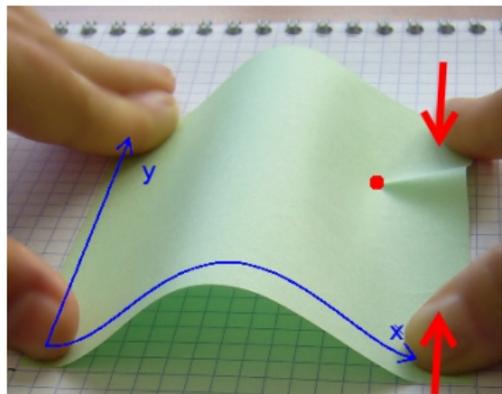
Validation de la position des points de fracture



Apparition du premier point de fracture



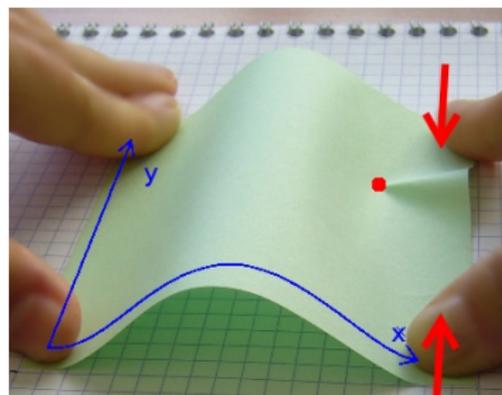
Validation de la position des points de fracture



