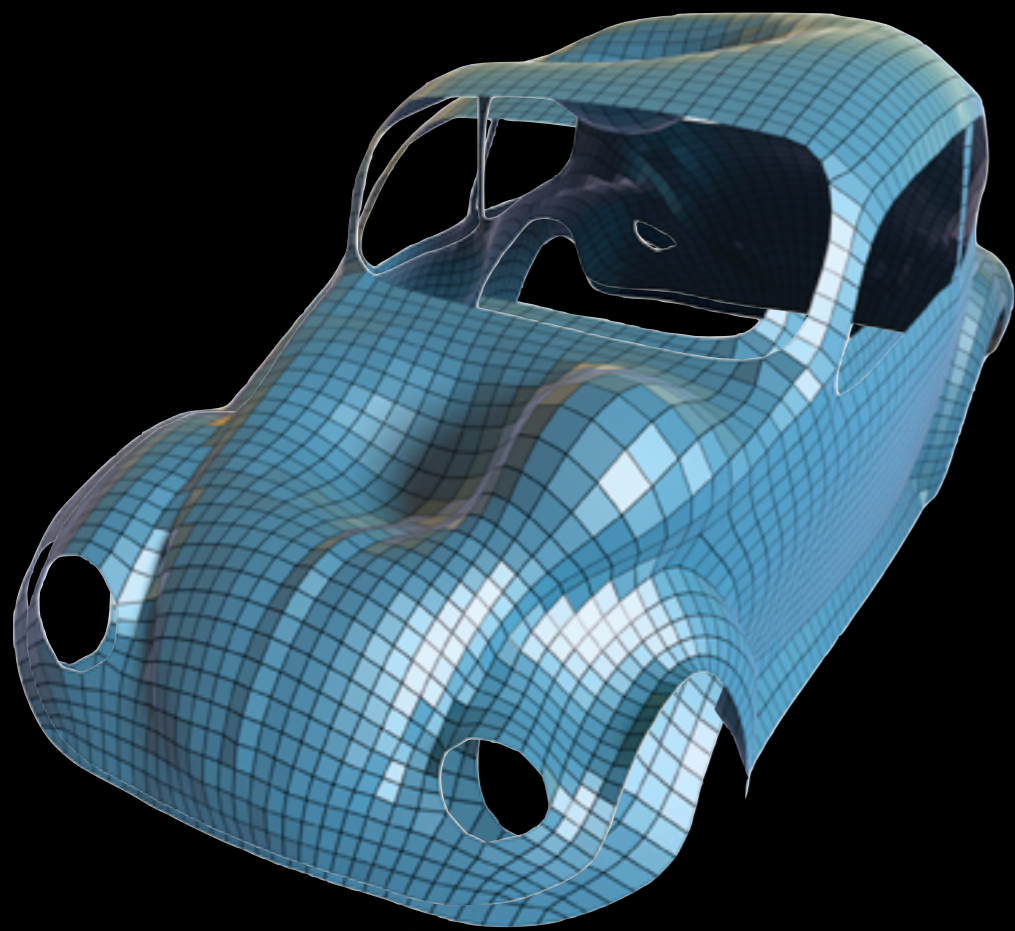




Le rendu réaliste :
beaucoup plus que de belles images

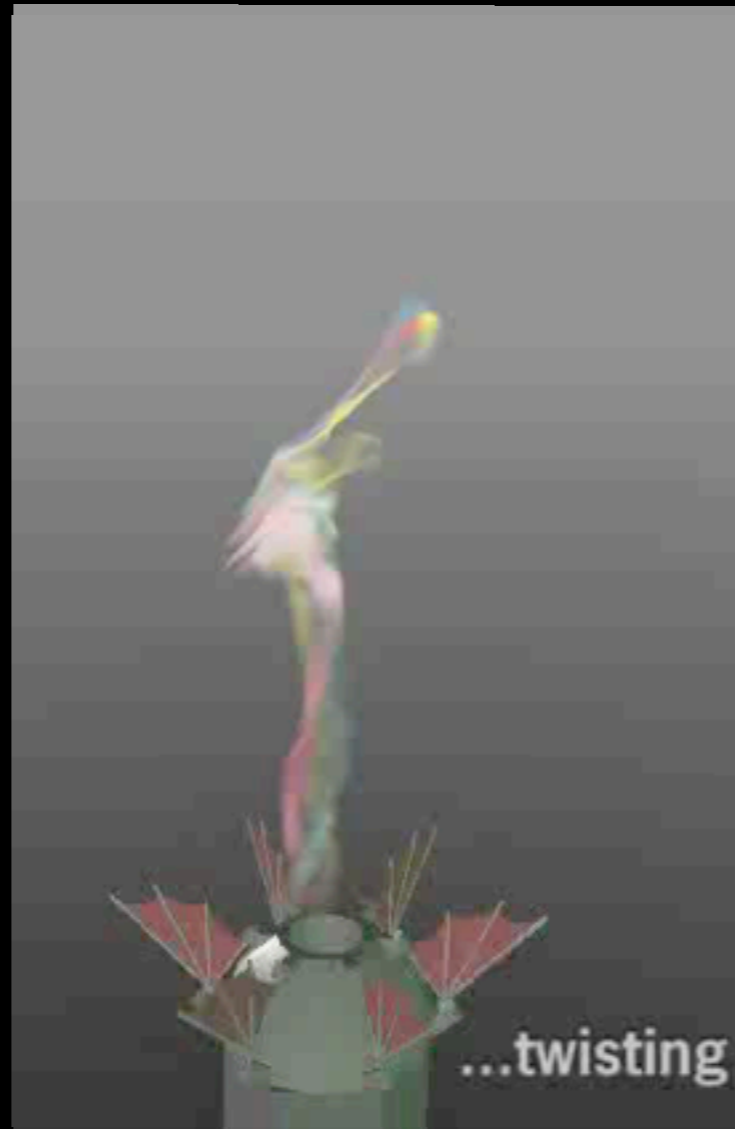
Derek Nowrouzezahrai
Université de Montréal

L'infographie en un mot



K. Crane

modélisation



animation



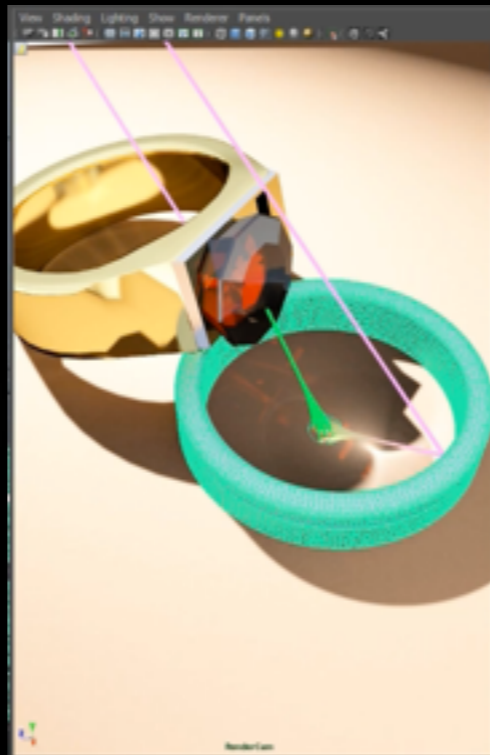
rendu

Ce soir

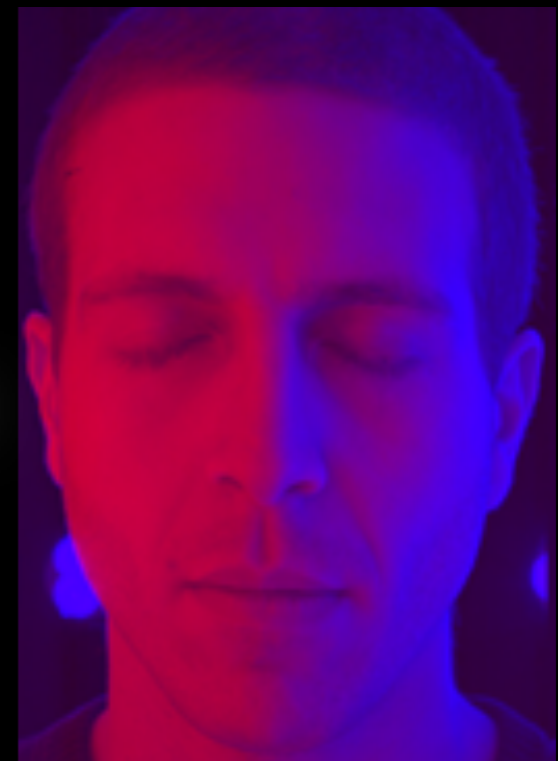
Comment **simuler** la lumière et
comment la **manipuler** :



synthèse
d'image

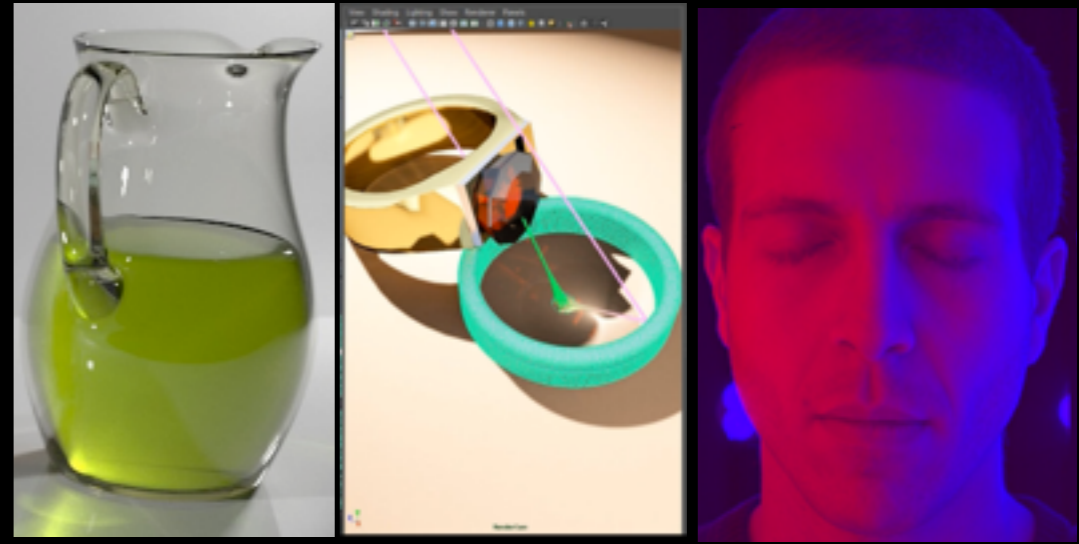


modification
de l'apparence

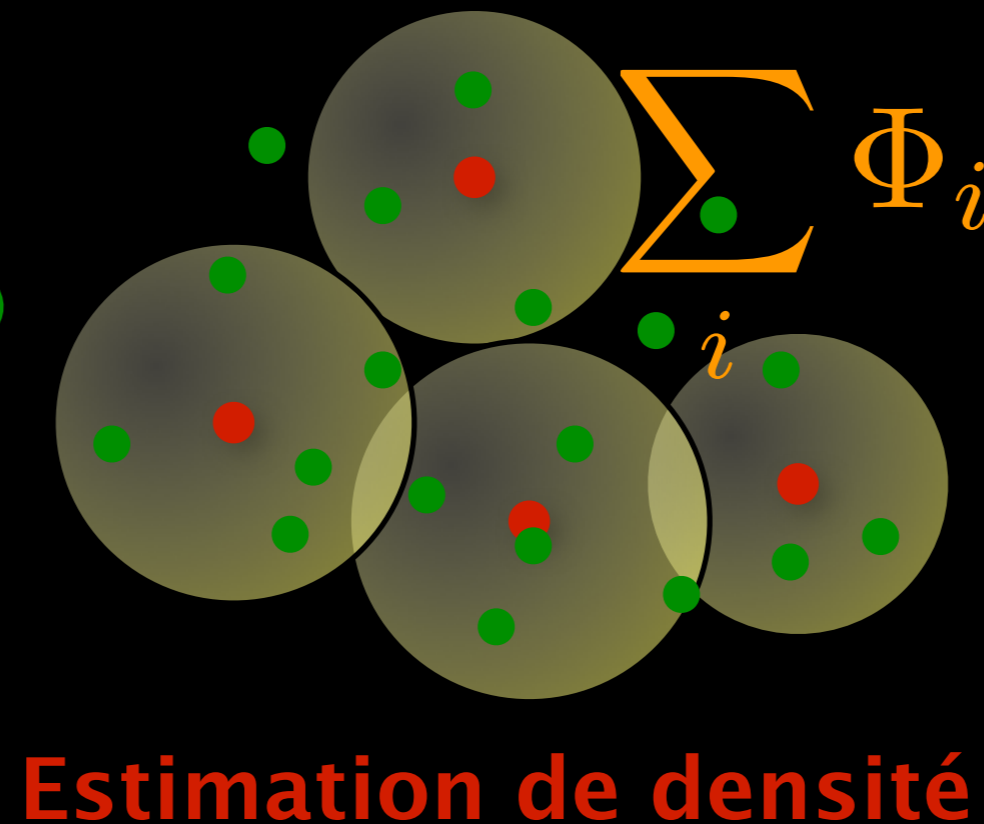
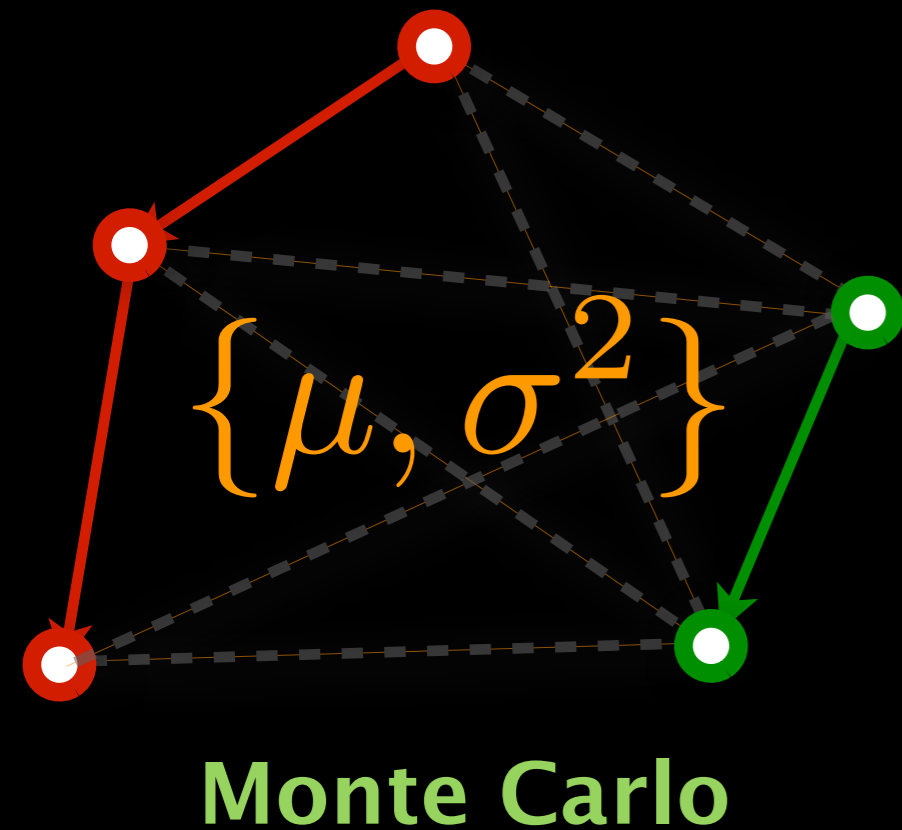