Apparition du premier point de fracture

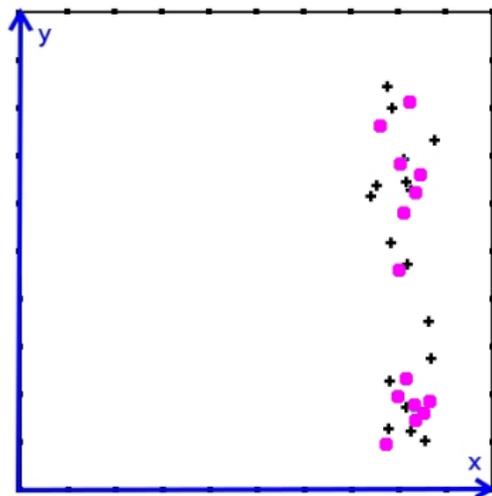


Validation de la position des points de fracture



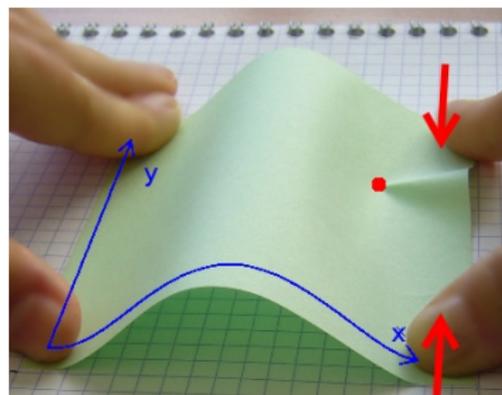
Apparition du premier point de fracture

Papier d'imprimante



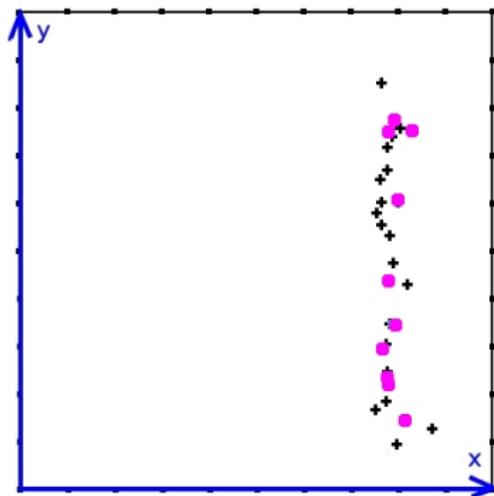
Compression 10%, $\sigma = 0.01$

Validation de la position des points de fracture



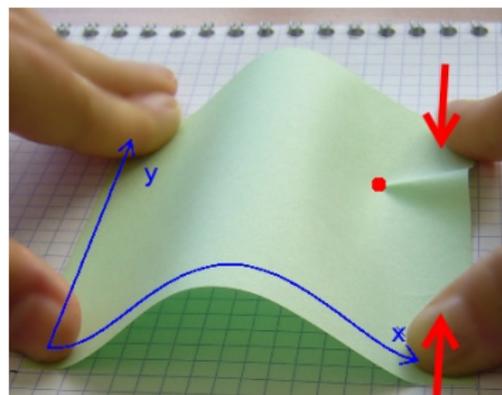
Apparition du premier point de fracture

Papier à carreaux



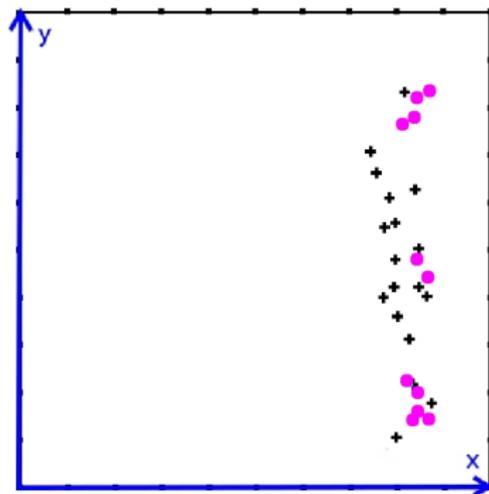
Compression 10%, $\sigma = 0.001$

Validation de la position des points de fracture



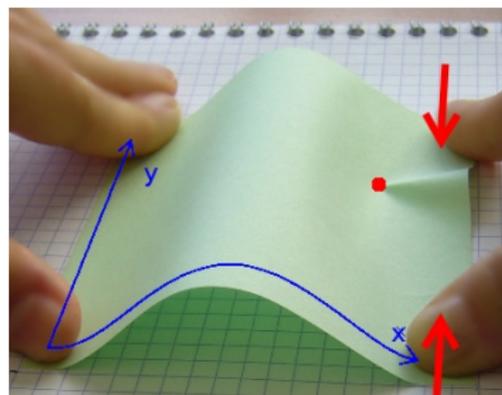
Apparition du premier point de fracture

Papier d'imprimante



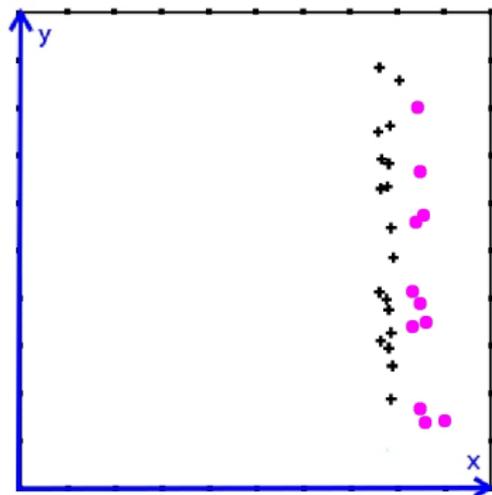
Compression 30%, $\sigma = 0.01$

Validation de la position des points de fracture



Apparition du premier point de fracture

Papier à carreaux



Compression 30%, $\sigma = 0.001$

Résultats

Performance : temps réel

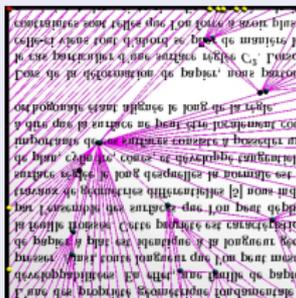
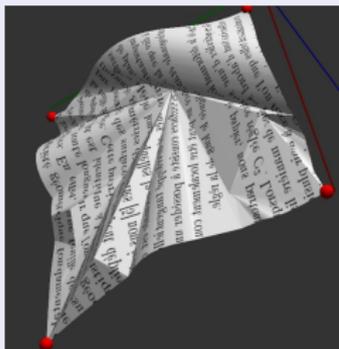
- 2.67 GHz, 8GiB
- 10 itérations pour résoudre les systèmes physiques

→ Plus de 15 fps jusqu'à 50 points de fracture + 50 points de contour.

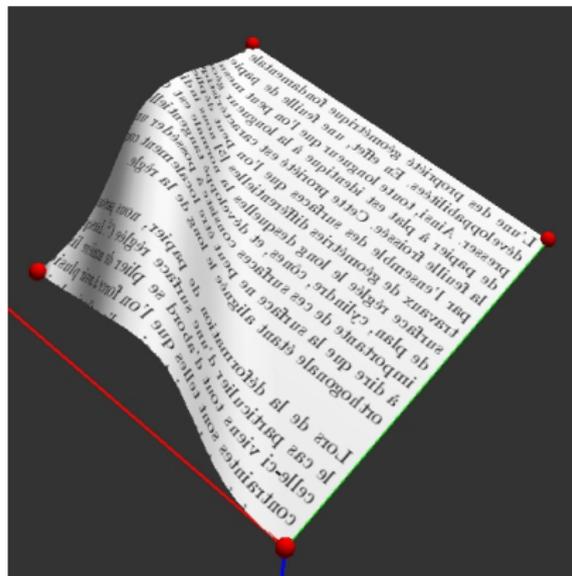
Quasi-isométrie

Déformation d'arêtes du maillage : $< 10\%$ sauf sur le bord des cônes.

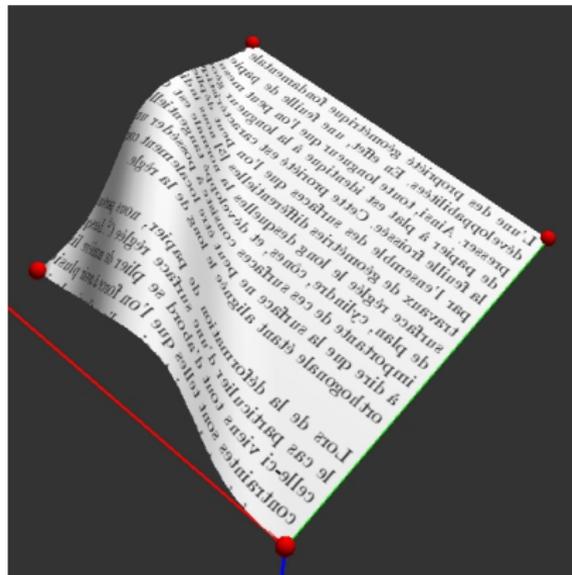
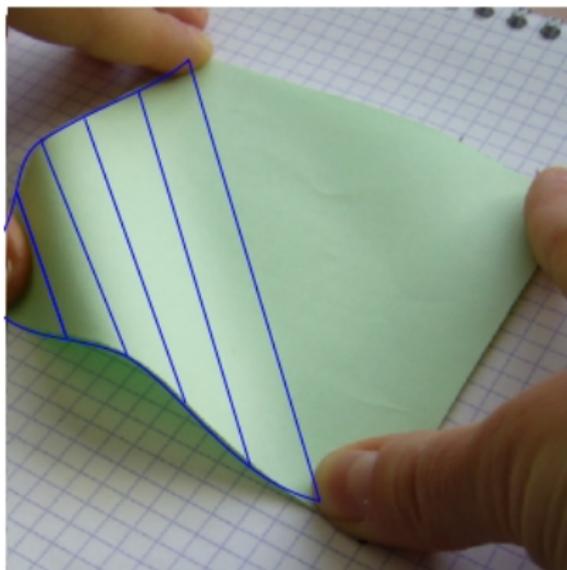
Maillage optimal