capturer le
monde réel

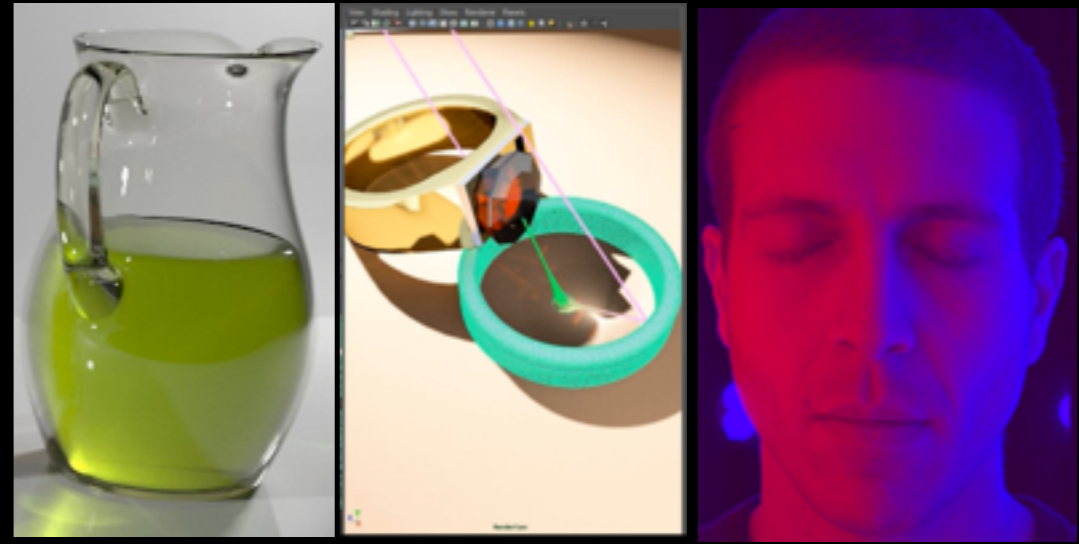
Ce soir



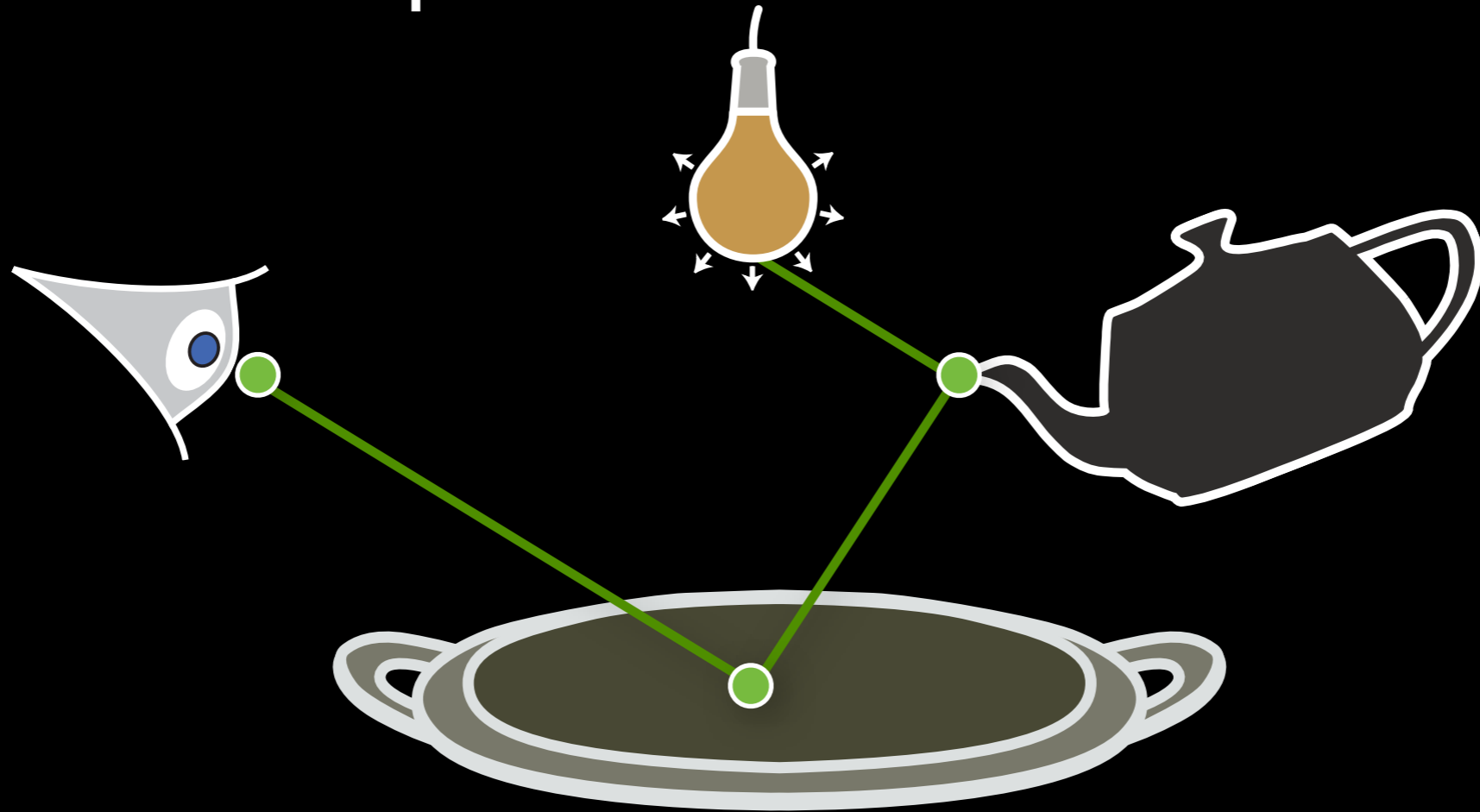
Simuler le transport de la lumière



Ce soir

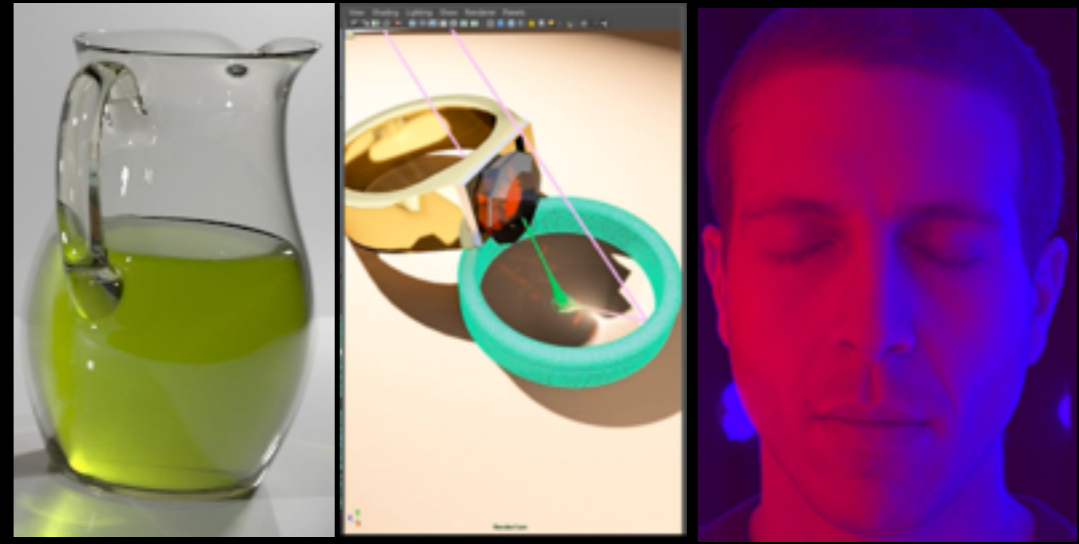


Simuler le transport de la lumière sur les surfaces

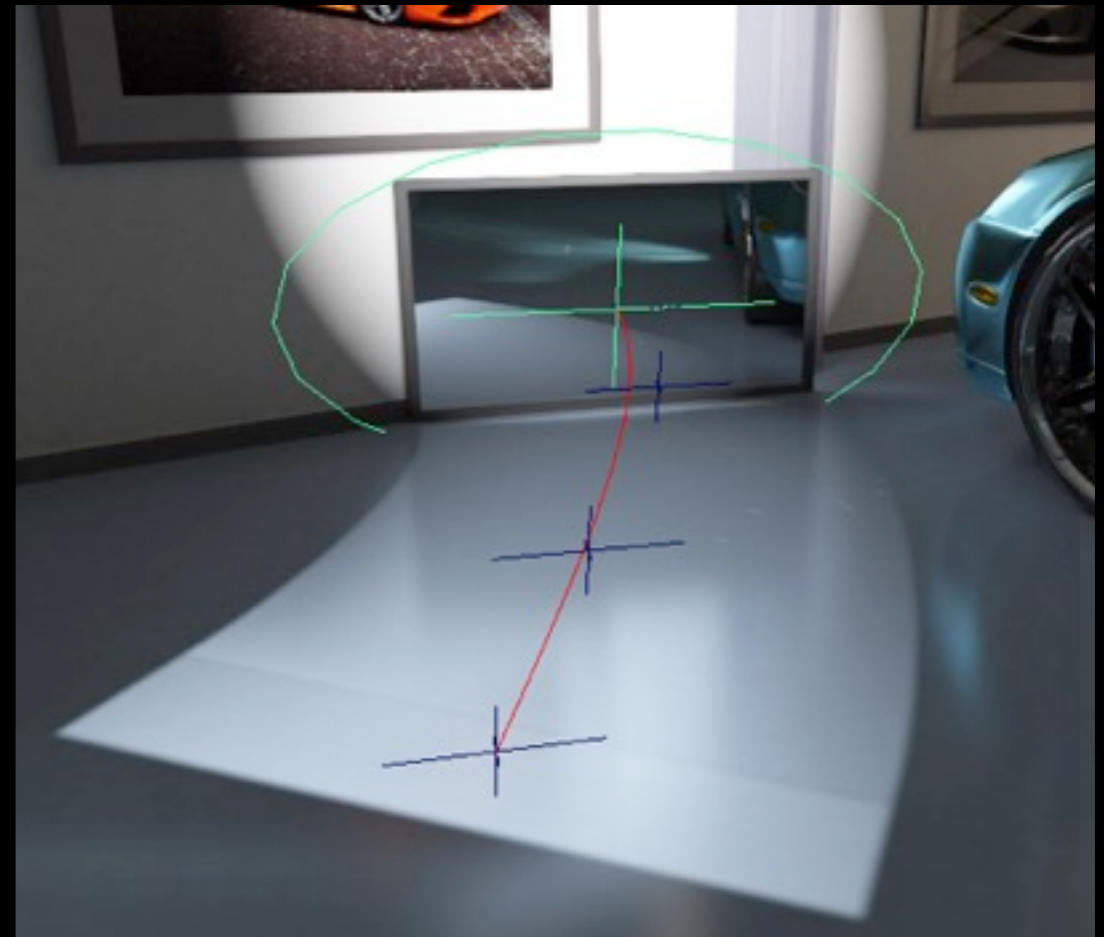
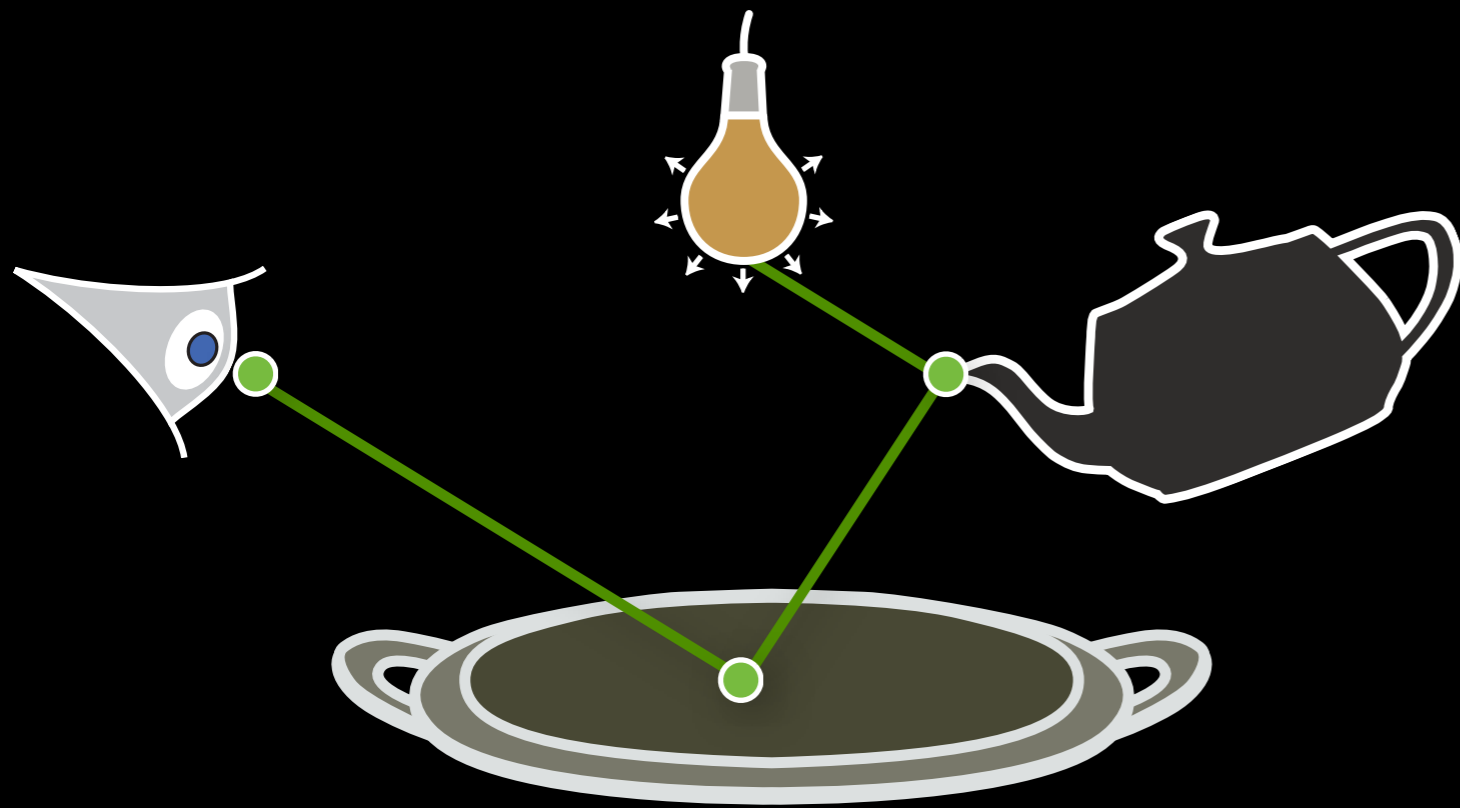


$$L(\mathbf{x}, \omega) = L_e(\mathbf{x}, \omega) + \int_{\Omega} L(\mathbf{x}, \omega') f_r(\mathbf{x}, \omega', \omega) d\omega'$$

Ce soir

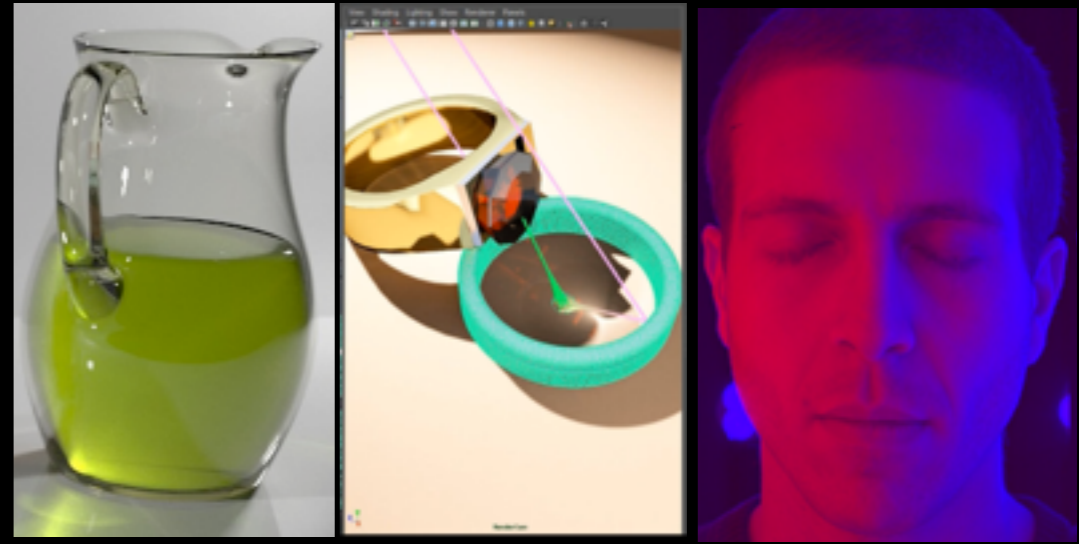


Simuler le transport de la lumière sur les surfaces

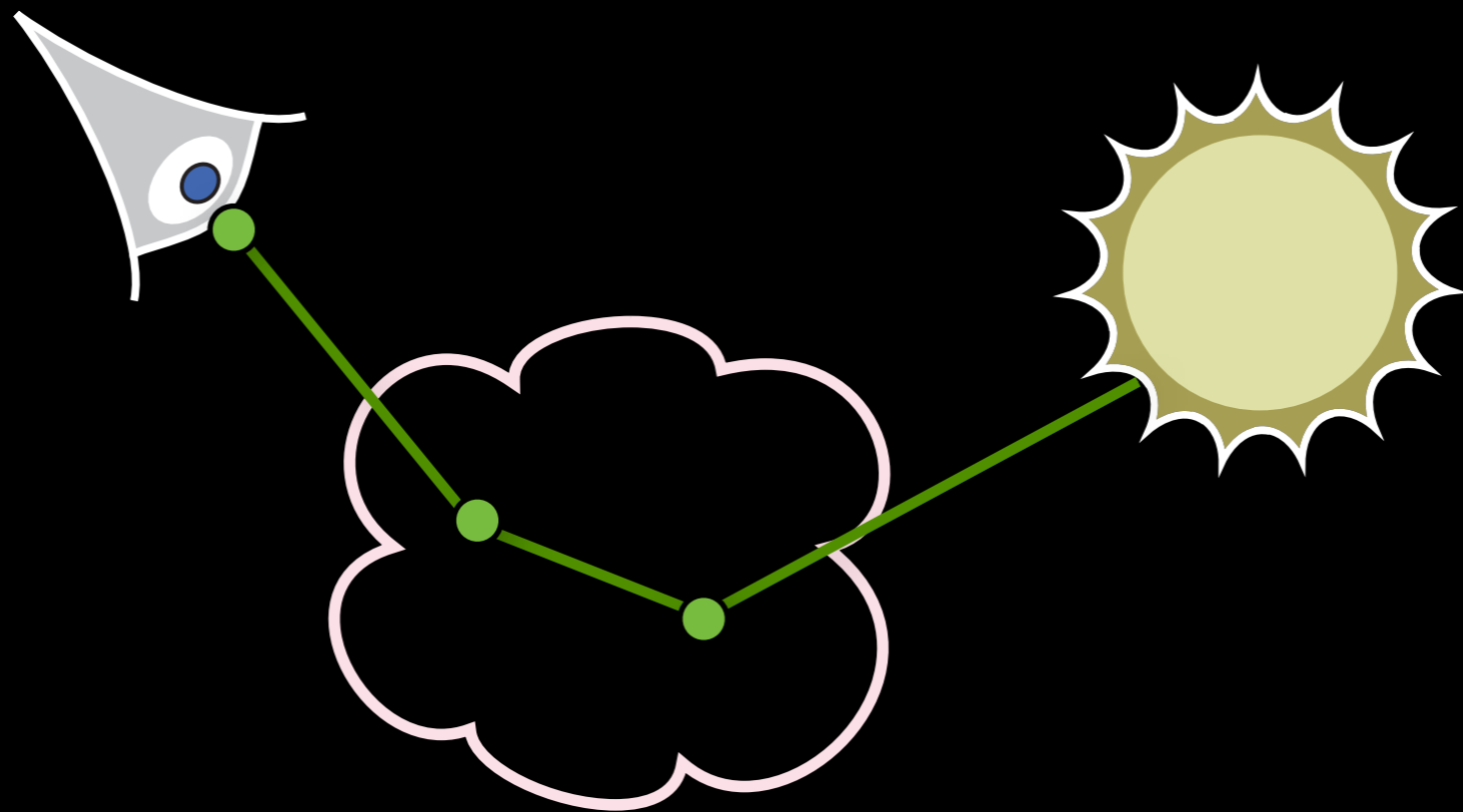


Manipuler la lumière sur les surfaces

Ce soir

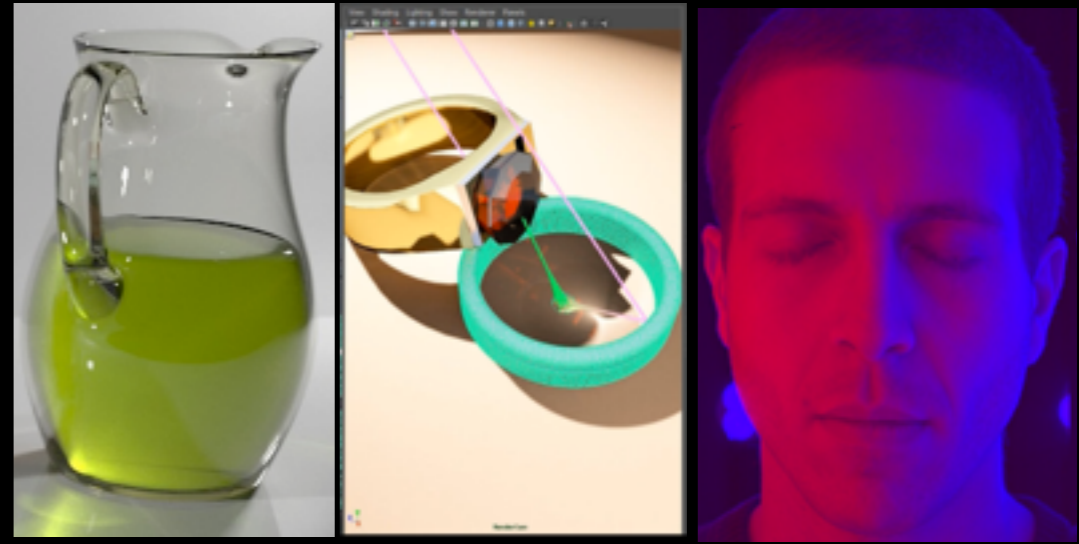


Simuler le transport dans les volumes

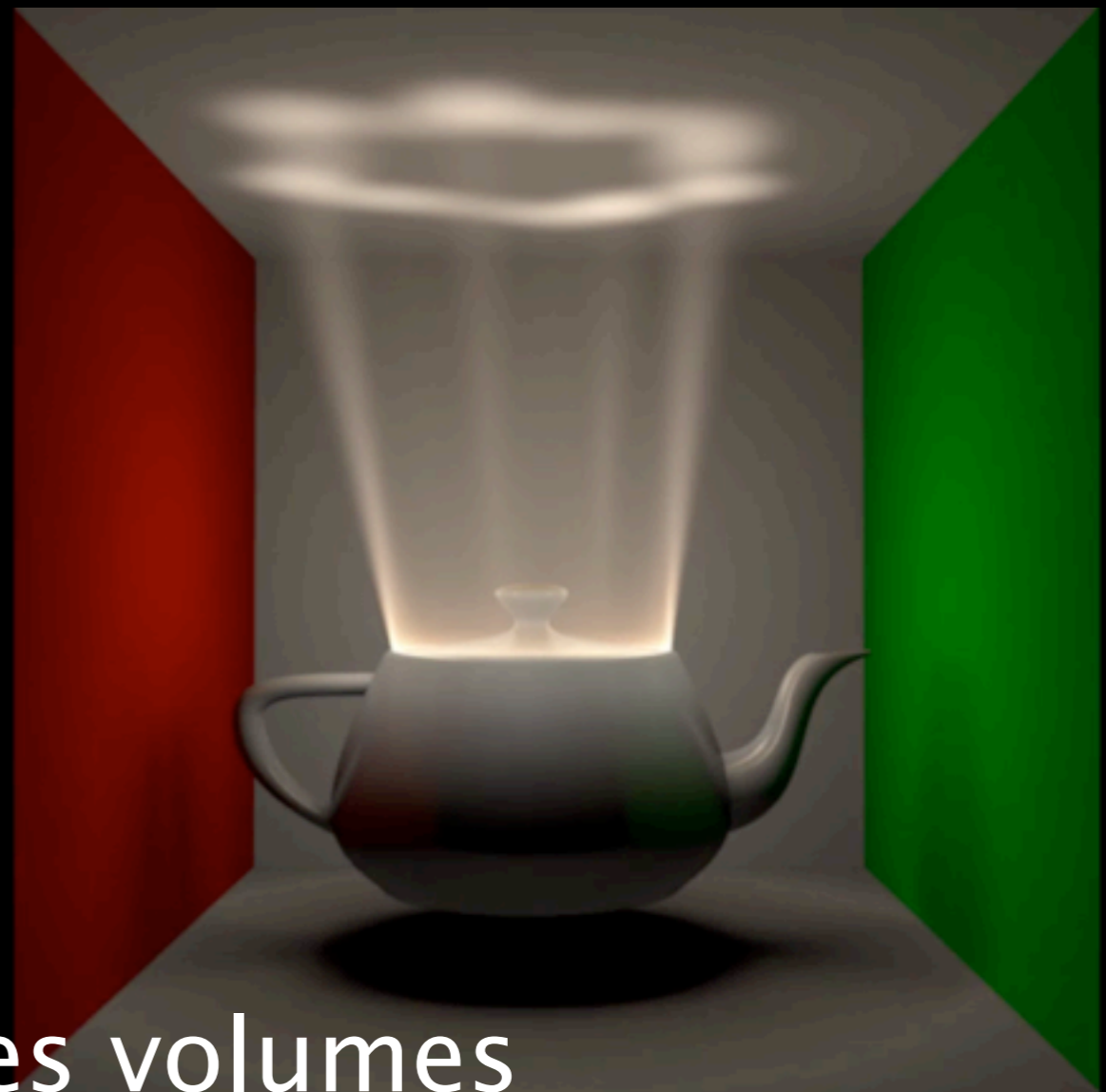
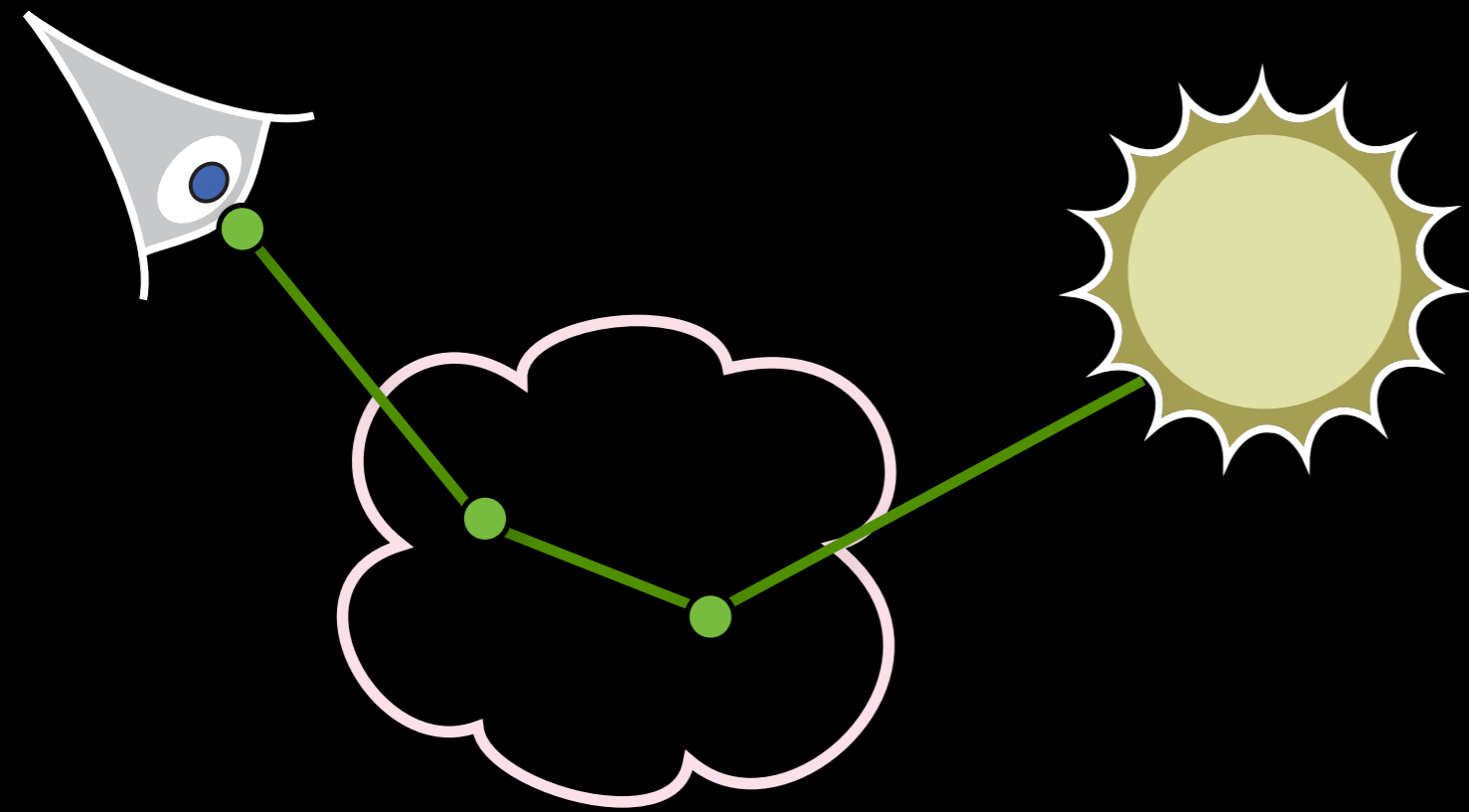


$$(\omega \cdot \nabla)L = -\sigma_t L + \sigma_s \int_{\Omega} L \cdot p_r \cdot d\omega$$