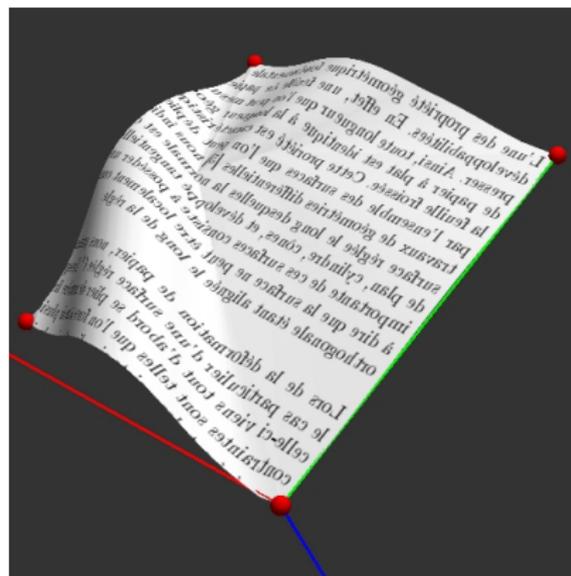
Comparaison visuelle dans un cas élémentaire



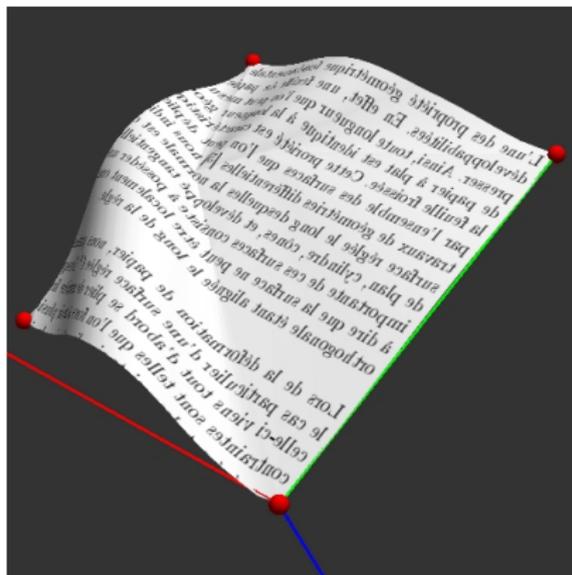
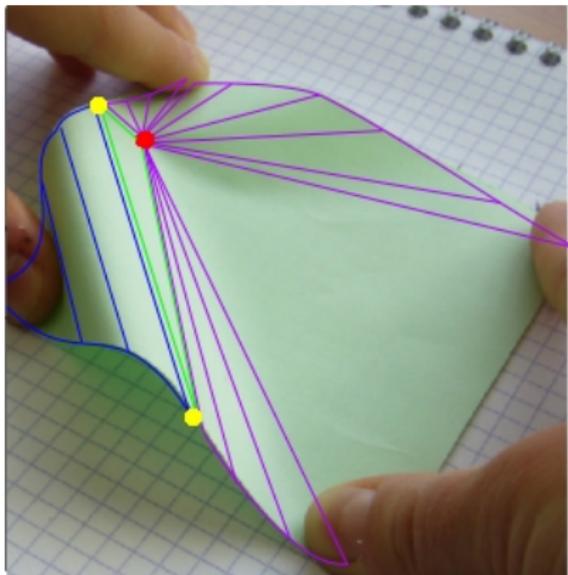
Comparaison visuelle dans un cas élémentaire



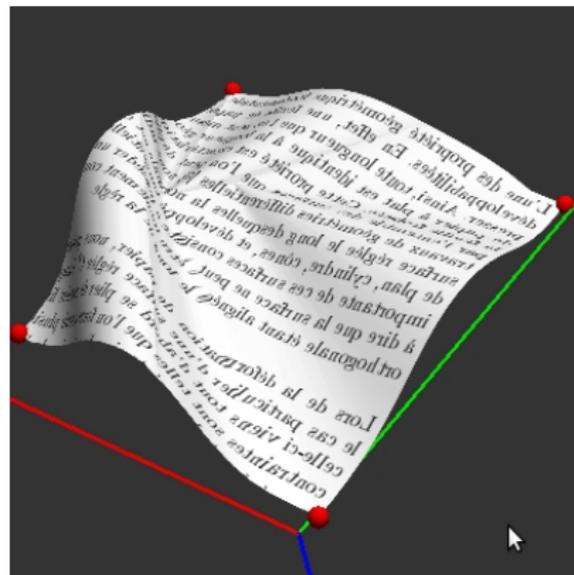
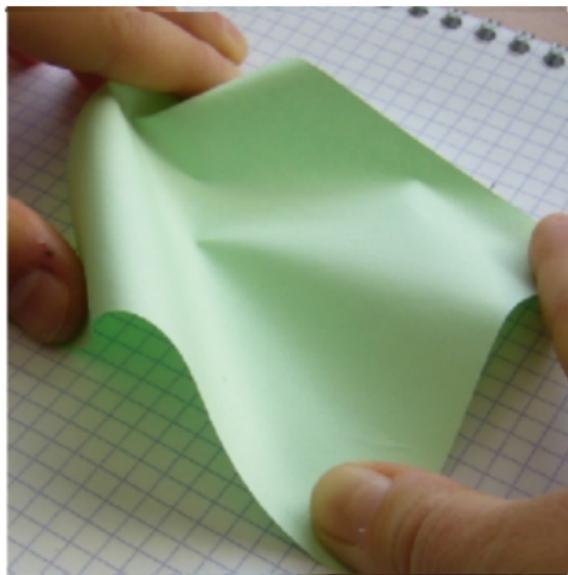
Comparaison visuelle dans un cas élémentaire



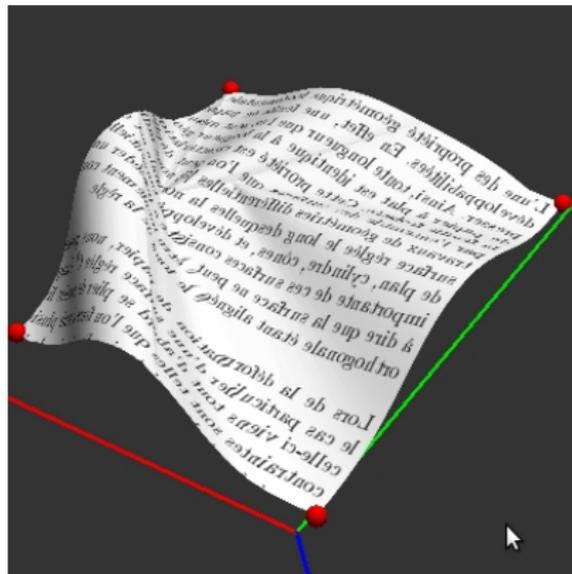
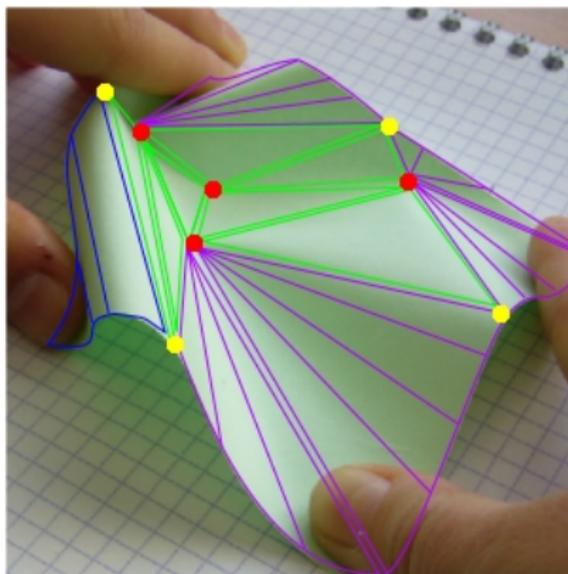
Comparaison visuelle dans un cas élémentaire