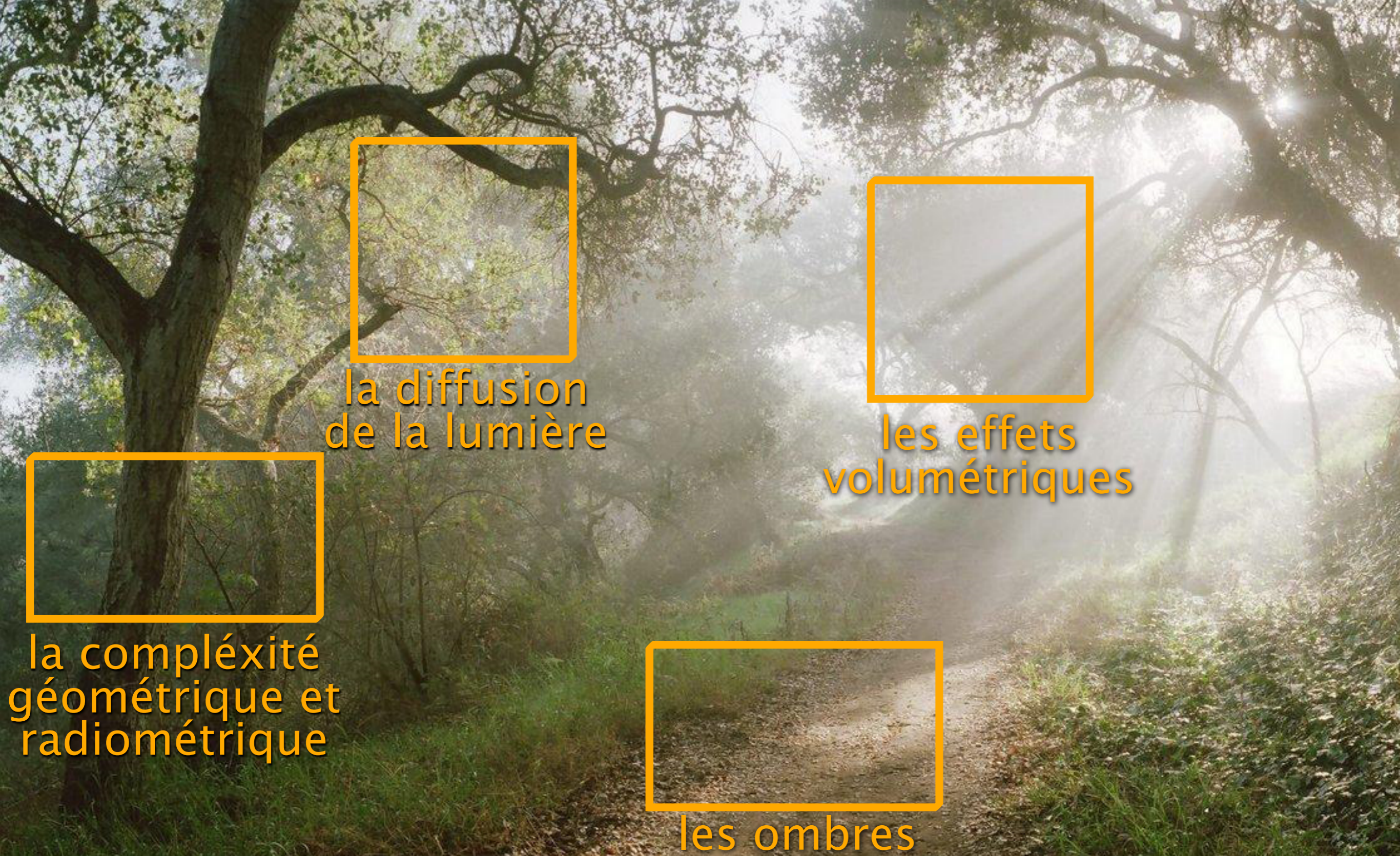
Ce soir



Simuler le transport dans les volumes



Manipuler la lumière dans les volumes



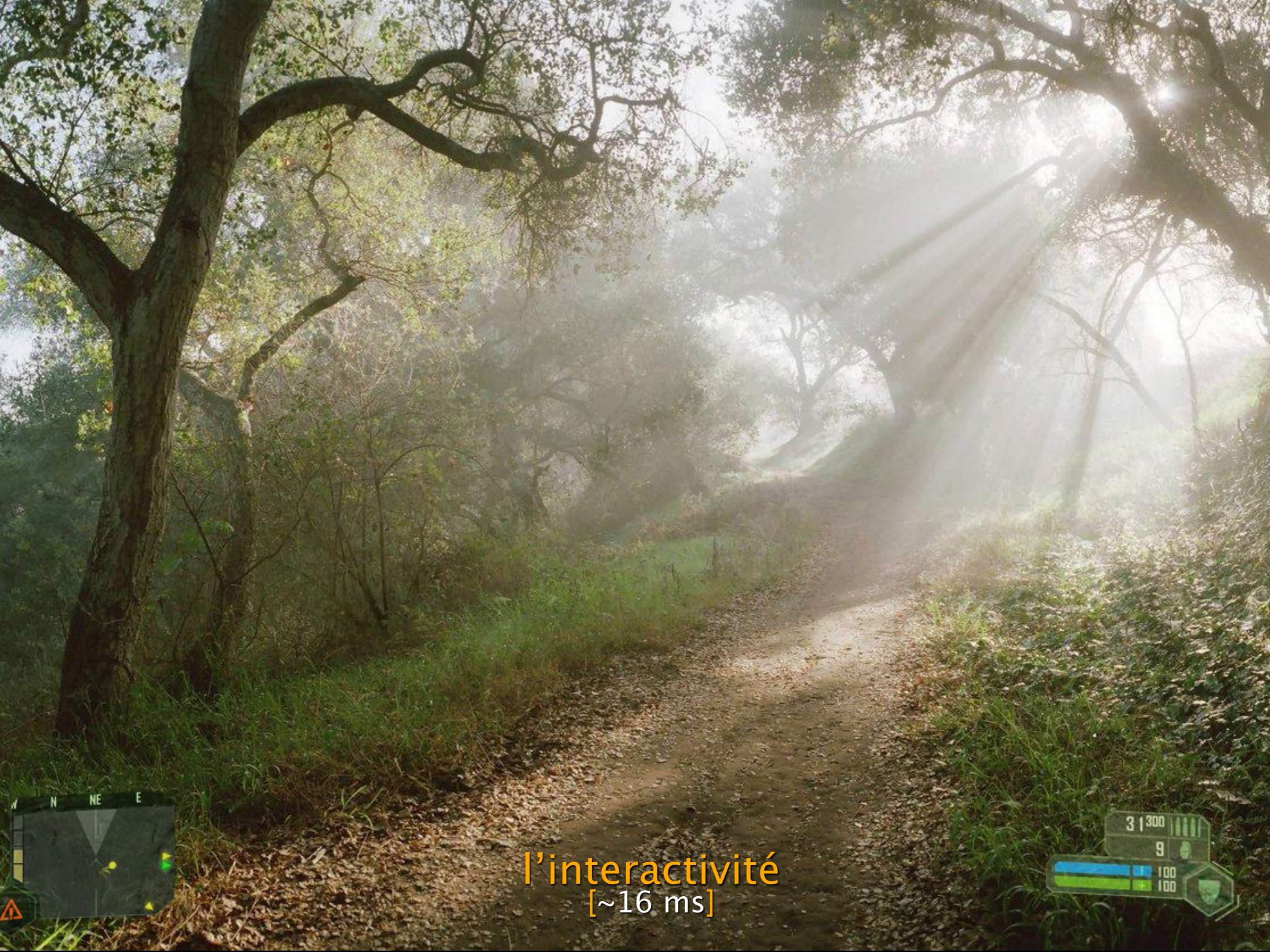
la diffusion
de la lumière

les effets
volumétriques

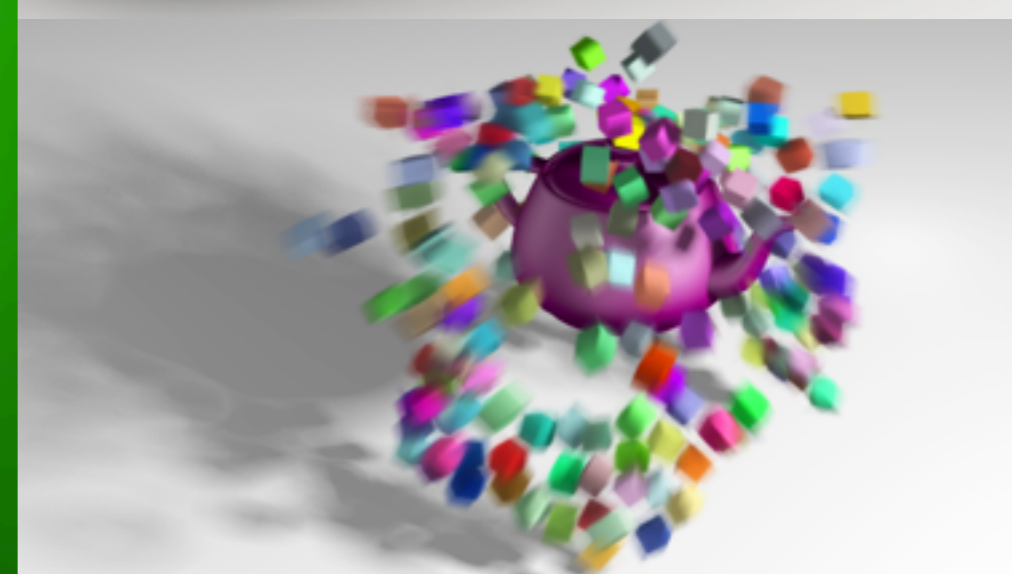
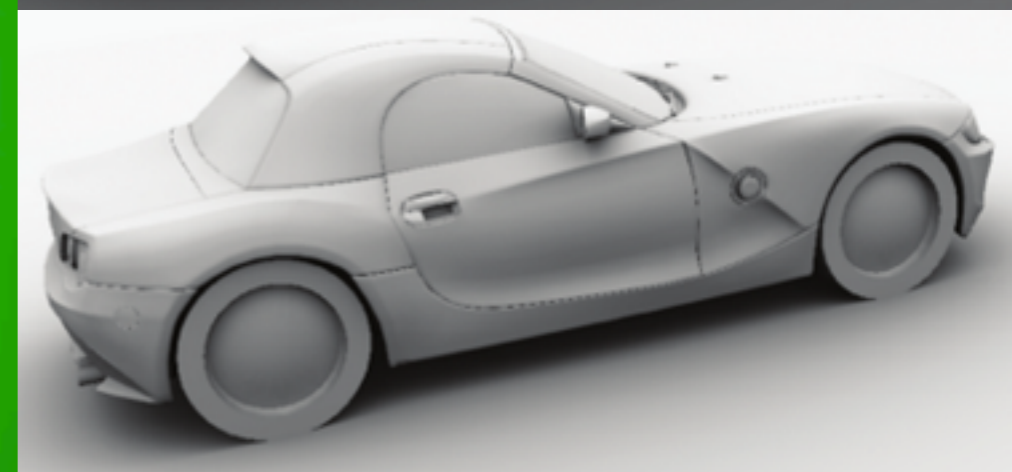
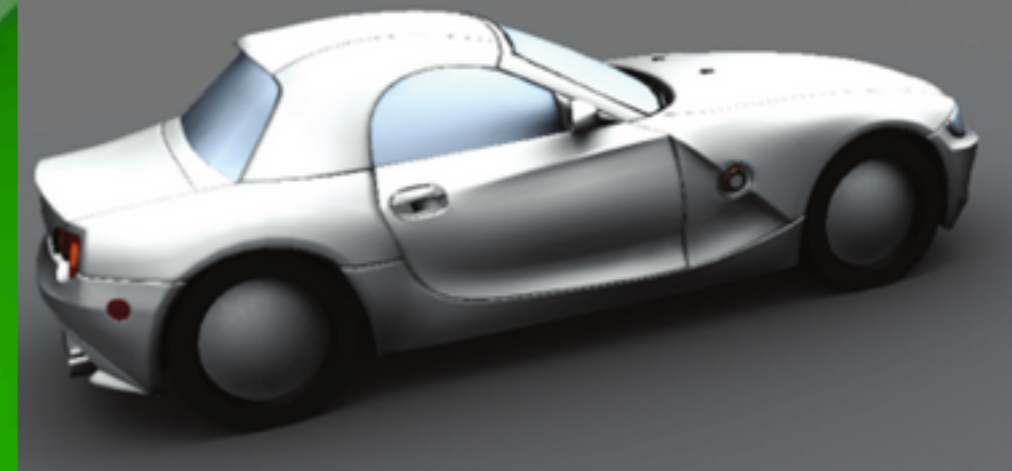
la complexité
géométrique et
radiométrique

les ombres

Le rendu est difficile

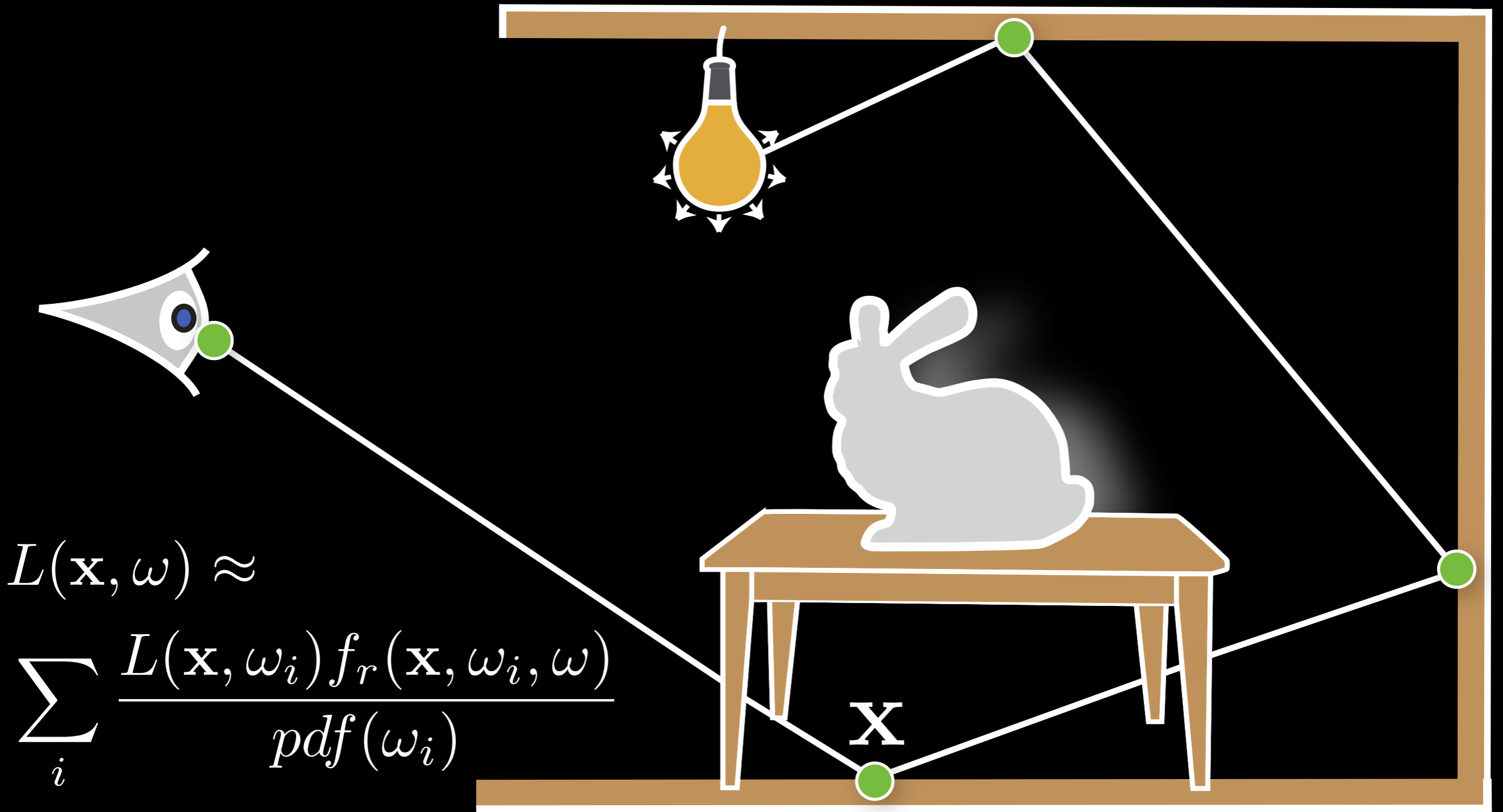
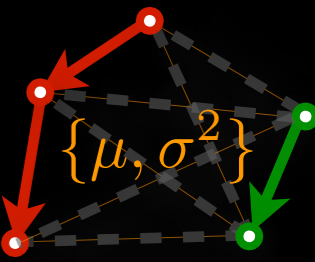


l'interactivité
[~16 ms]



Le transport sur les surfaces

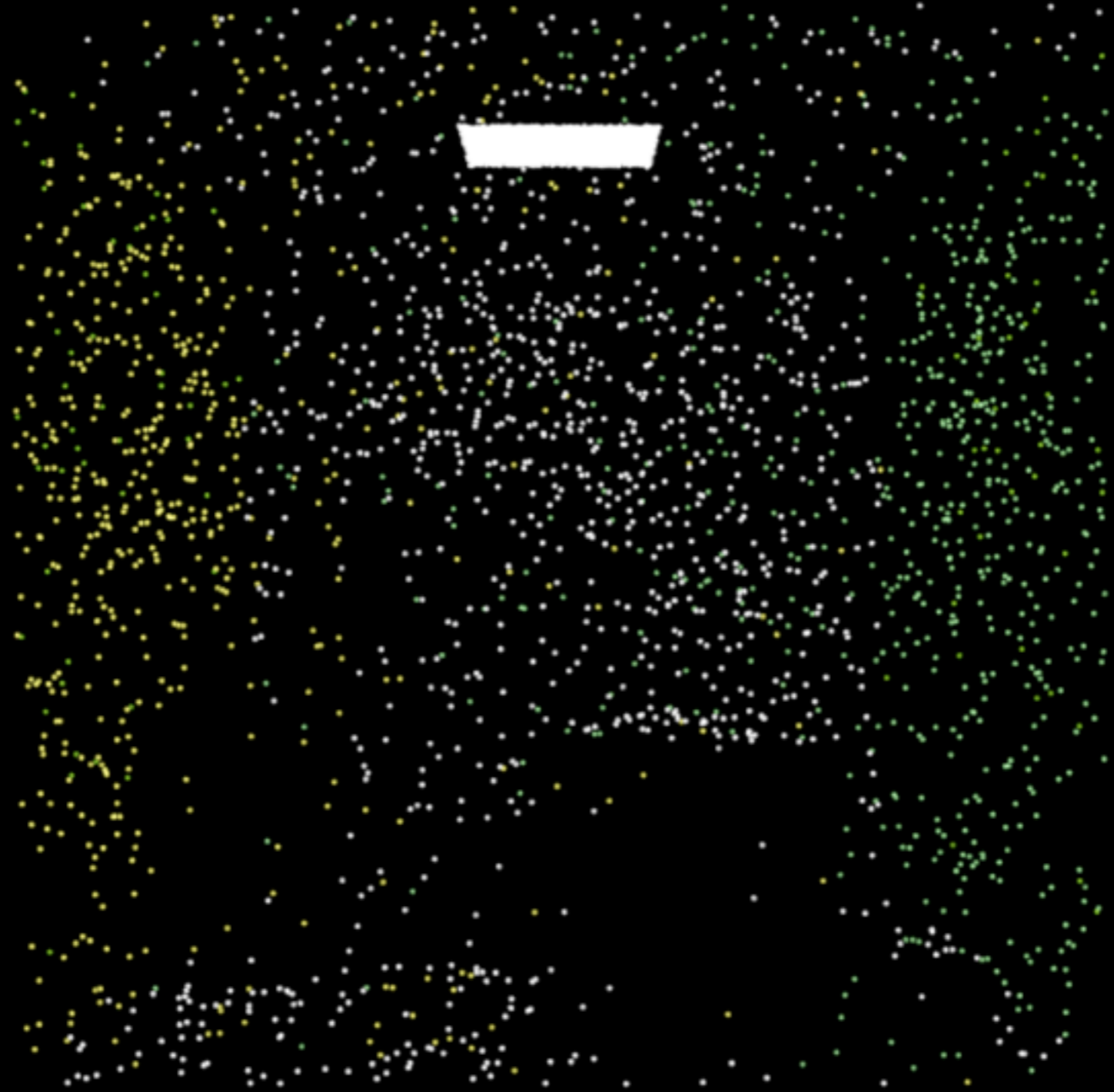
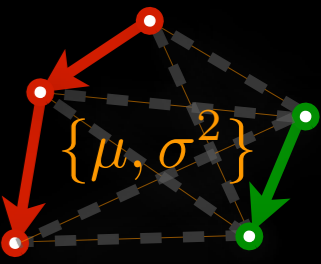
Les méthodes Monte Carlo



$$L(\mathbf{x}, \omega) \approx \sum_i \frac{L(\mathbf{x}, \omega_i) f_r(\mathbf{x}, \omega_i, \omega)}{pdf(\omega_i)}$$

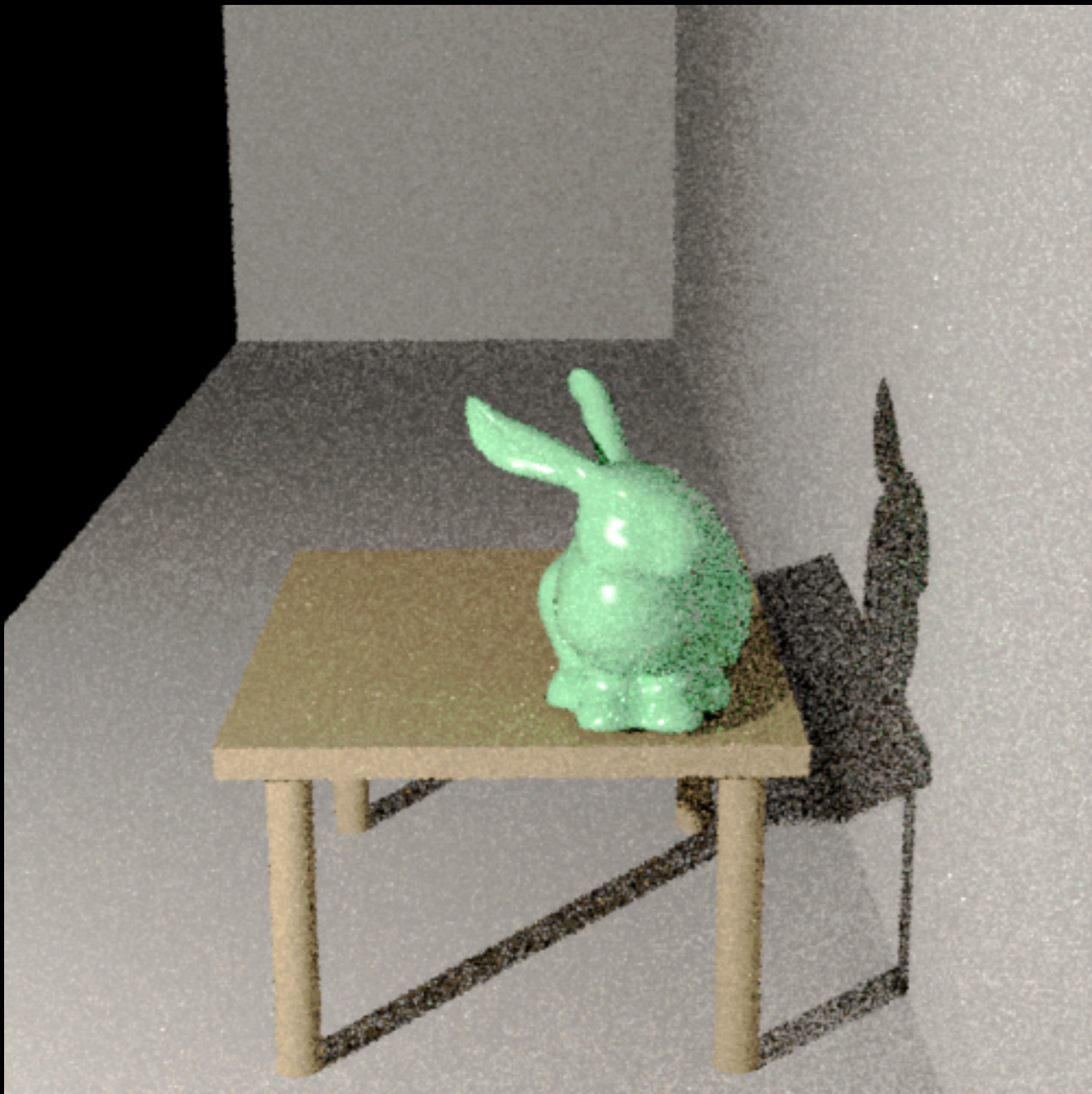
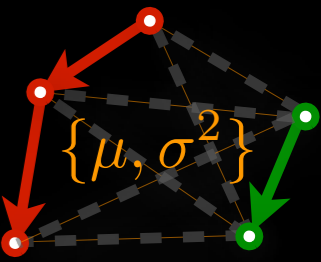
$$L(\mathbf{x}, \omega) = L_e(\mathbf{x}, \omega) + \int_{\Omega} L(\mathbf{x}, \omega') f_r(\mathbf{x}, \omega', \omega) d\omega'$$