Comparaison visuelle dans un cas élémentaire



Comparaison visuelle dans un cas élémentaire



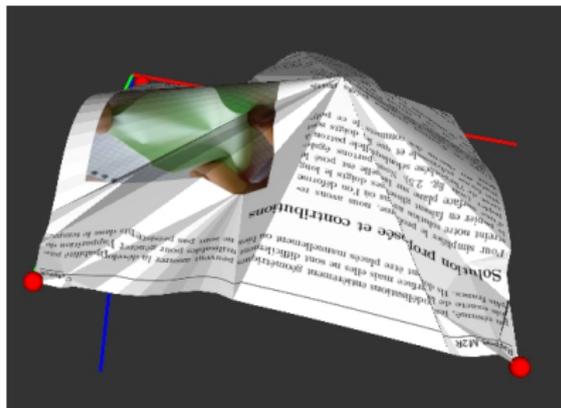
Index

- 1 Une approche mixte pour la modélisation du papier
- 2 Analyse et déformation de la surface
- 3 Simulation physique
- 4 Validation et résultats
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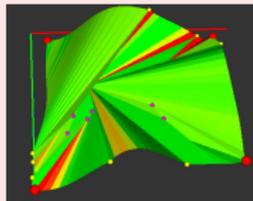
Conclusion

- + Temps réel
- + Interactivité
- + Plis francs
- + Plasticité
- + Maillage optimale
- + Quasi-isométrie



Limitations

- Cas particulier
- Stabilité du système physique
- Défaut d'isométrie sur le bord des cônes



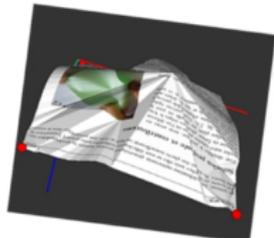
- Auto-intersections non gérées.



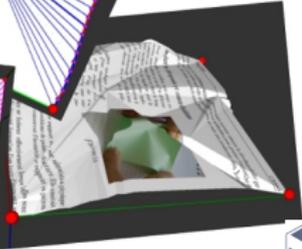
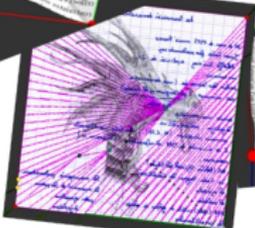
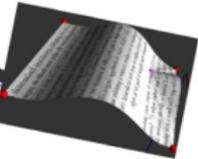
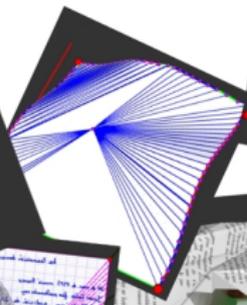
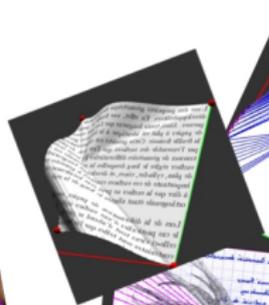
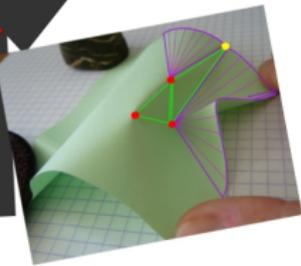
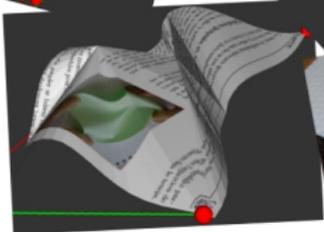
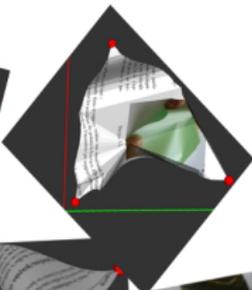
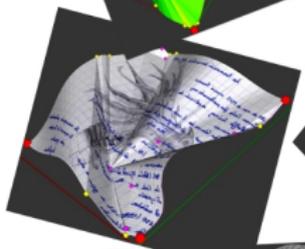
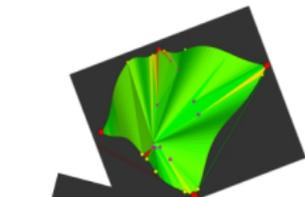
Perspectives

- Généralisation : déplacement de doigts dans l'espace...
- Gestion des collisions : peu de temps de calcul.
- Arêtes en arc-de-cercle.