Les méthodes Monte Carlo

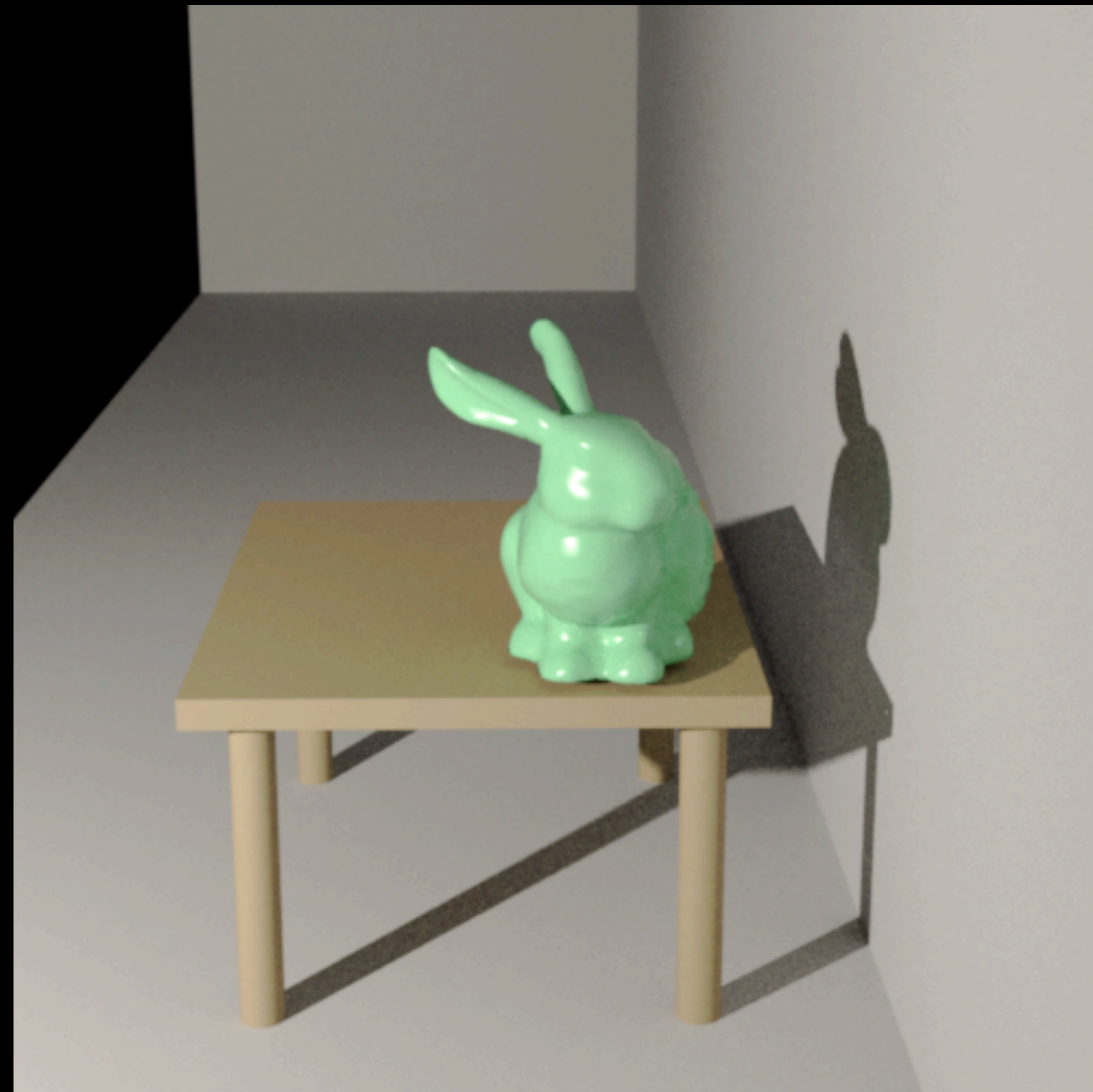


L'artefact principal : un **bruit à haute fréquence**

Les méthodes Monte Carlo



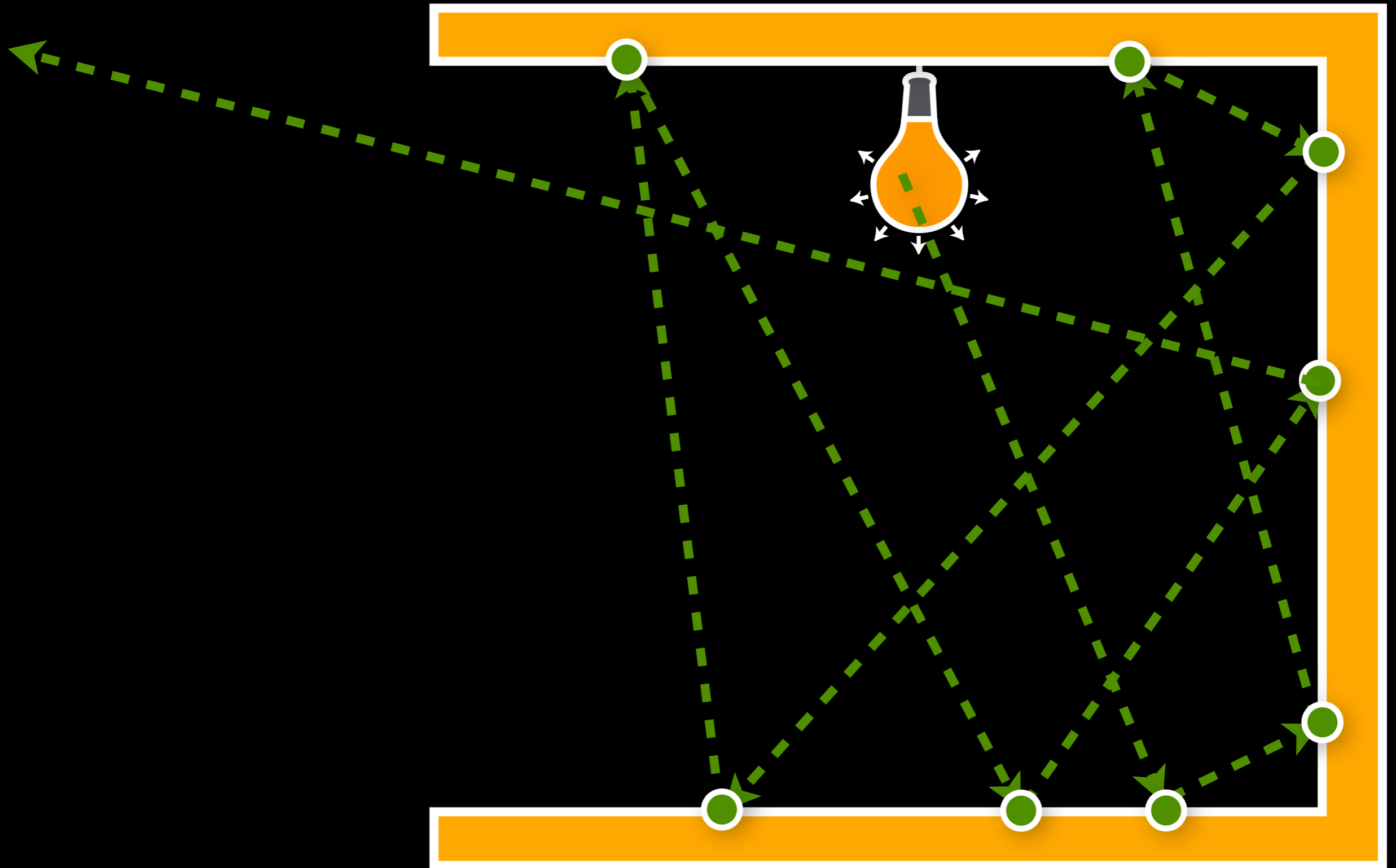
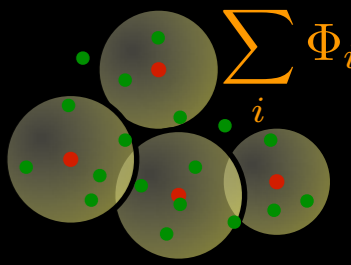
N = 100



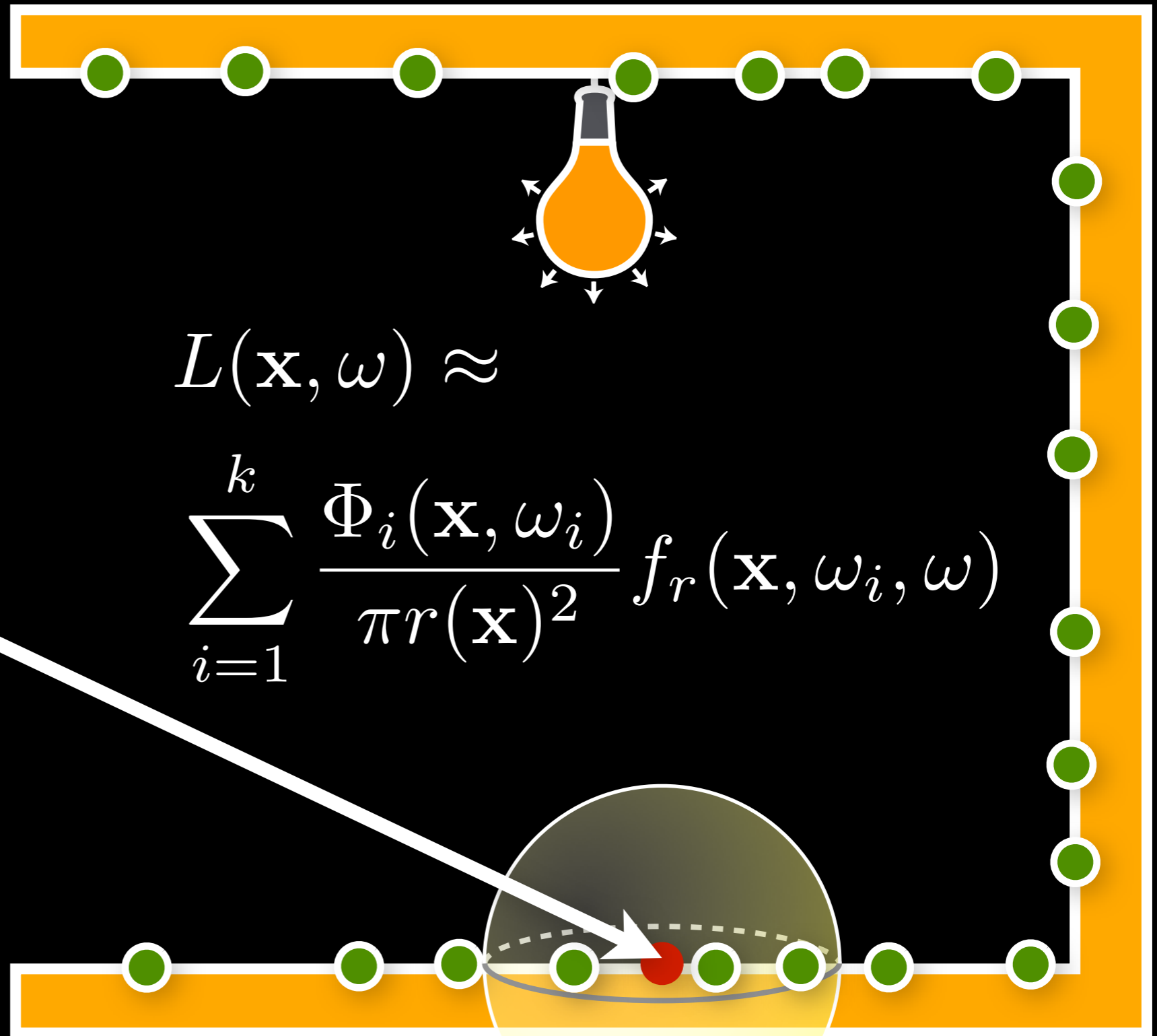
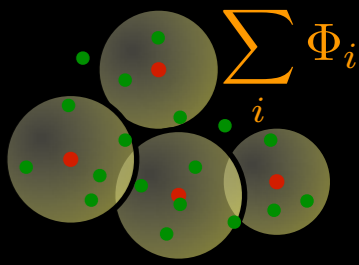
N = 10,000

$$O(N^{-1/2})$$

Les méthodes d'estimation de la densité

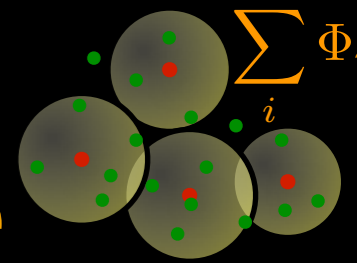


Les méthodes d'estimation de la densité

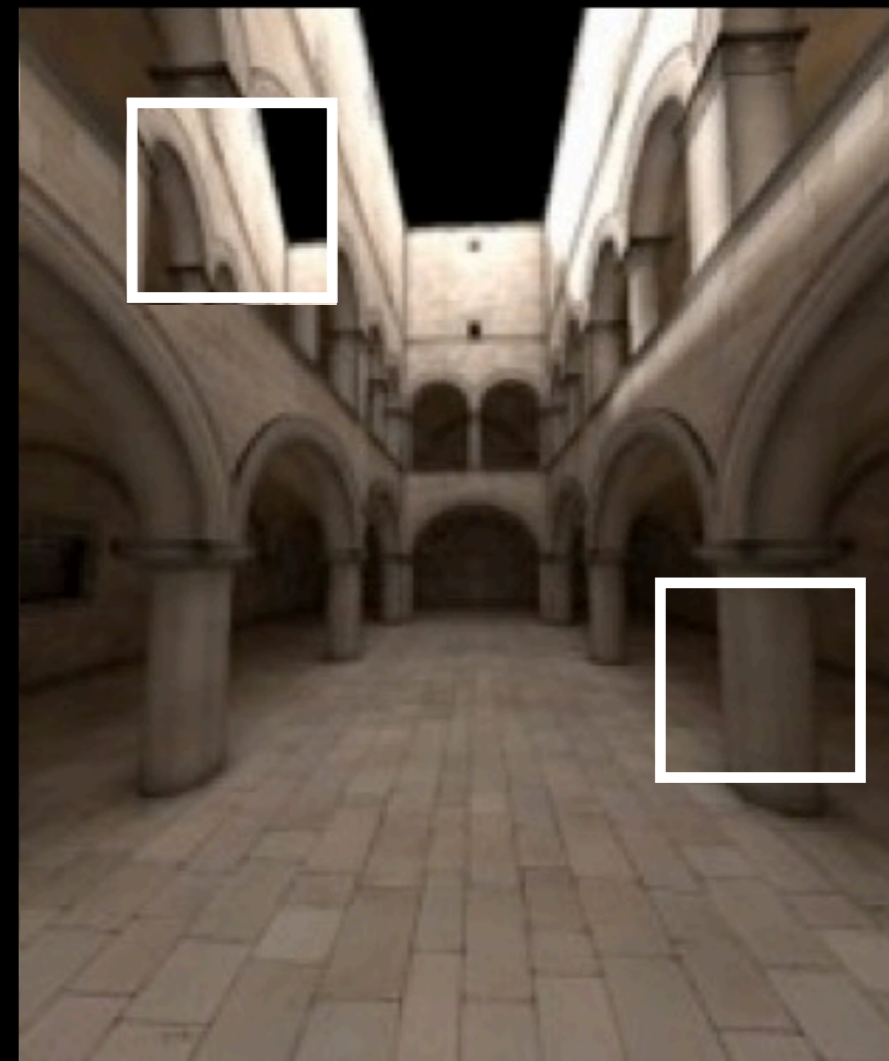
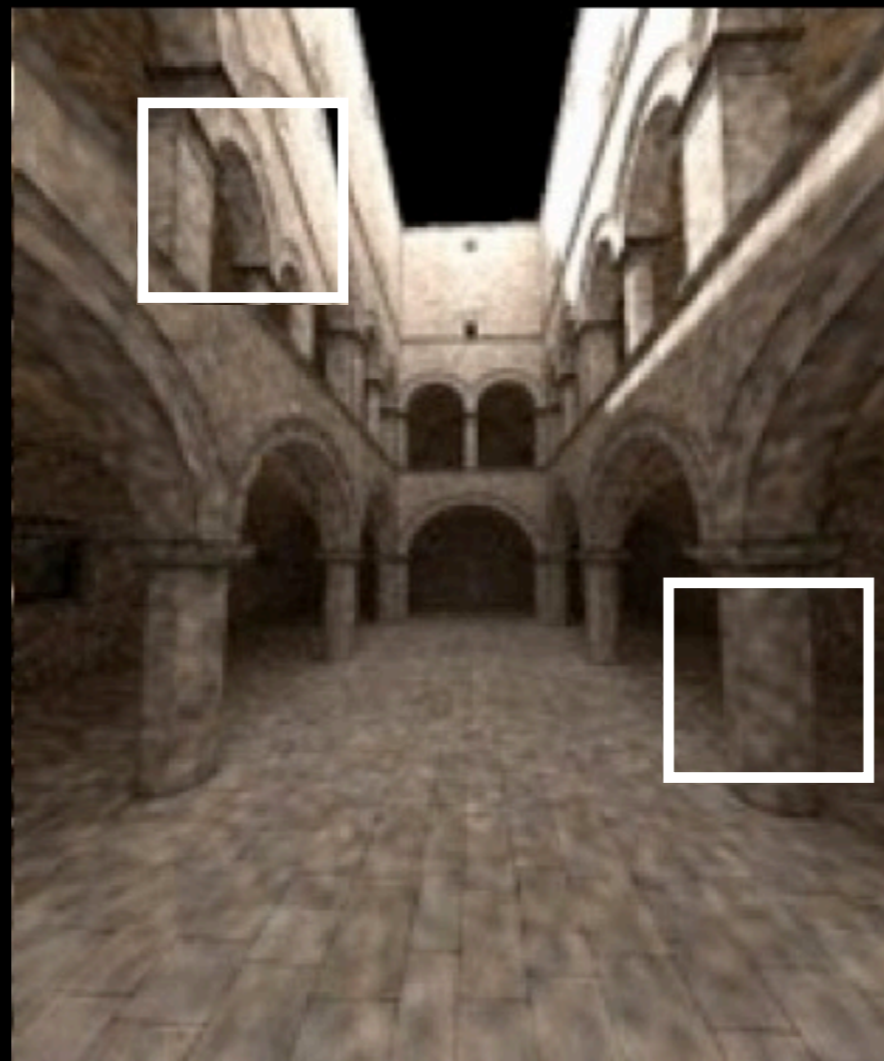
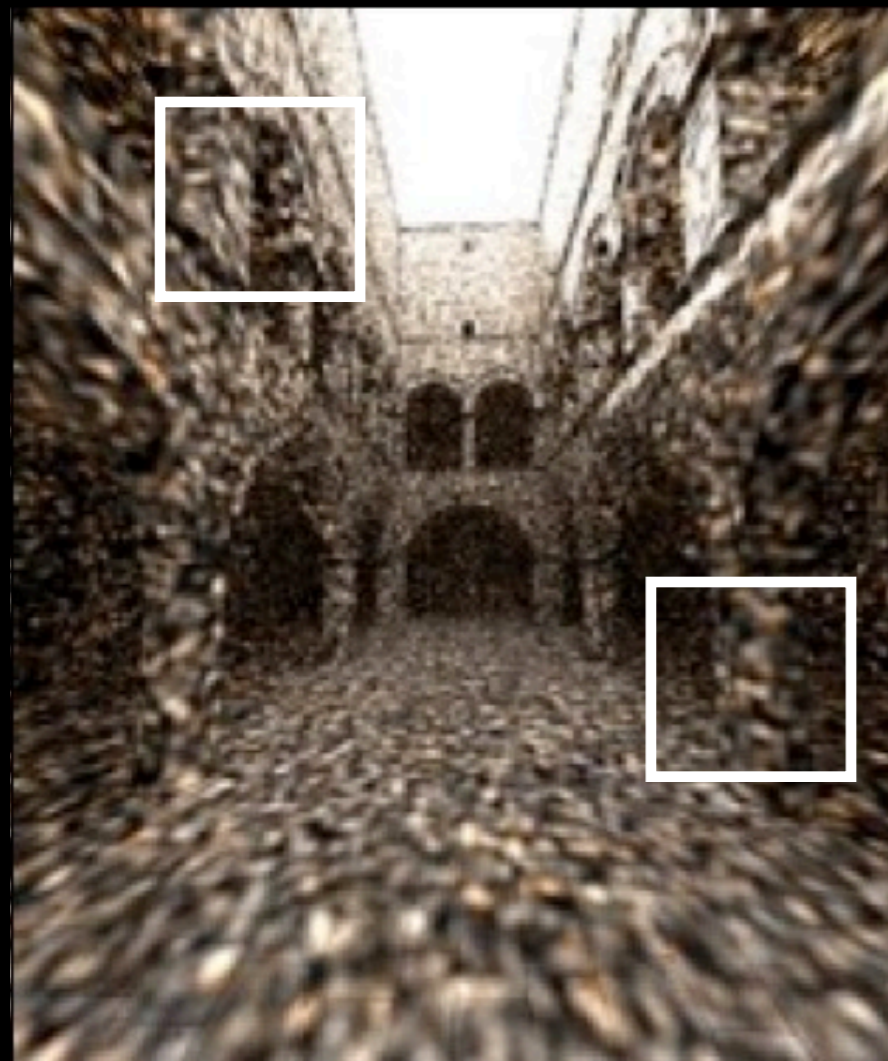


$$L(\mathbf{x}, \omega) \approx$$

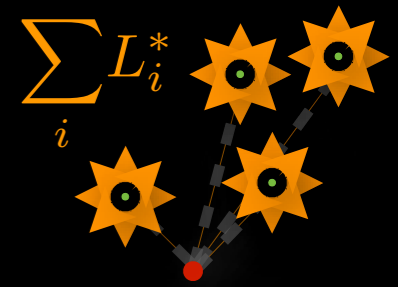
$$\sum_{i=1}^k \frac{\Phi_i(\mathbf{x}, \omega_i)}{\pi r(\mathbf{x})^2} f_r(\mathbf{x}, \omega_i, \omega)$$



Les méthodes d'estimation de la densité

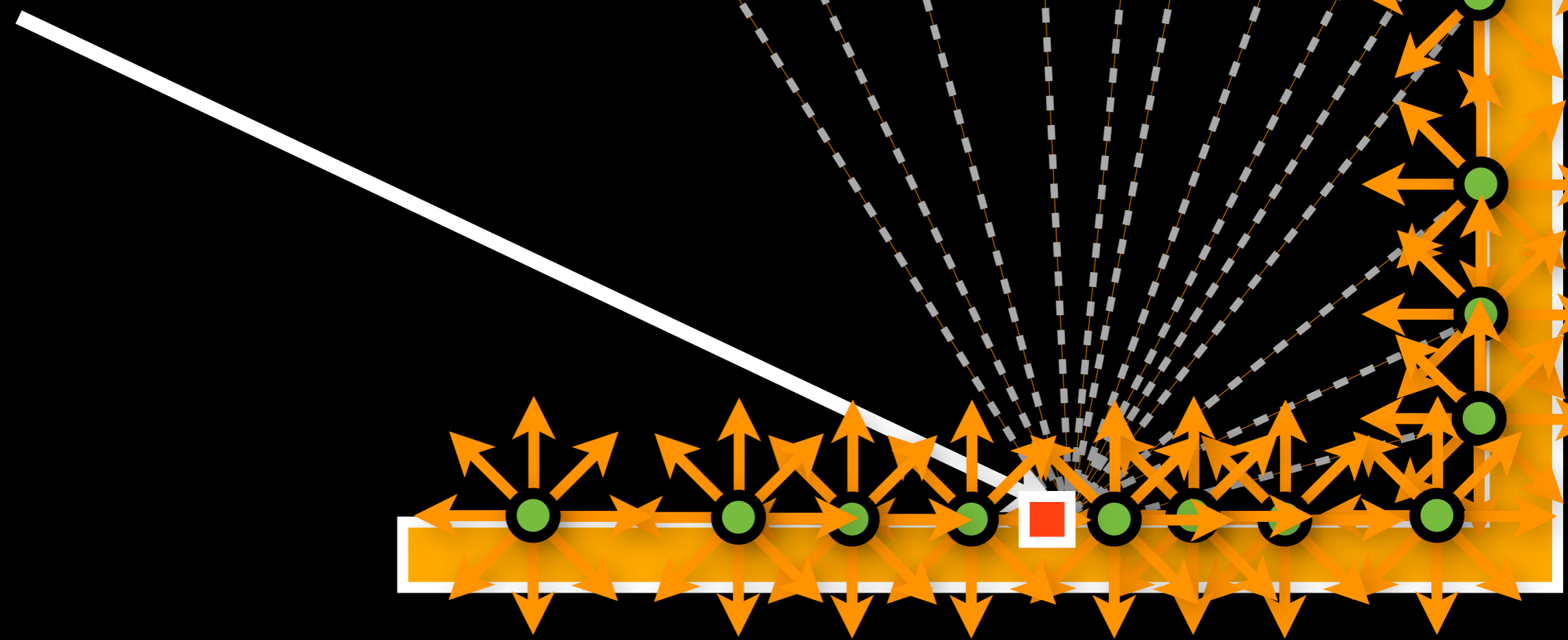
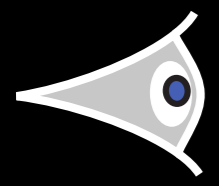


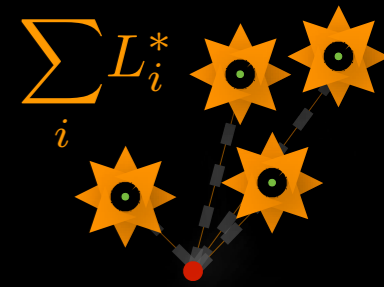
L'artefact principal : des détails flous



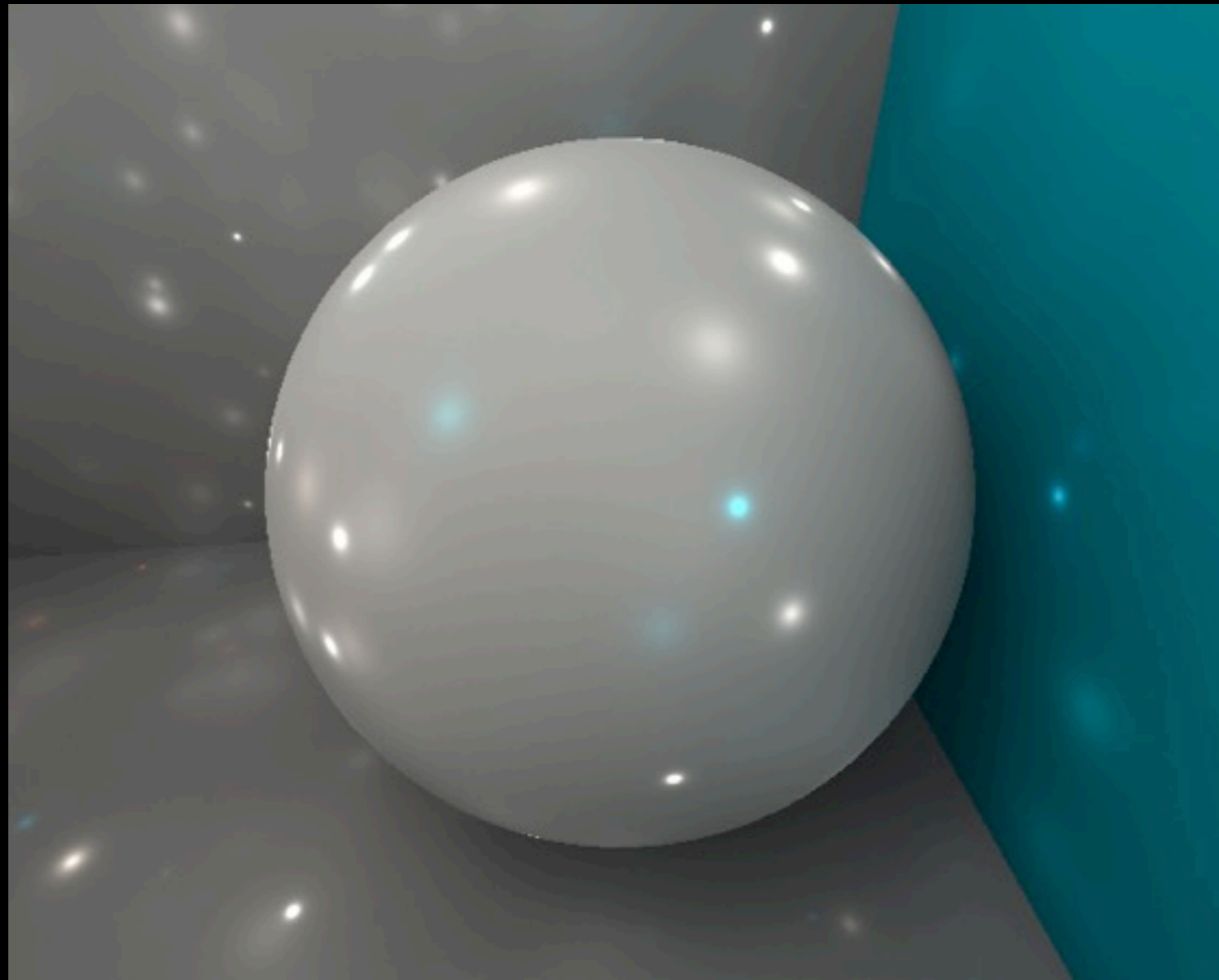
Les méthodes de lumières virtuelles

$$L_+(\mathbf{x}, \omega) \approx \sum_i \frac{\Phi_i}{r(\mathbf{x}_i)^2} V(\mathbf{x}, \omega_i) f_r(\mathbf{x}, \omega_i, \omega)$$



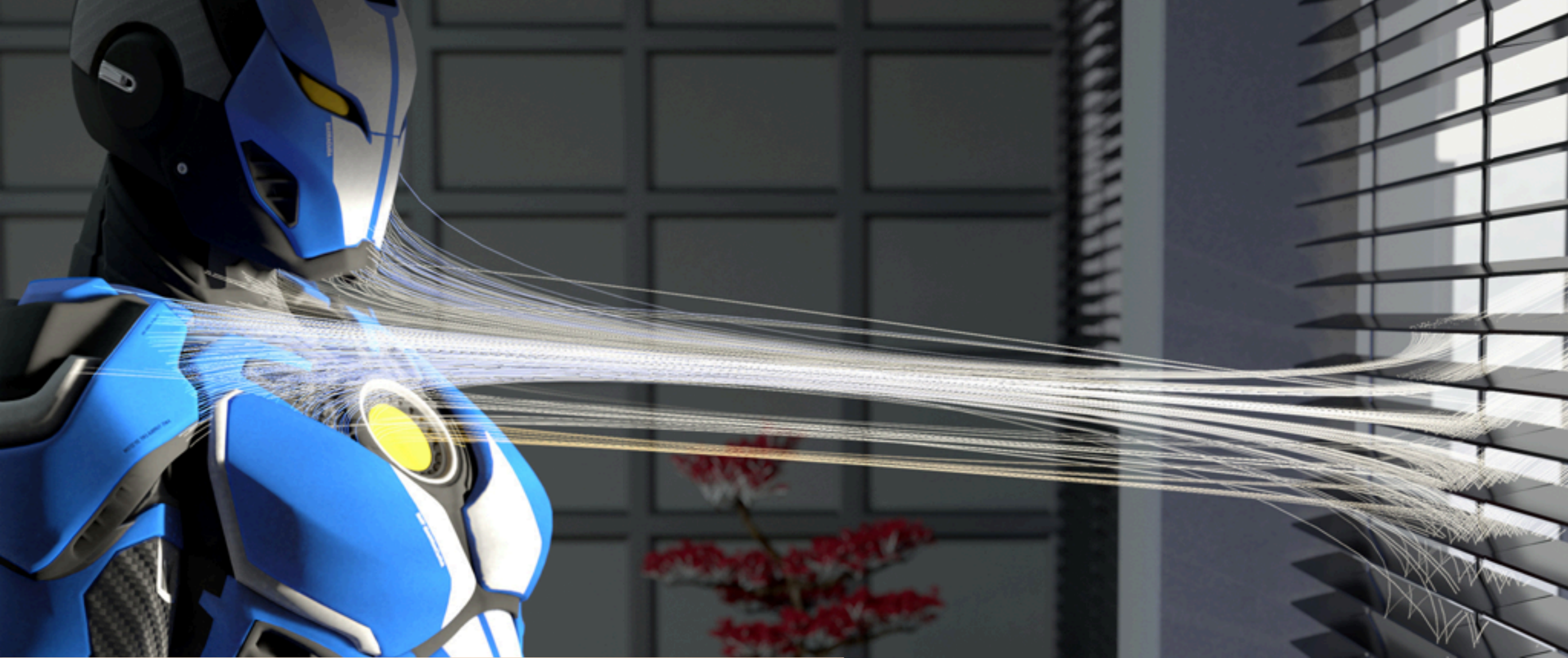


Les méthodes de lumières virtuelles



$$L(\mathbf{x}, \omega) \approx \sum_i \frac{\Phi_i}{r(\mathbf{x}_i)^2} V(\mathbf{x}, \omega_i) f_r(\mathbf{x}, \omega_i, \omega)$$