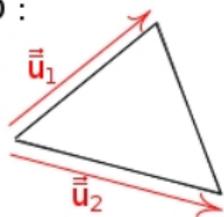


Merci de votre attention !

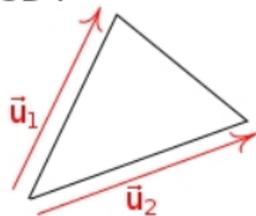


Matrice de compression

2D :



3D :



Matrice de compression :

$$U = \sqrt{T^T T}$$

$$U = \lambda_1 \vec{e}_1 \vec{e}_1^T + \lambda_2 \vec{e}_2 \vec{e}_2^T$$

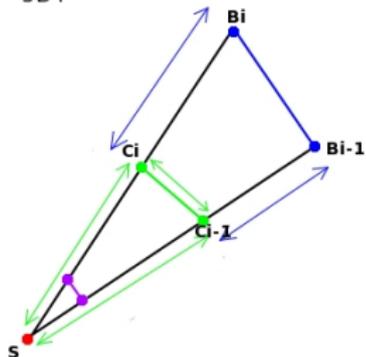
$1 - \lambda_2$ et $1 - \lambda_1 \in [0, 1]$: taux de compression minimal et maximal.

\vec{e}_1 et \vec{e}_2 : directions principales de compression.

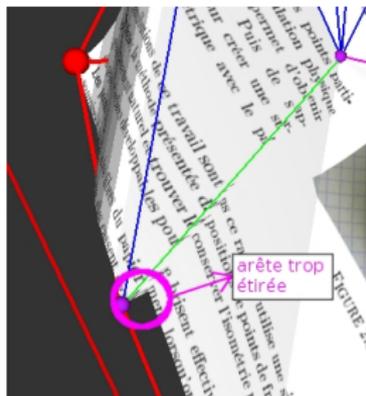
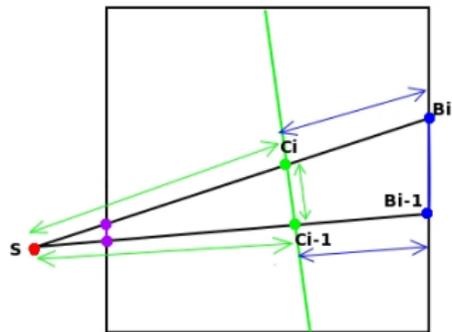


Isométrie des cônes

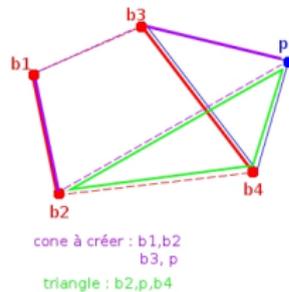
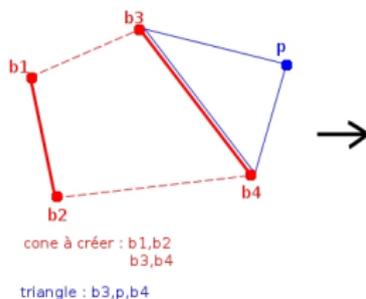
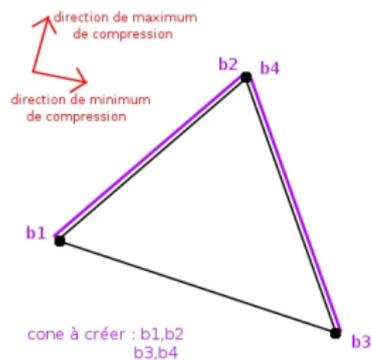
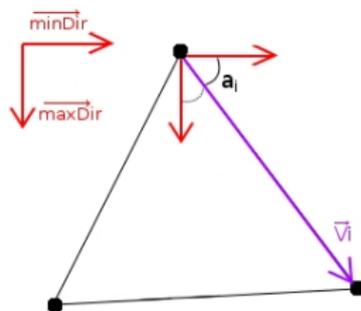
3D :