L'artefact principal : les singularités de proximité

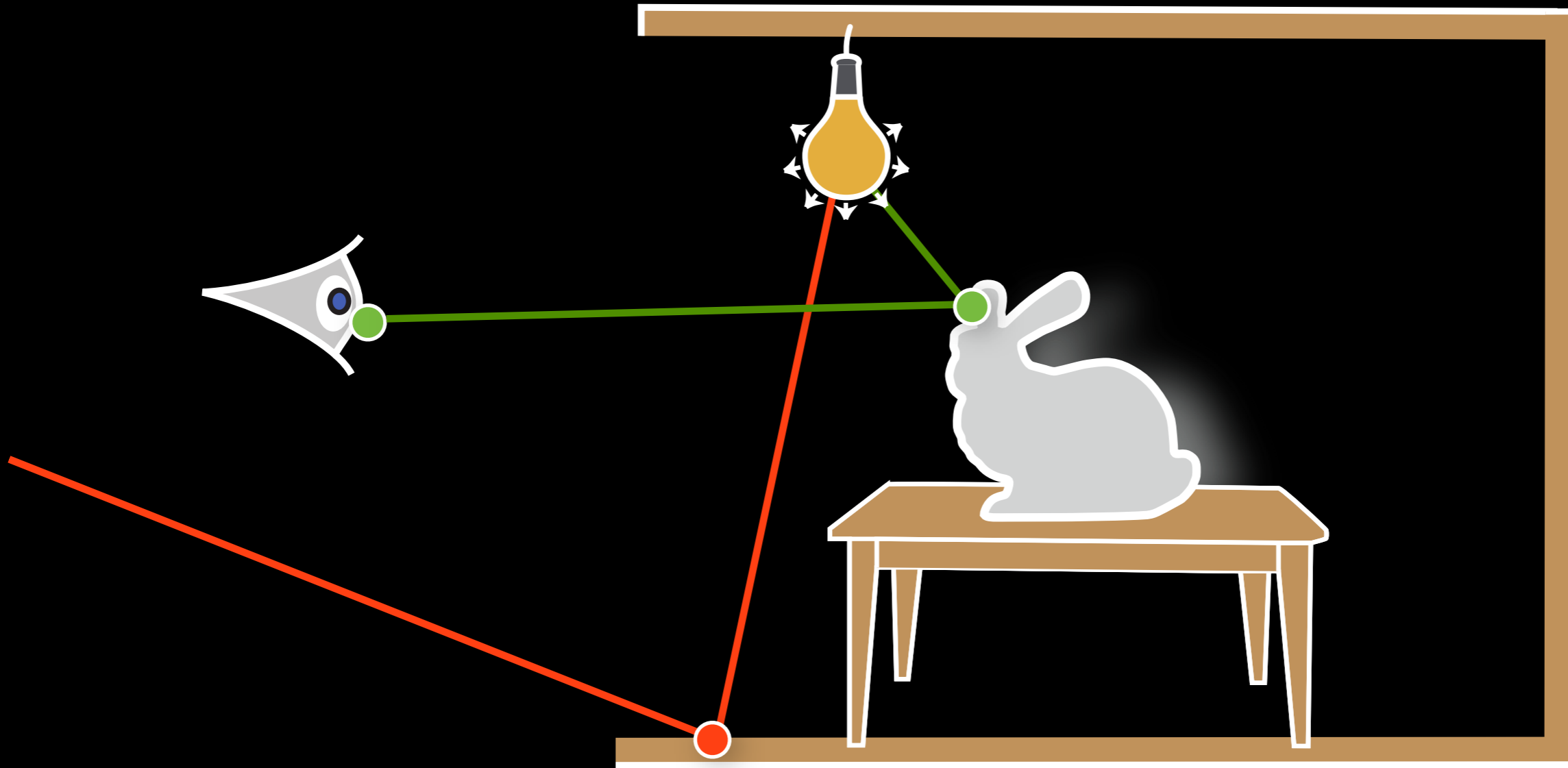


Manipulation de la lumière sur les surfaces

Contourner les lois de la physique

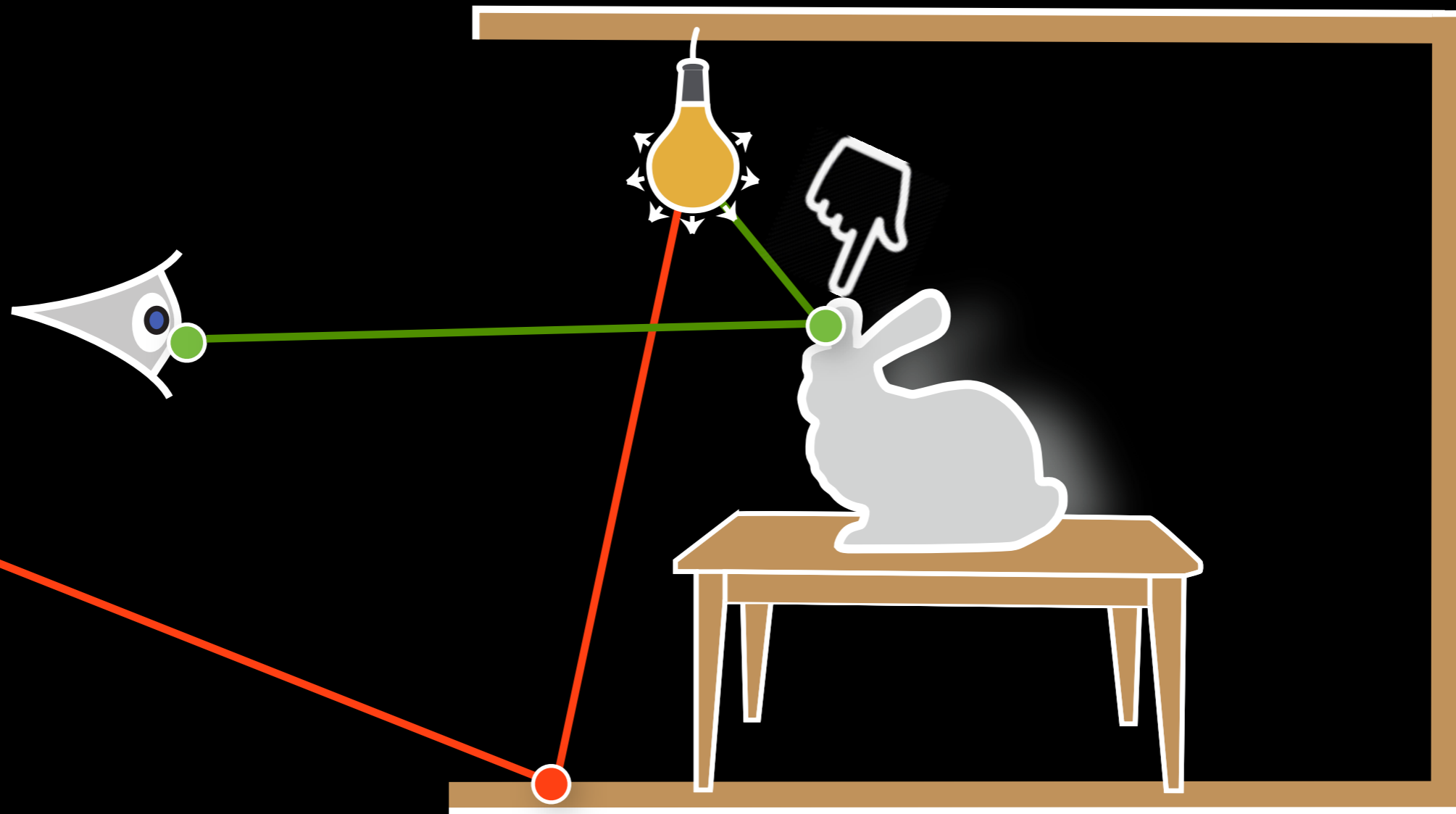


Rechercher & remplacer pour le rendu



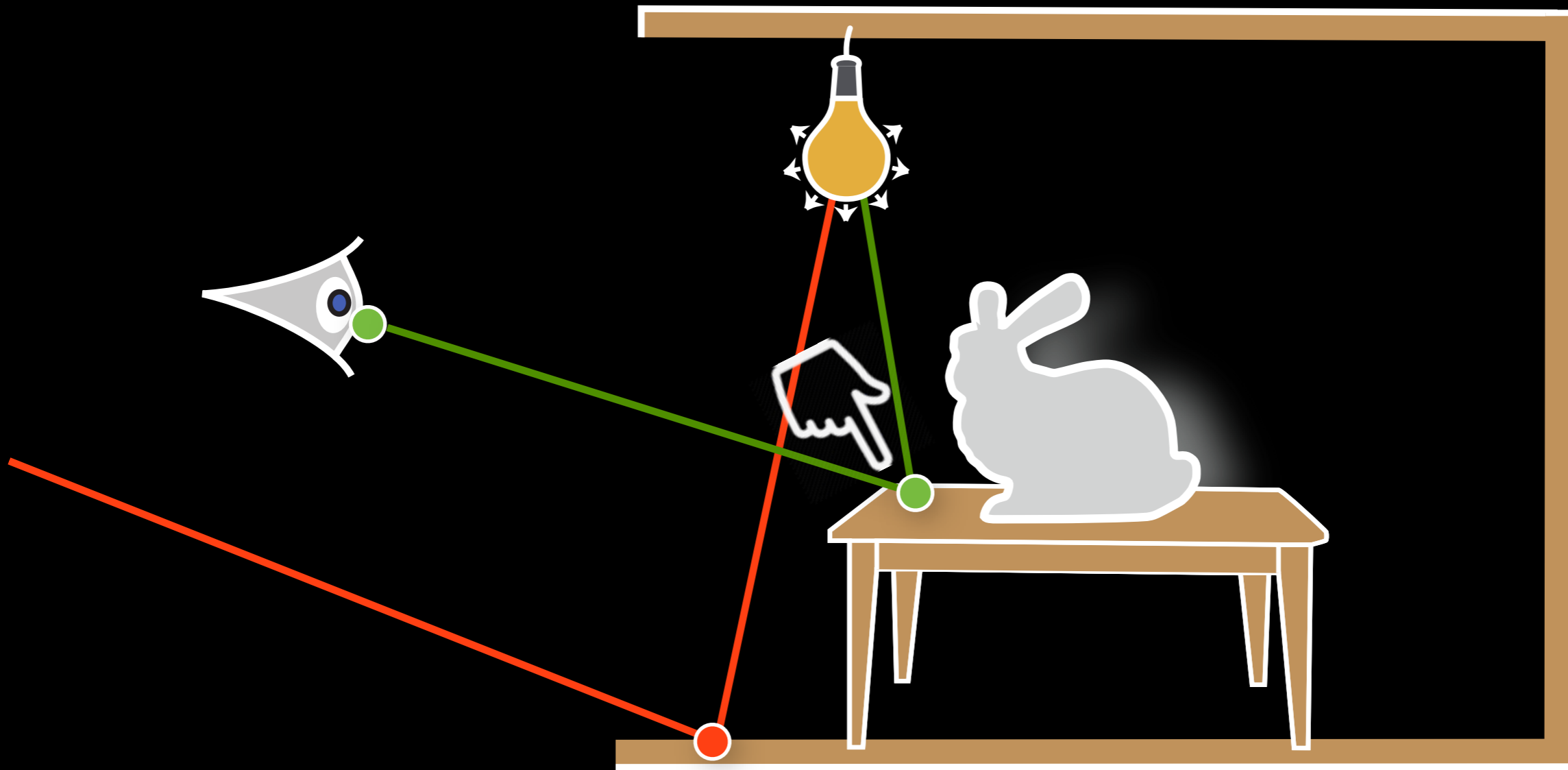
2013b

Rechercher & remplacer pour le rendu

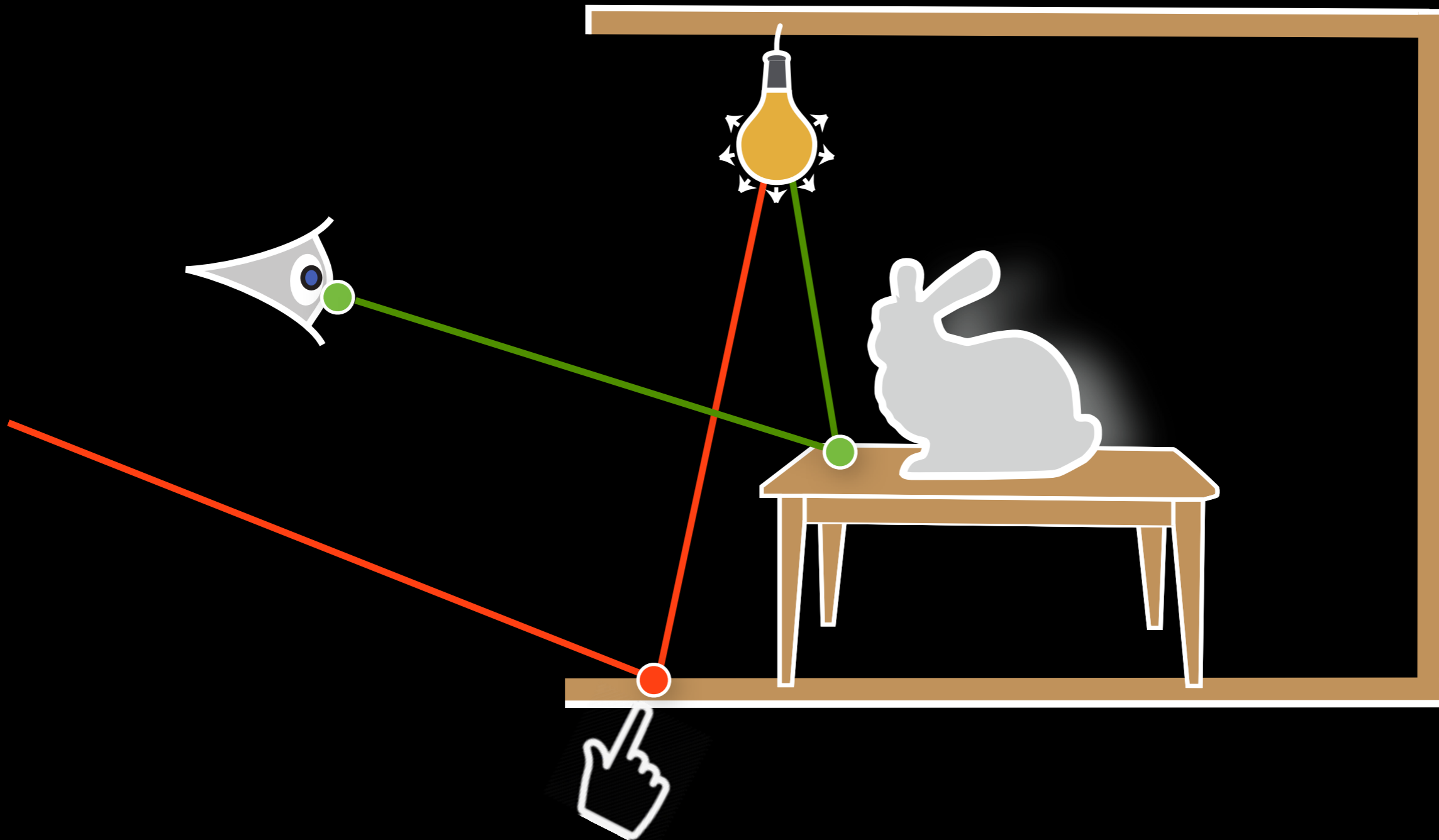


2013b

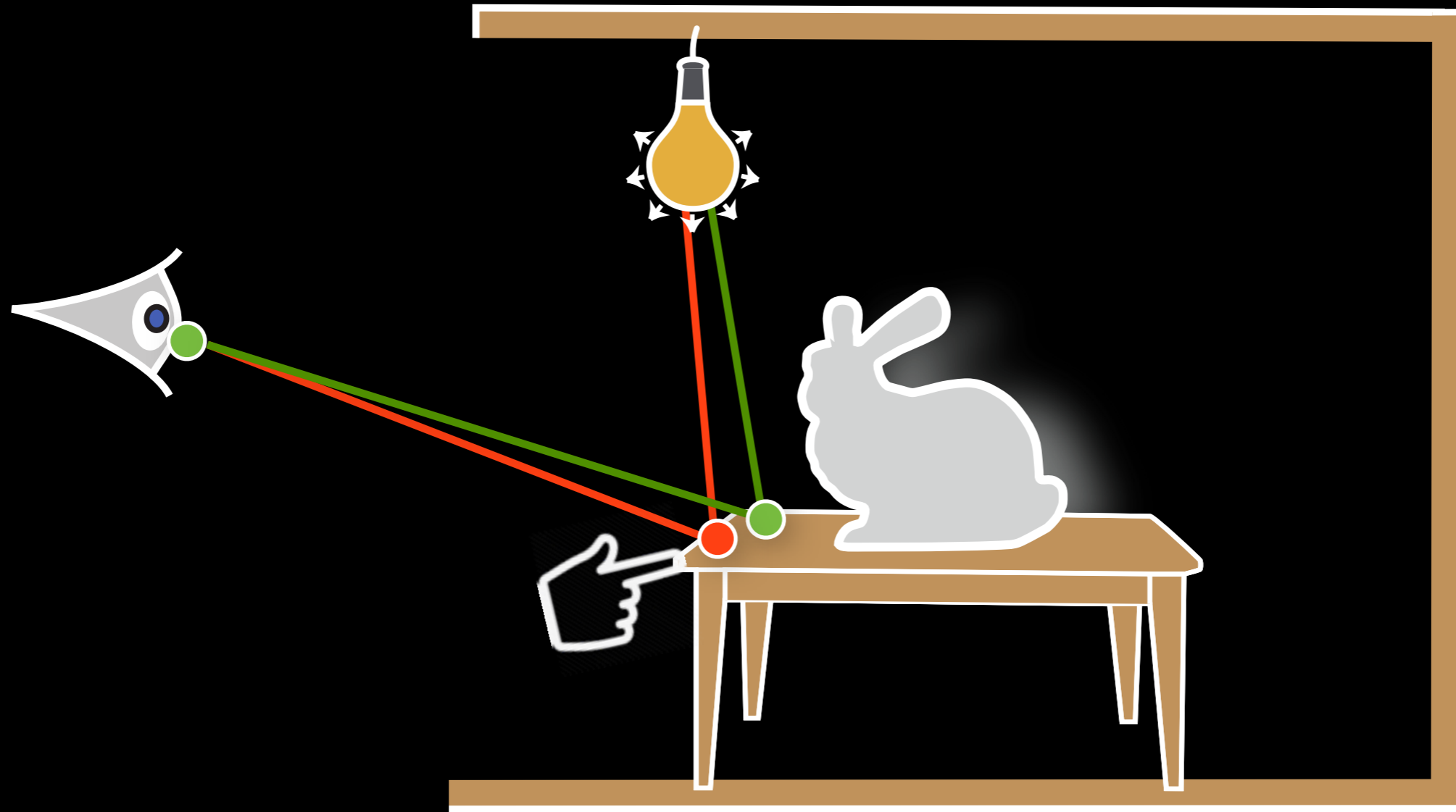
Rechercher & remplacer pour le rendu



Rechercher & remplacer pour le rendu



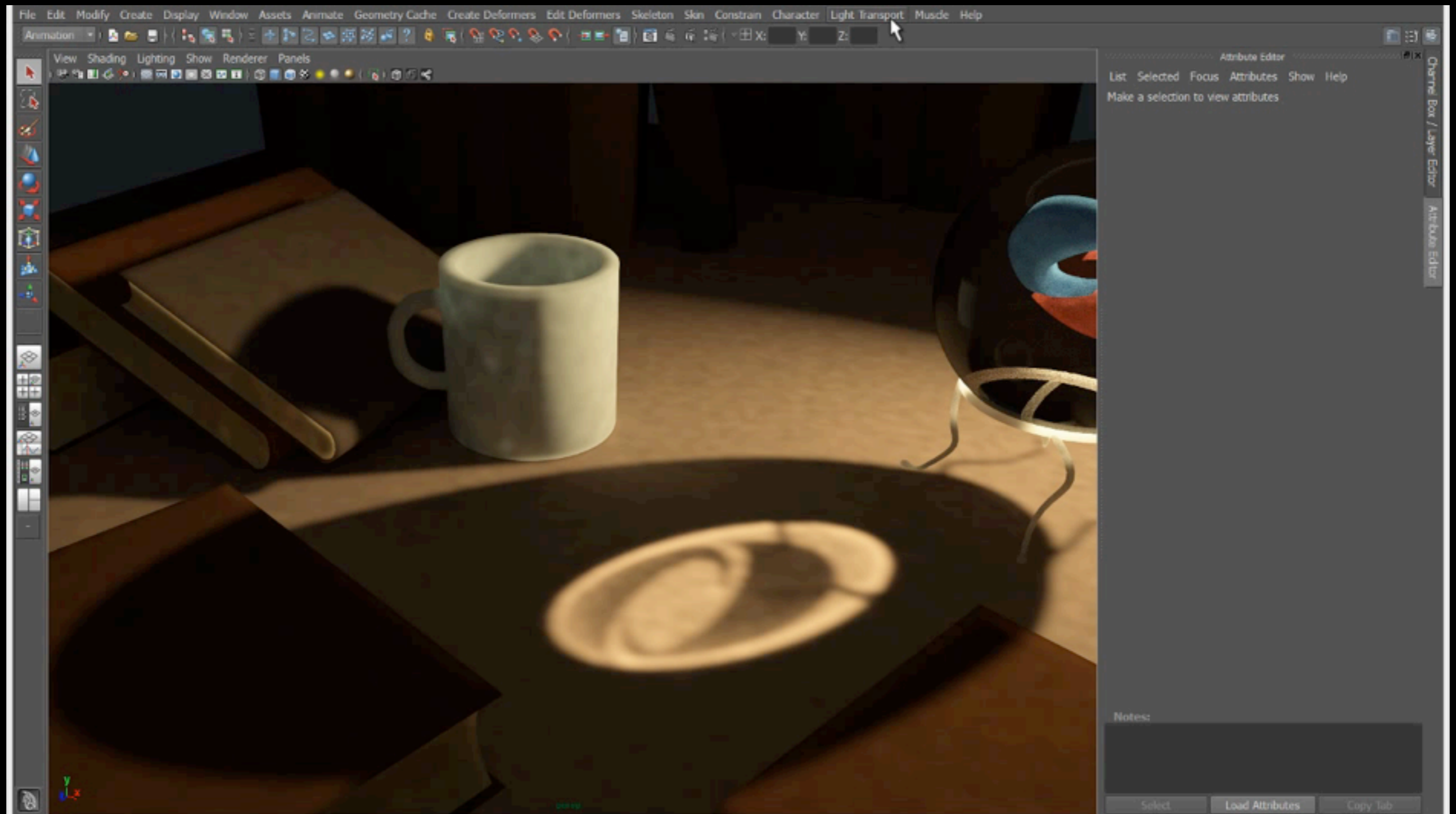
Rechercher & remplacer pour le rendu



Manipulation directe des vidéos



Manipulation de chemin



2013b

Deux défis

1. Rechercher

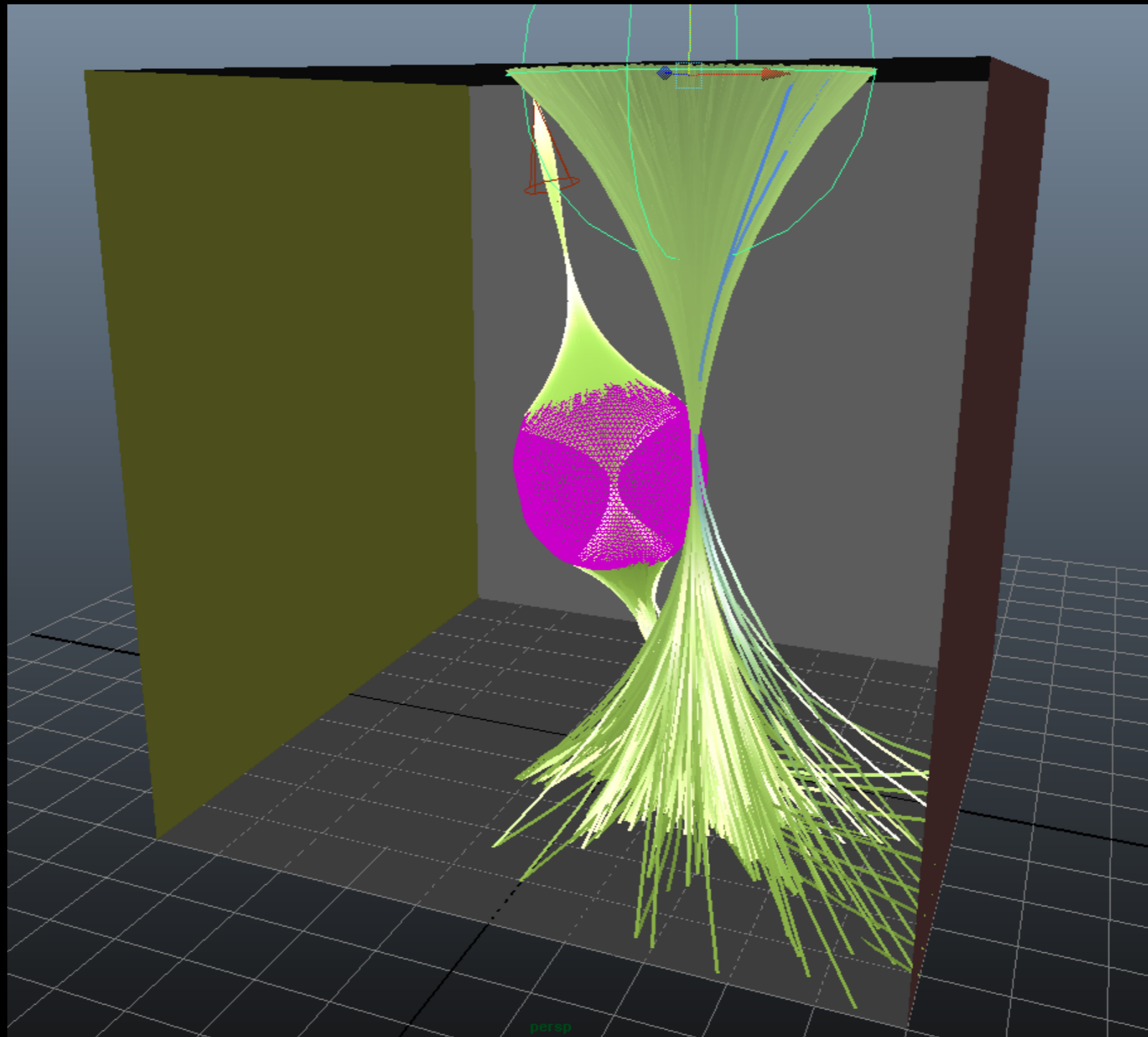
Comment peut-on **naviguer** dans l'espace des chemins lumineux?

2. Remplacer

Comment **éditer** ces données?



Trouver et choisir des chemins



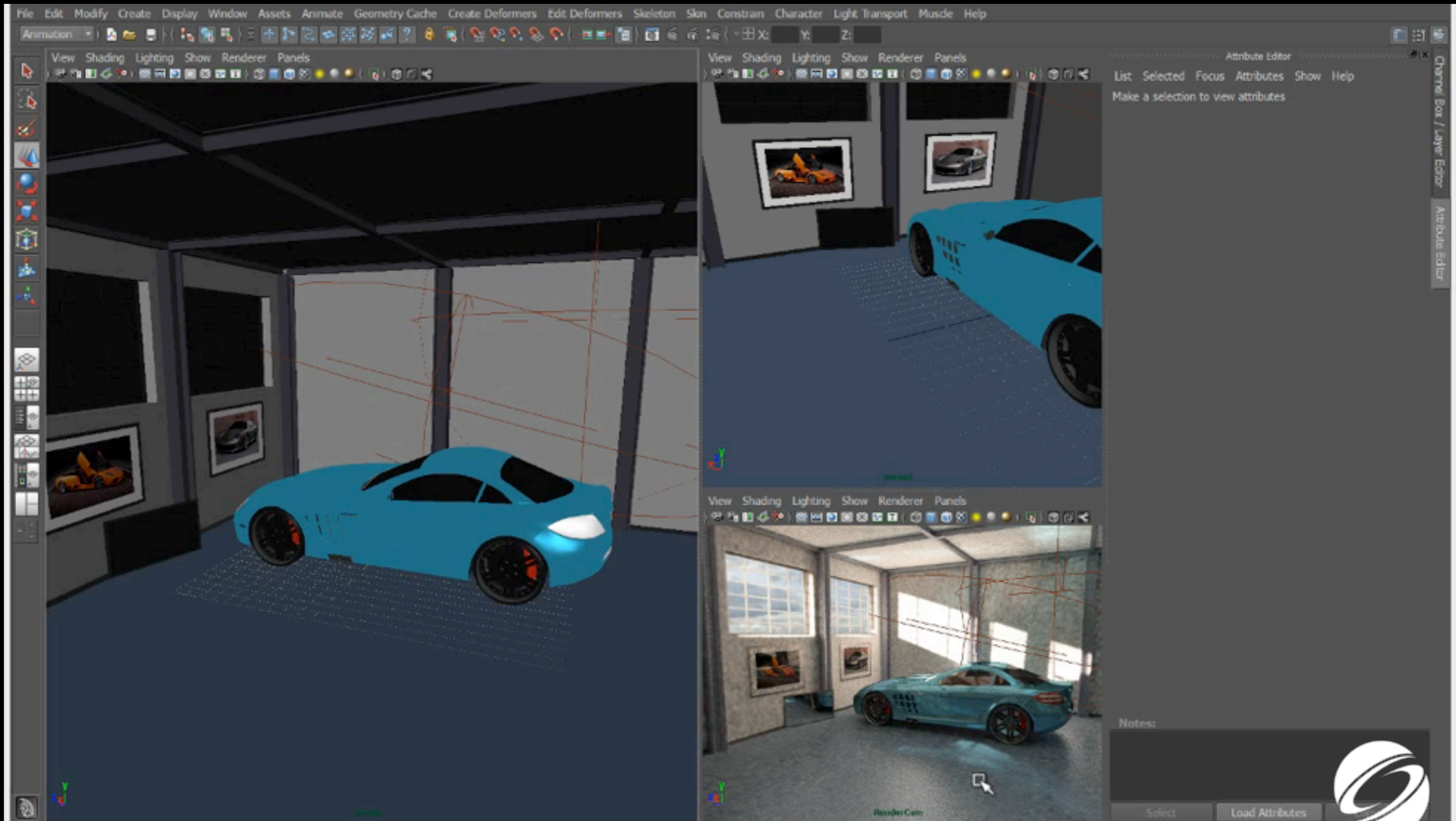
Nous adaptions **edge bundling** [Holten & van Wijk 2009]
pour regrouper et visualiser nos chemins lumineux

Manipulation de chemins

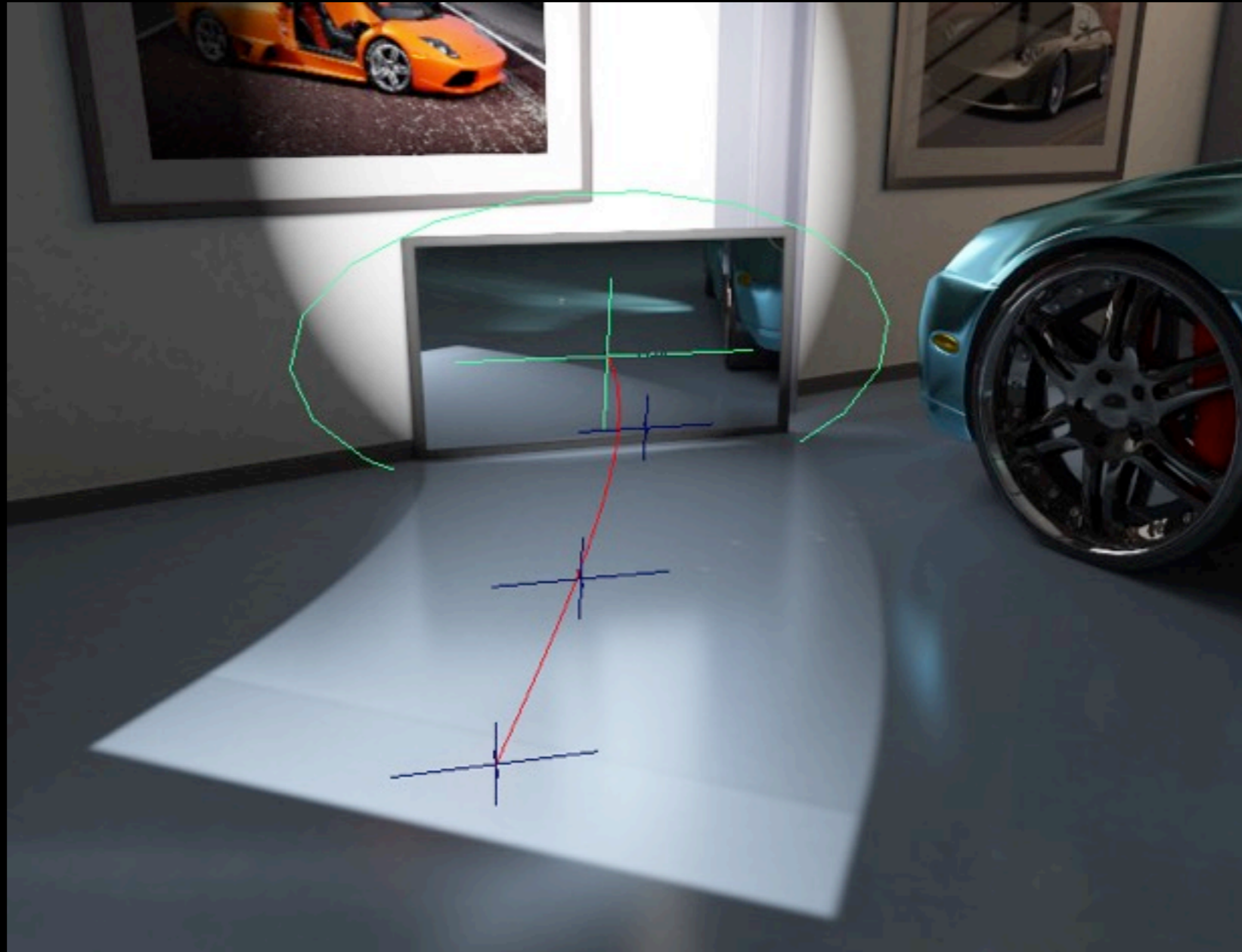


2013b

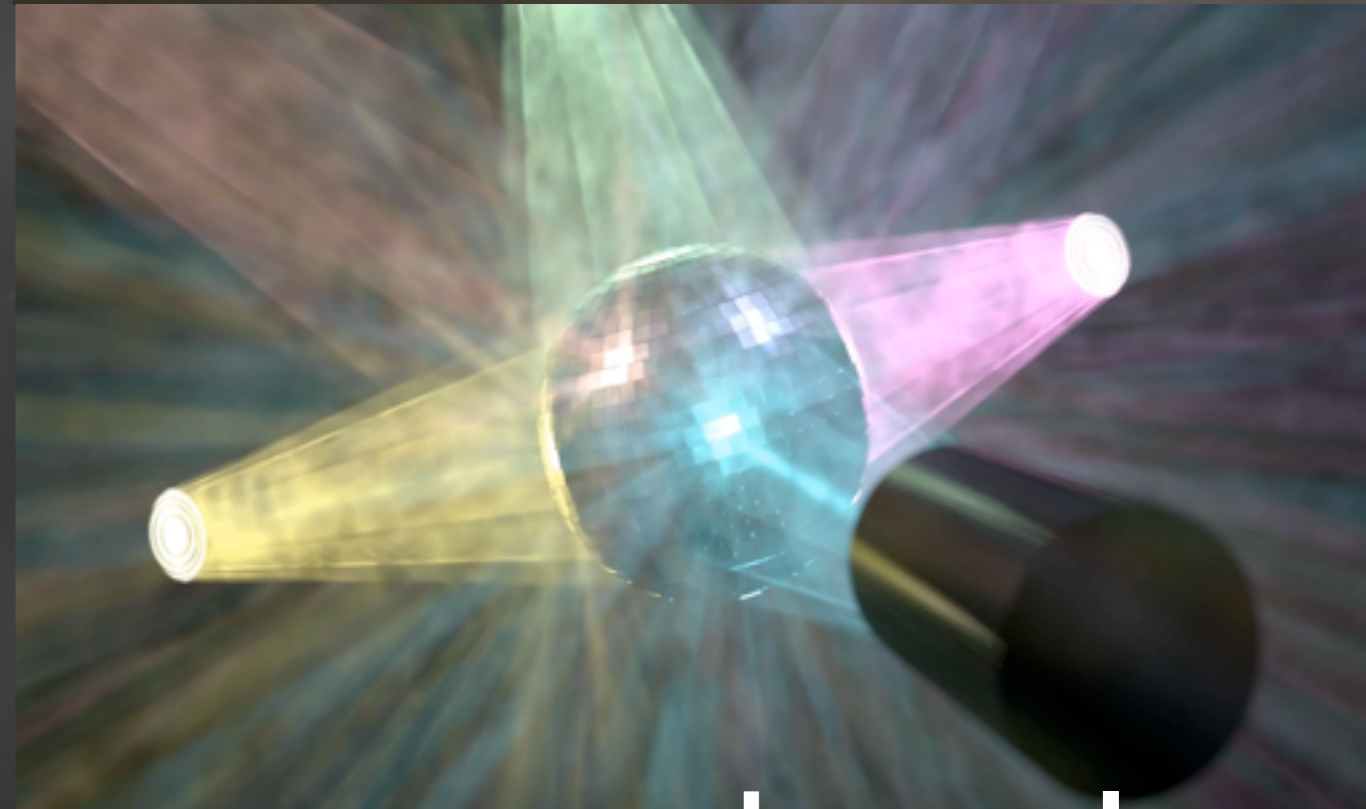
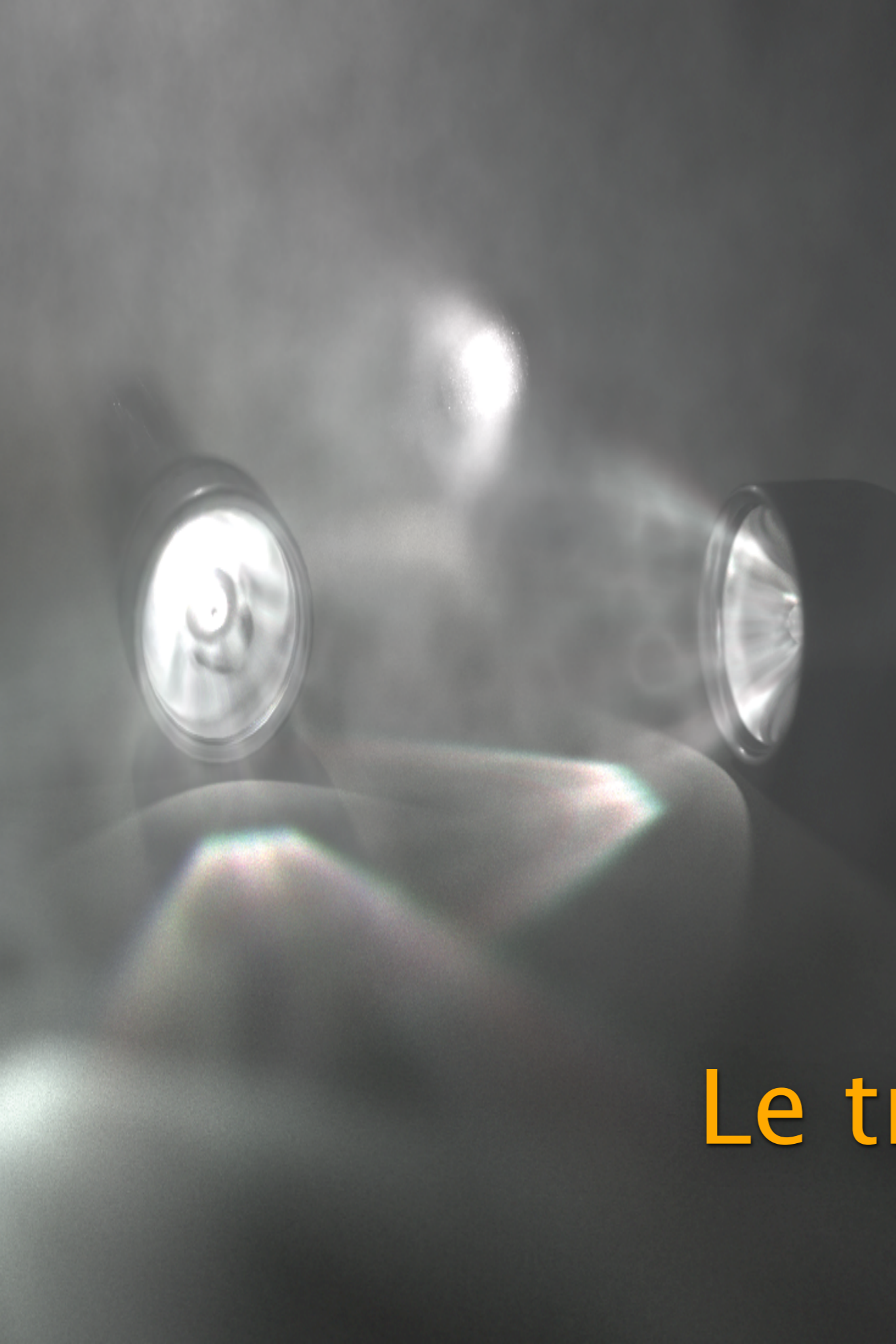
Manipulation de chemins



Manipulation de chemins



2013b



Le transport dans les volumes

Transport volumétrique

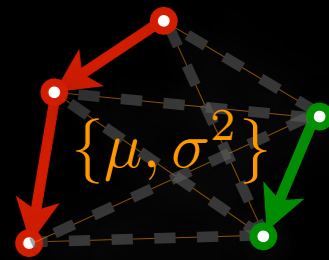
Un rayon de lumière ne subit aucun événement de diffusion si il est dans le vide



L'équation de transfert décrit le comportement de la lumière en présence d'un milieu **volumétrique**

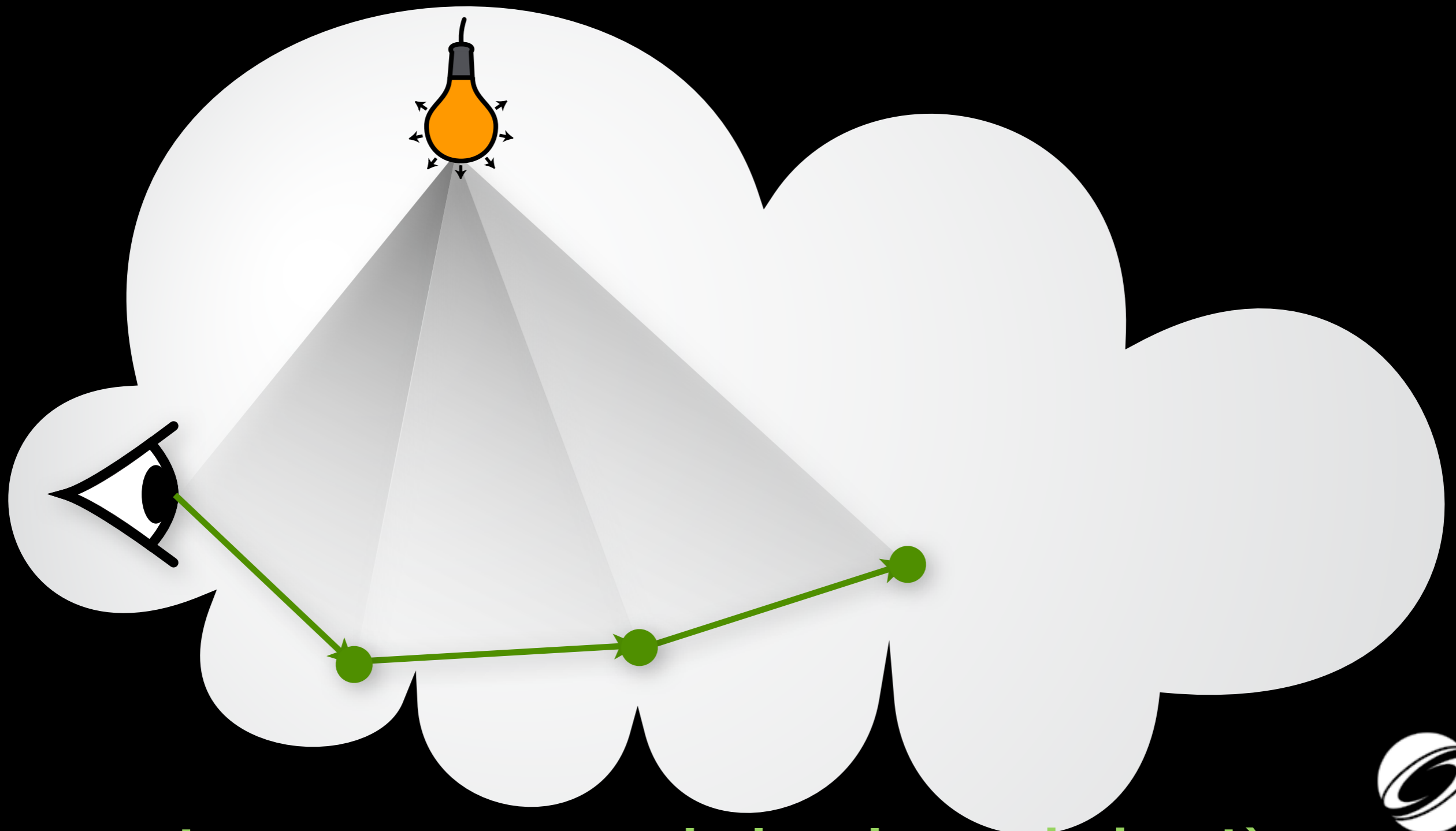
$$(\omega \cdot \nabla)L = -\sigma_t L + \sigma_s \int_{\Omega} L \cdot p_r \cdot d\omega$$

Les méthodes Monte Carlo



Méthode traditionnelle
 $O(N^{-1/3})$ [Kalos 1963]

Connexion par segment de bord



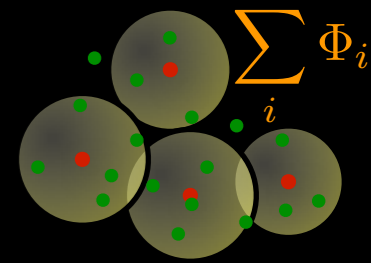
Connexion par segment de bord



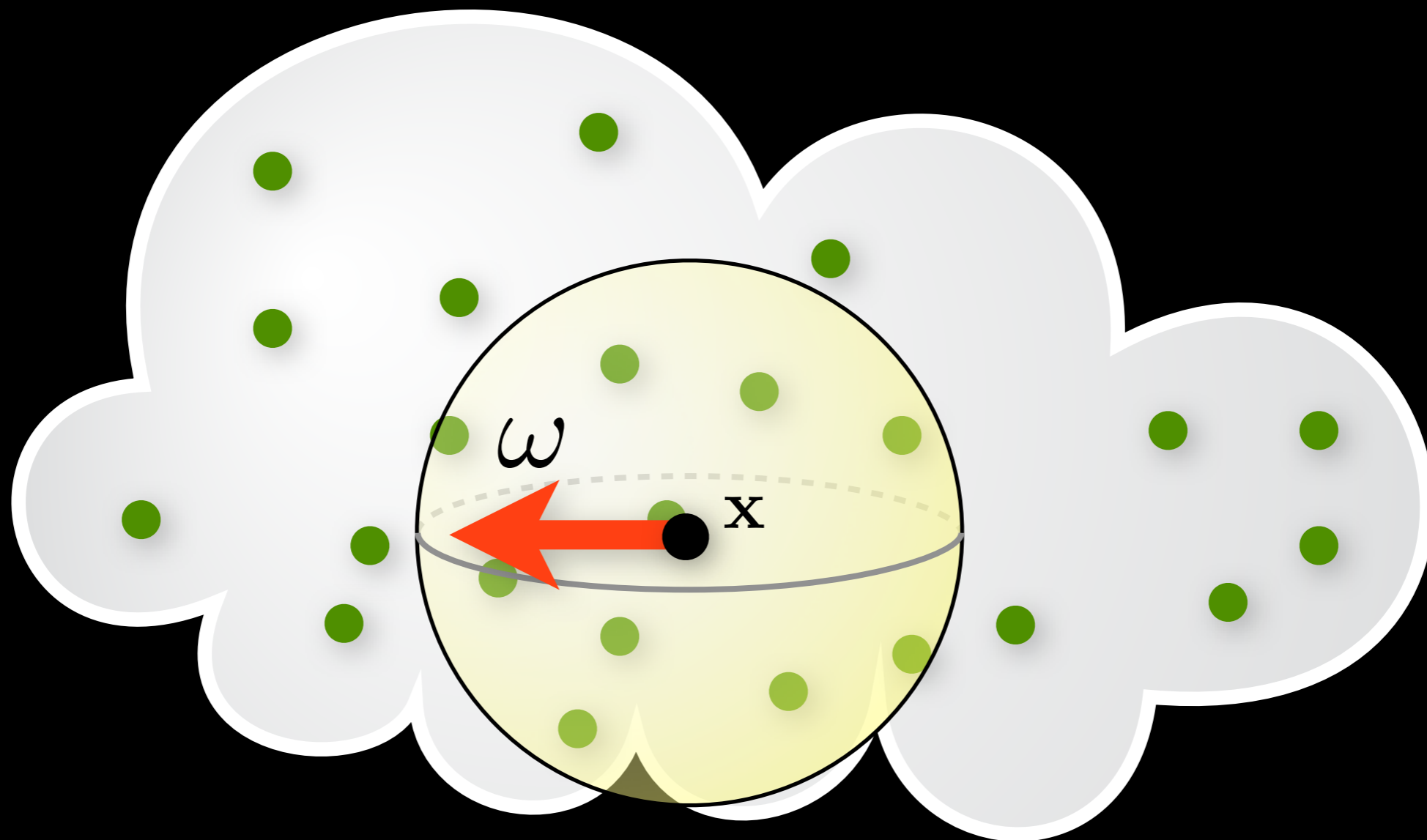
Réduction de la variance de plus de 1000x



2013c

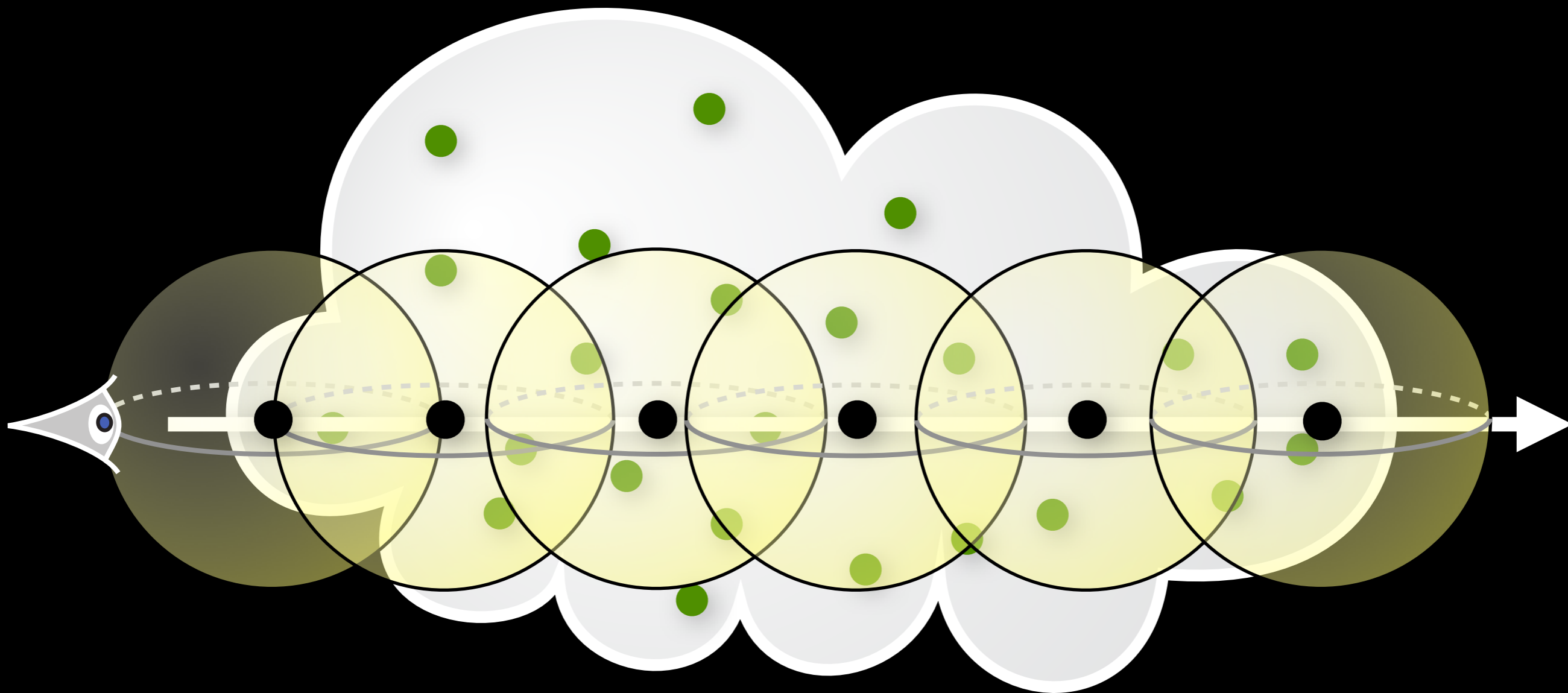
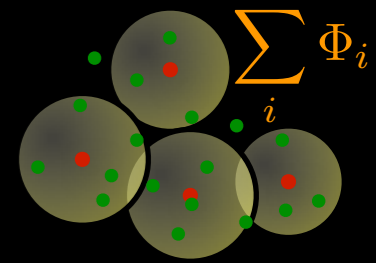


Les méthodes d'estimation de la densité



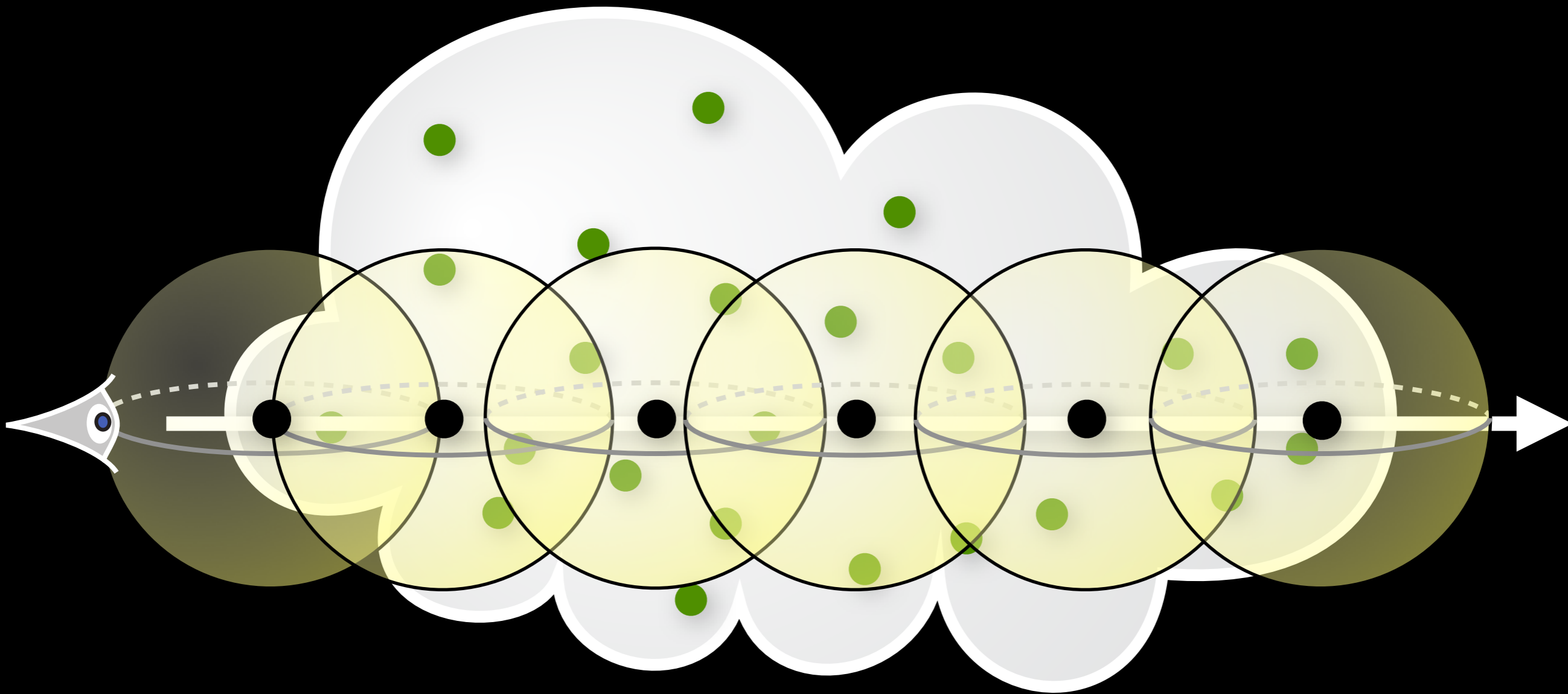
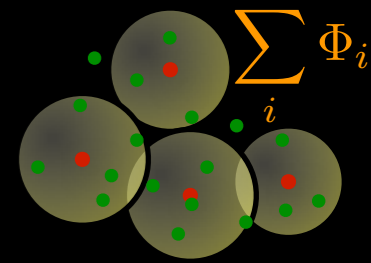
$$L_i(\mathbf{x}, \omega) \approx \sum_{i=1}^k p_r(\mathbf{x}, \omega_i, \omega) \frac{\Phi_i(\mathbf{x}, \omega_i)}{\frac{4}{3}\pi r(\mathbf{x})^3}$$

Les méthodes d'estimation de la densité

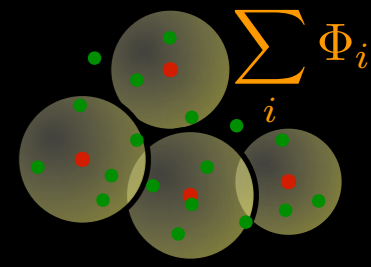


$$L_m(\mathbf{x}, \omega) = \int_0^s T_r(\mathbf{x} \leftrightarrow \mathbf{x}_t) \sigma_s(\mathbf{x}_t) L_i(\mathbf{x}_t, \omega) dt$$

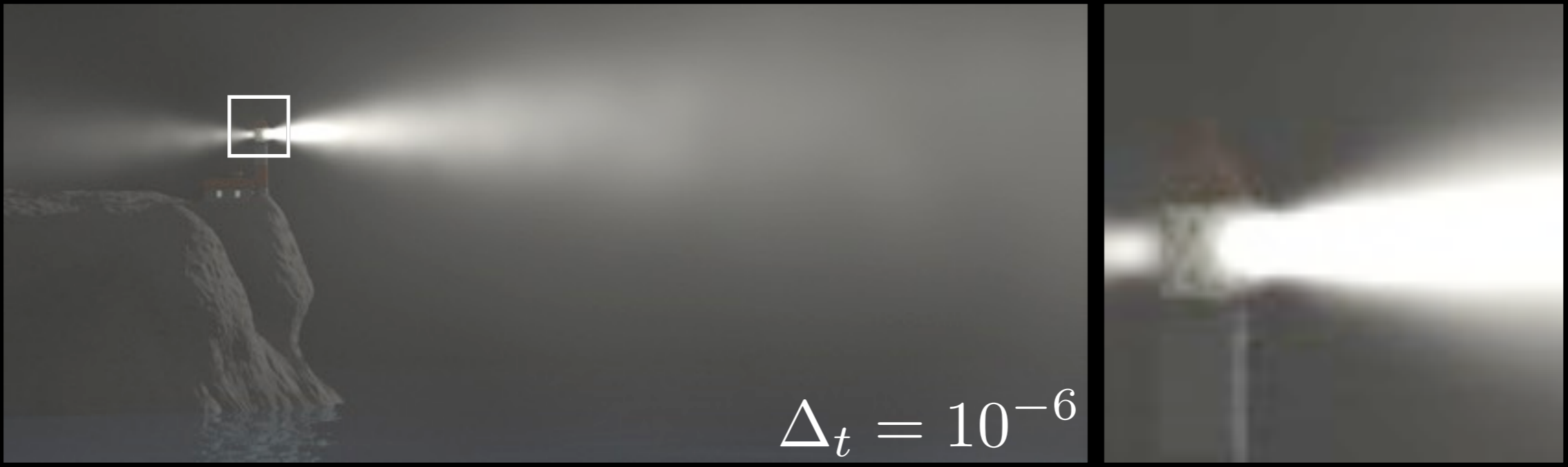
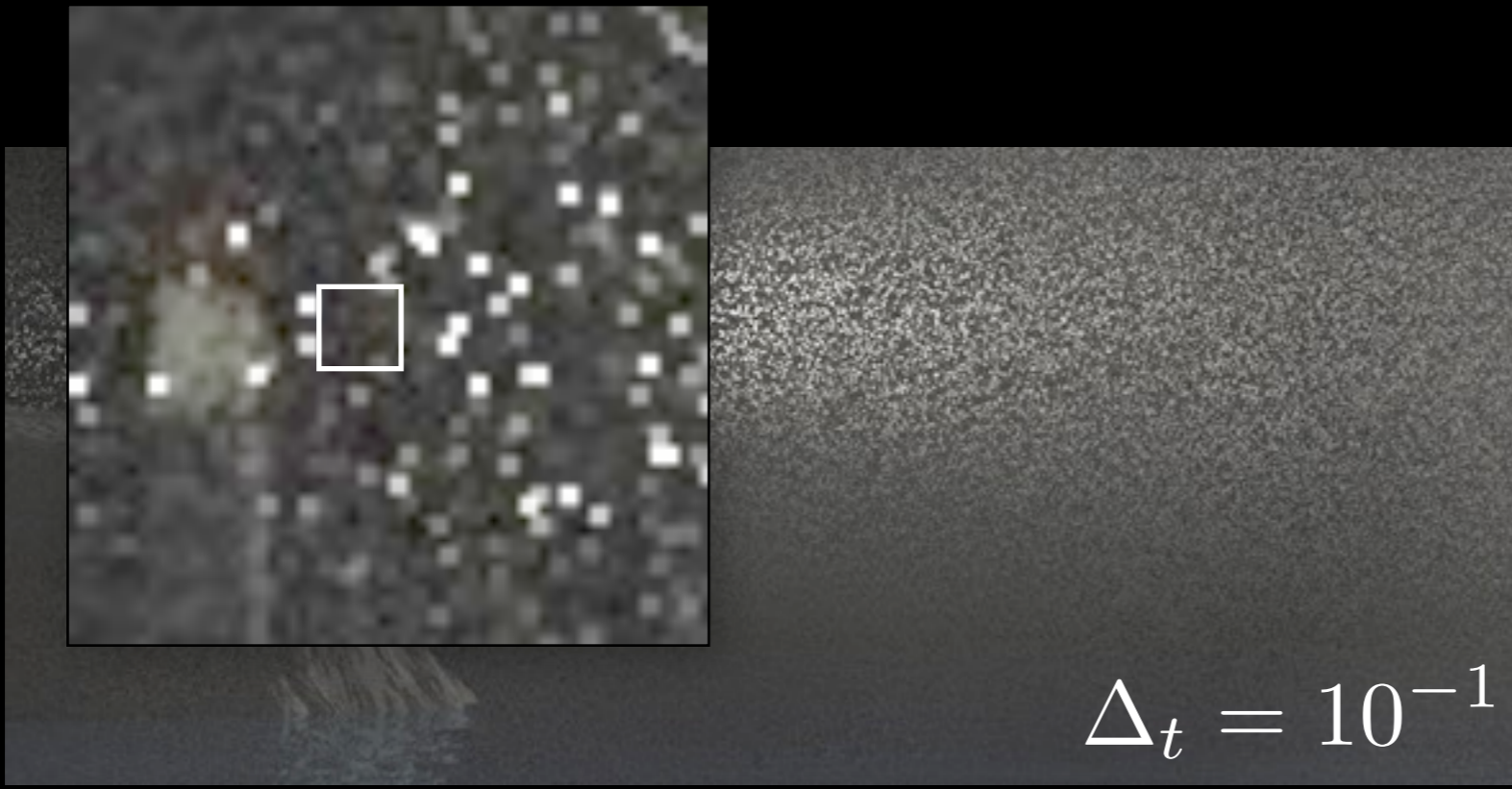
Les méthodes d'estimation de la densité



$$L(\mathbf{x}, \omega) \approx \sum_{t=0}^S T_r(\mathbf{x} \leftrightarrow \mathbf{x}_t) \sigma_s(\mathbf{x}_t) L_i(\mathbf{x}_t, \omega) \Delta_t$$