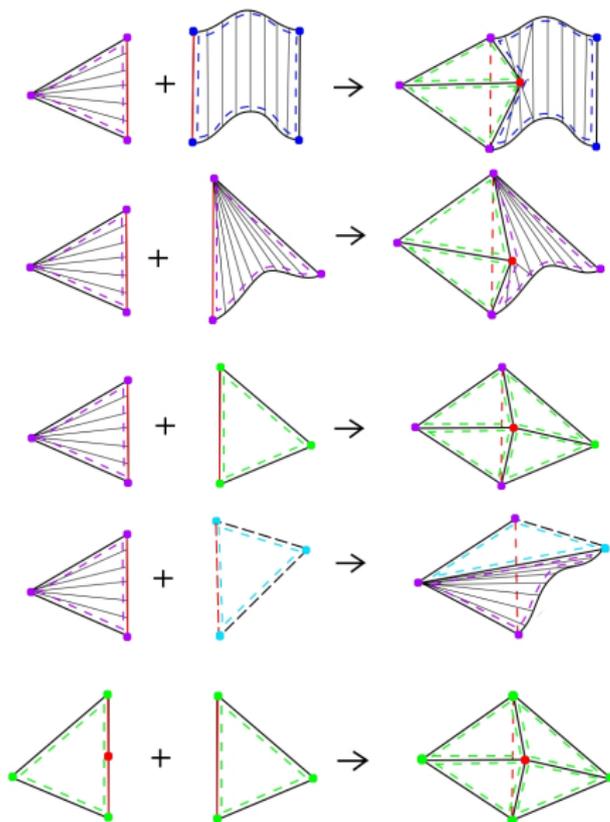
2D :



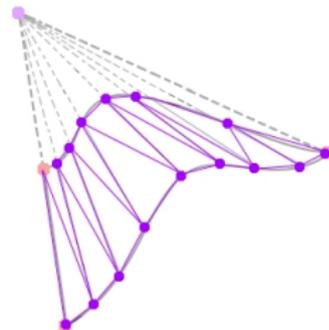
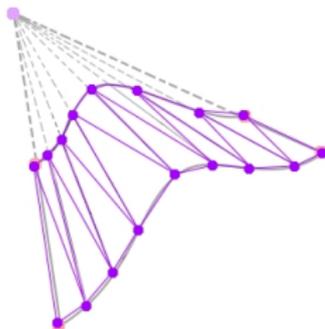
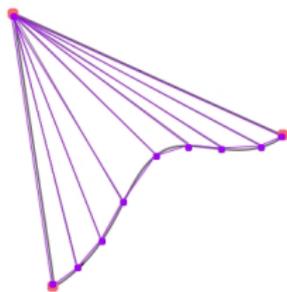
Rassembler les triangles



Joindre les cônes

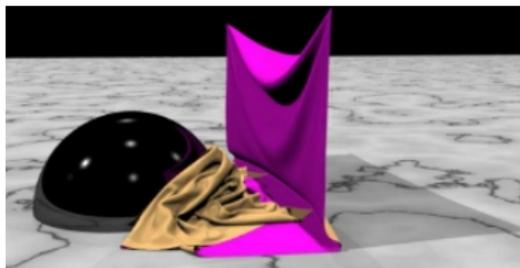


Maillage



Collisions ?

- Méthode naïve
- [*Bridson, SIGGRAPH'02*]



Arc de cercle ?

- Propagation des points de fracture
- [Kilian, SIGGRAPH'08]