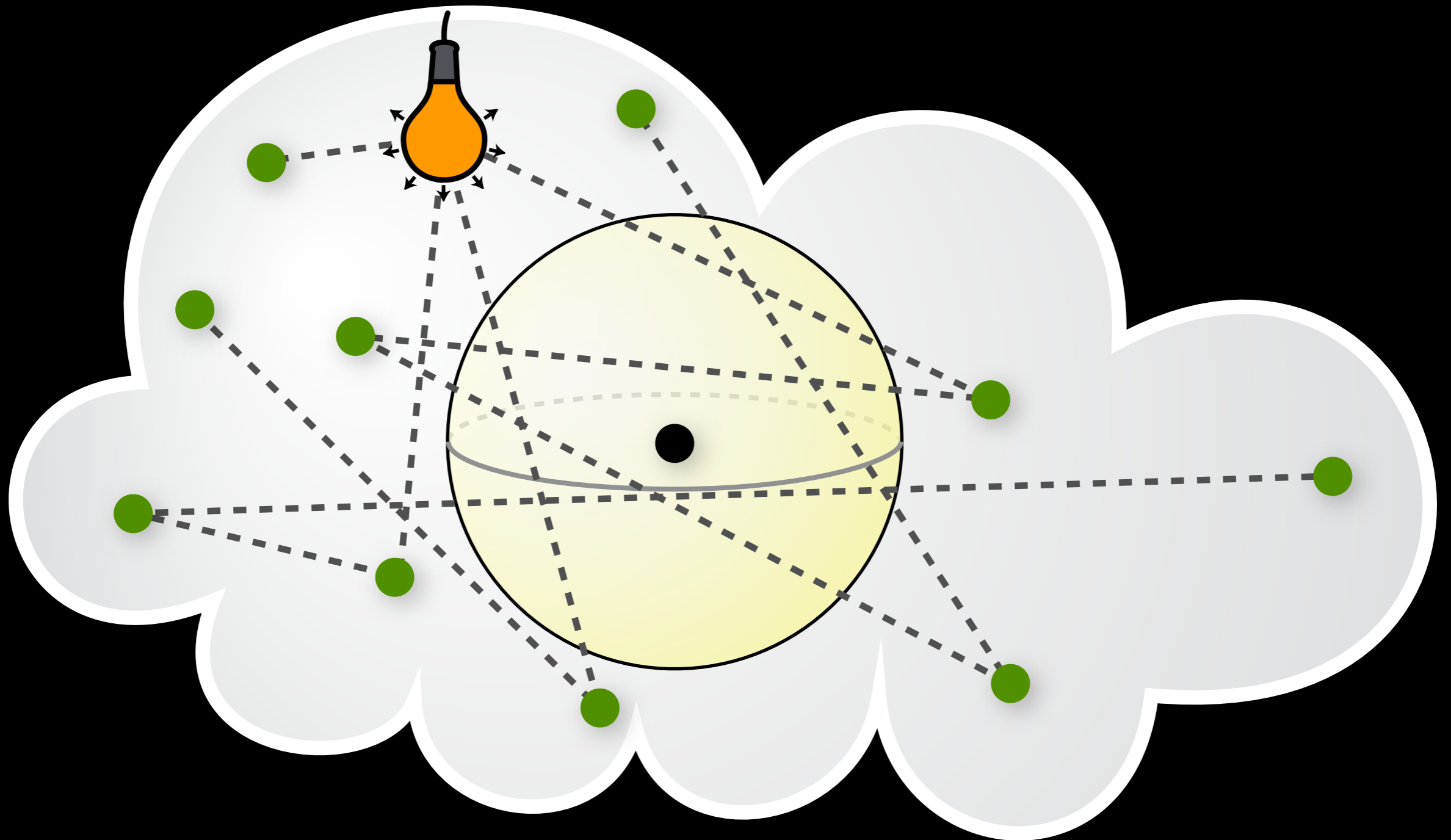
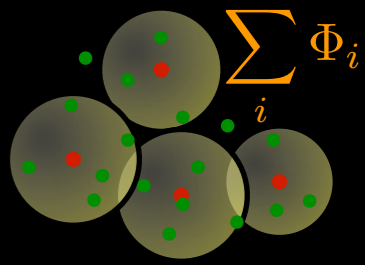


Les méthodes d'estimation de la densité



L'artefact principal: des **détails flous** et du **bruit**

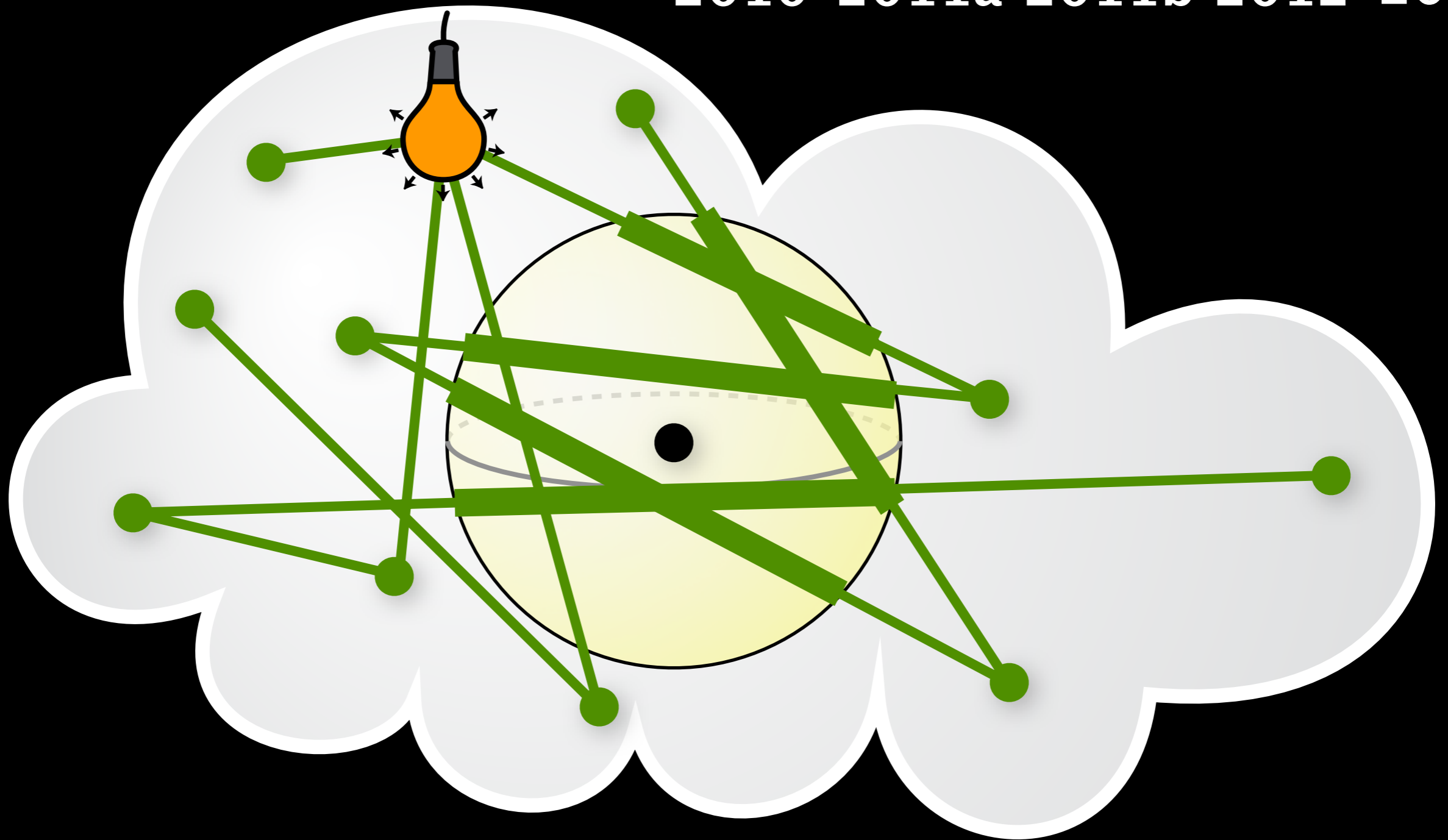
Les méthodes d'estimation de la densité



Les Photons

Photon Beams

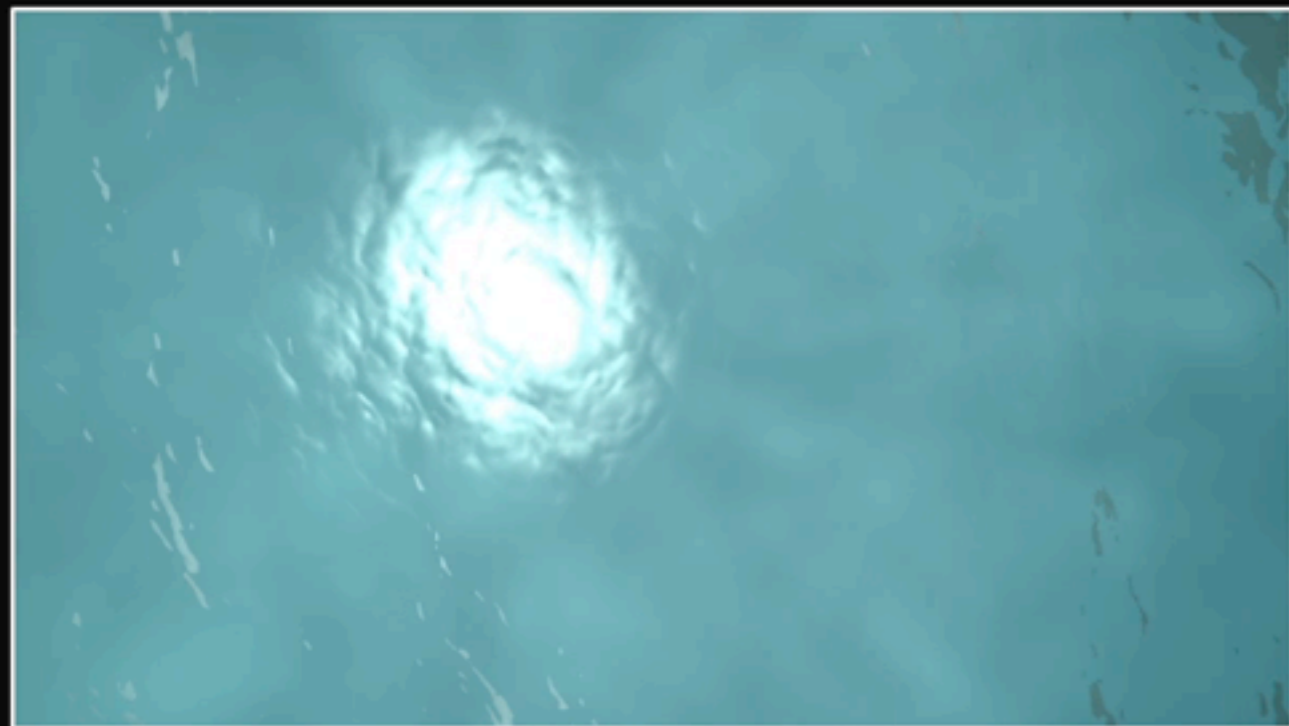
    **EGSR**
2010 2011a 2011b 2012 2012



Photon Beams

Rayons de soleil sous l'eau

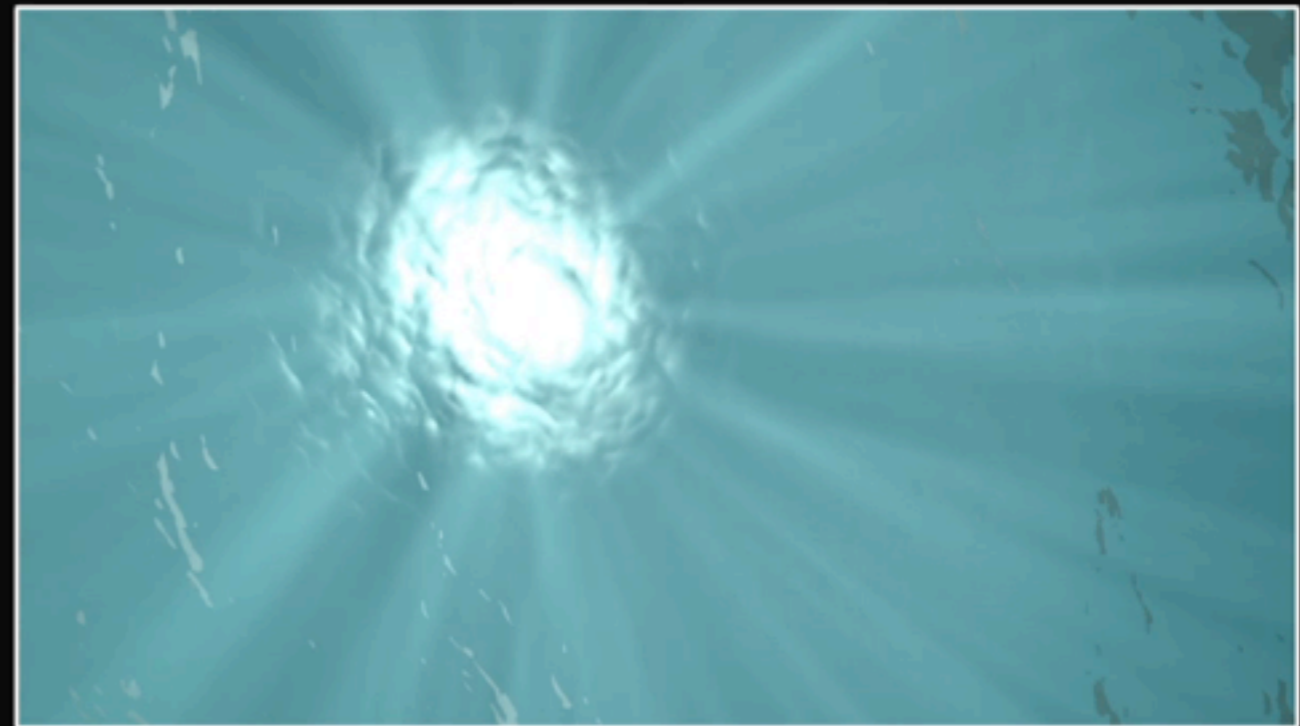
Photons



100K Photon Points
~ 204 seconds/frame

Roughly Equal Time

Photon Beams



25K Photon Beams
~ 200 seconds/frame



2010



2011a



2011b

De la théorie à la pratique

Une propriété importante des **Photon Beams**:

```
struct photon {          struct beam {
    vec3 position;        vec3 position;
    vec3 direction;      vec3 endpoint;
    vec3 puissance;      vec3 puissance;
};                        float rayon;
                        };
```

Intégration très facile dans les bases de codes existantes



2010

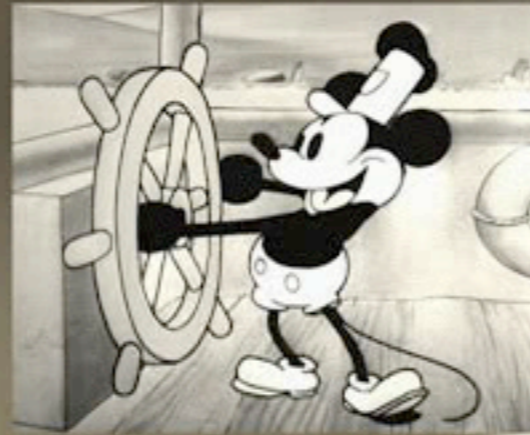


2011a



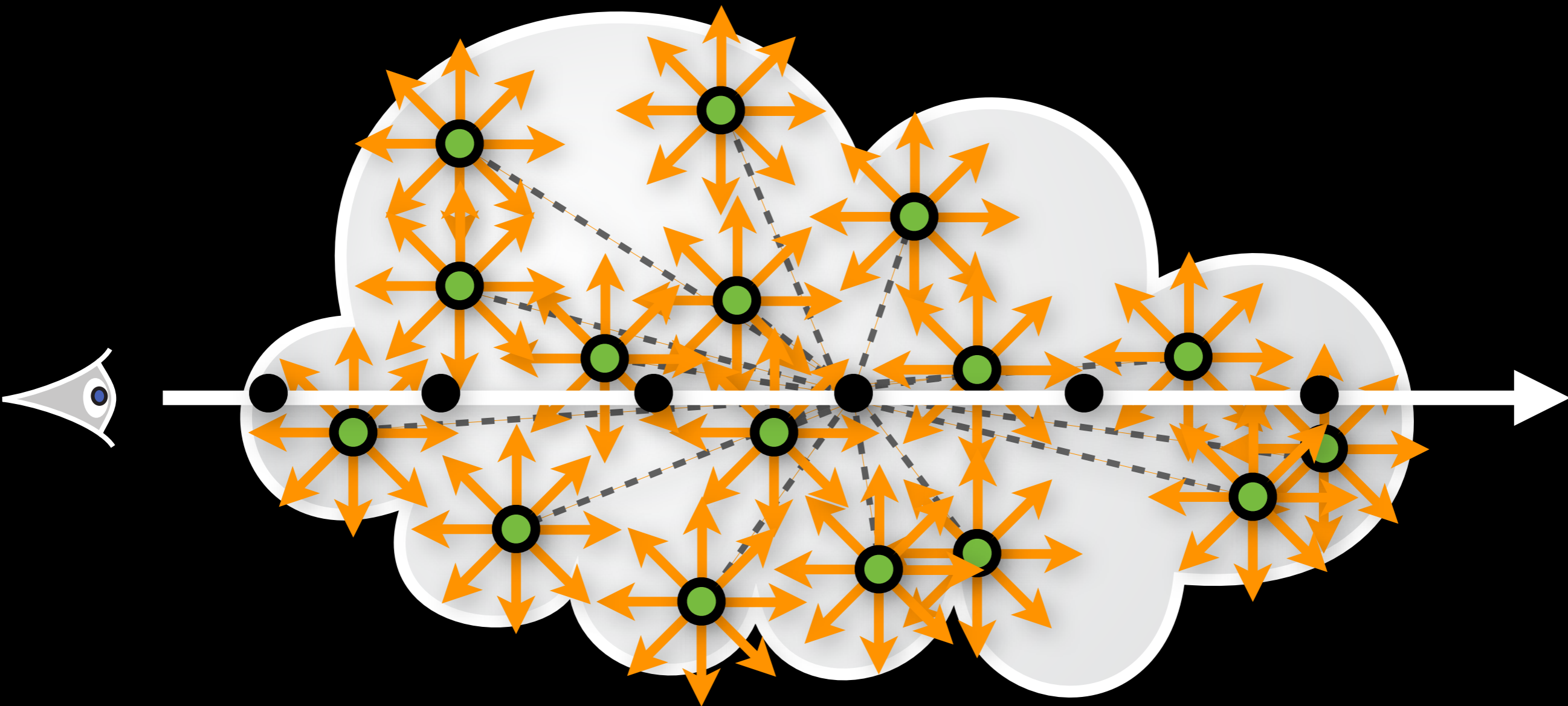
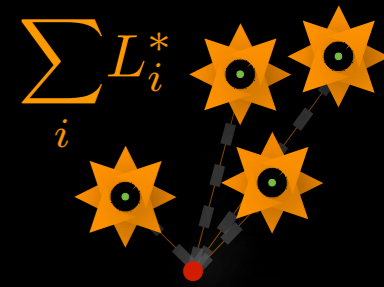
2011b

Beams : adoption industrielle



WALT DISNEY
ANIMATION STUDIOS

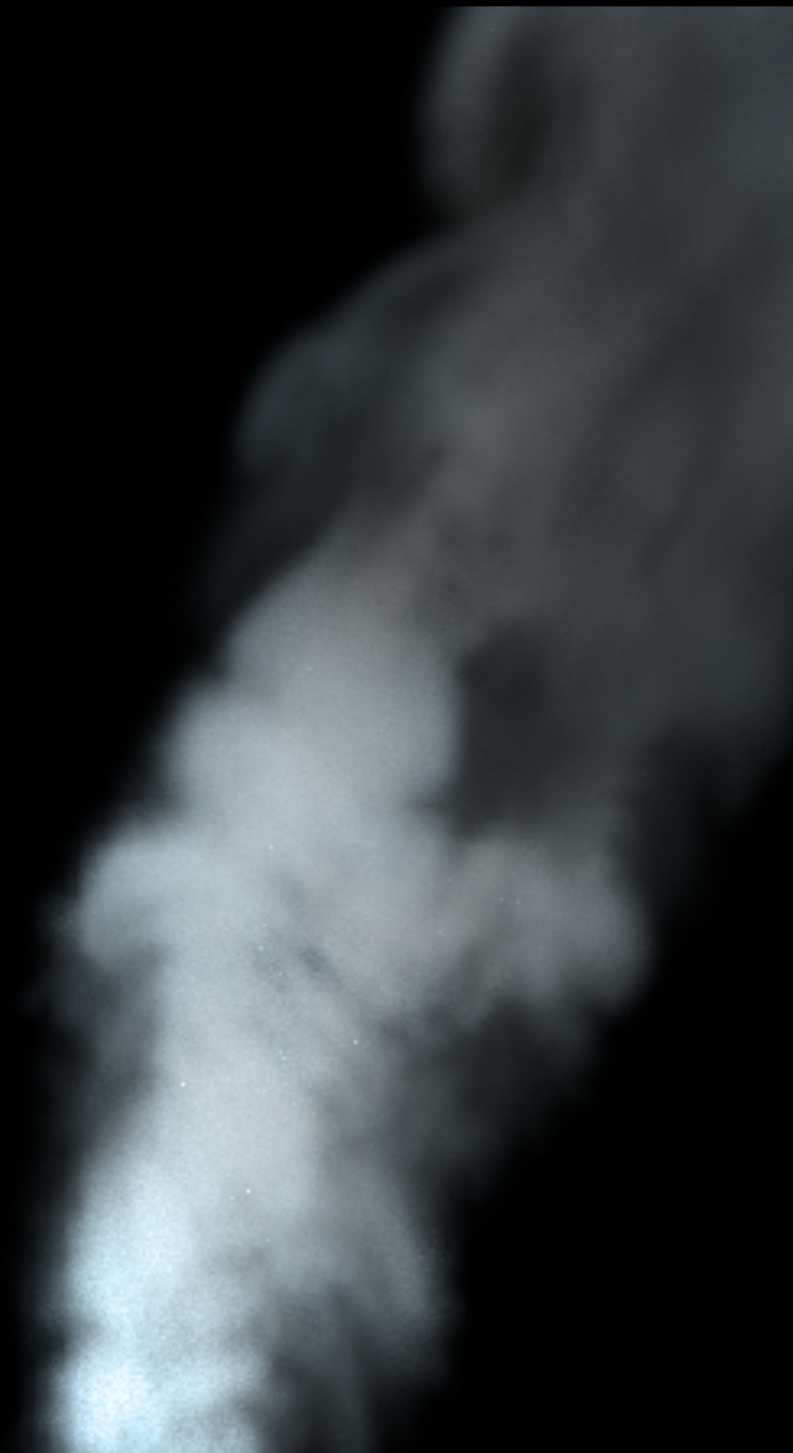
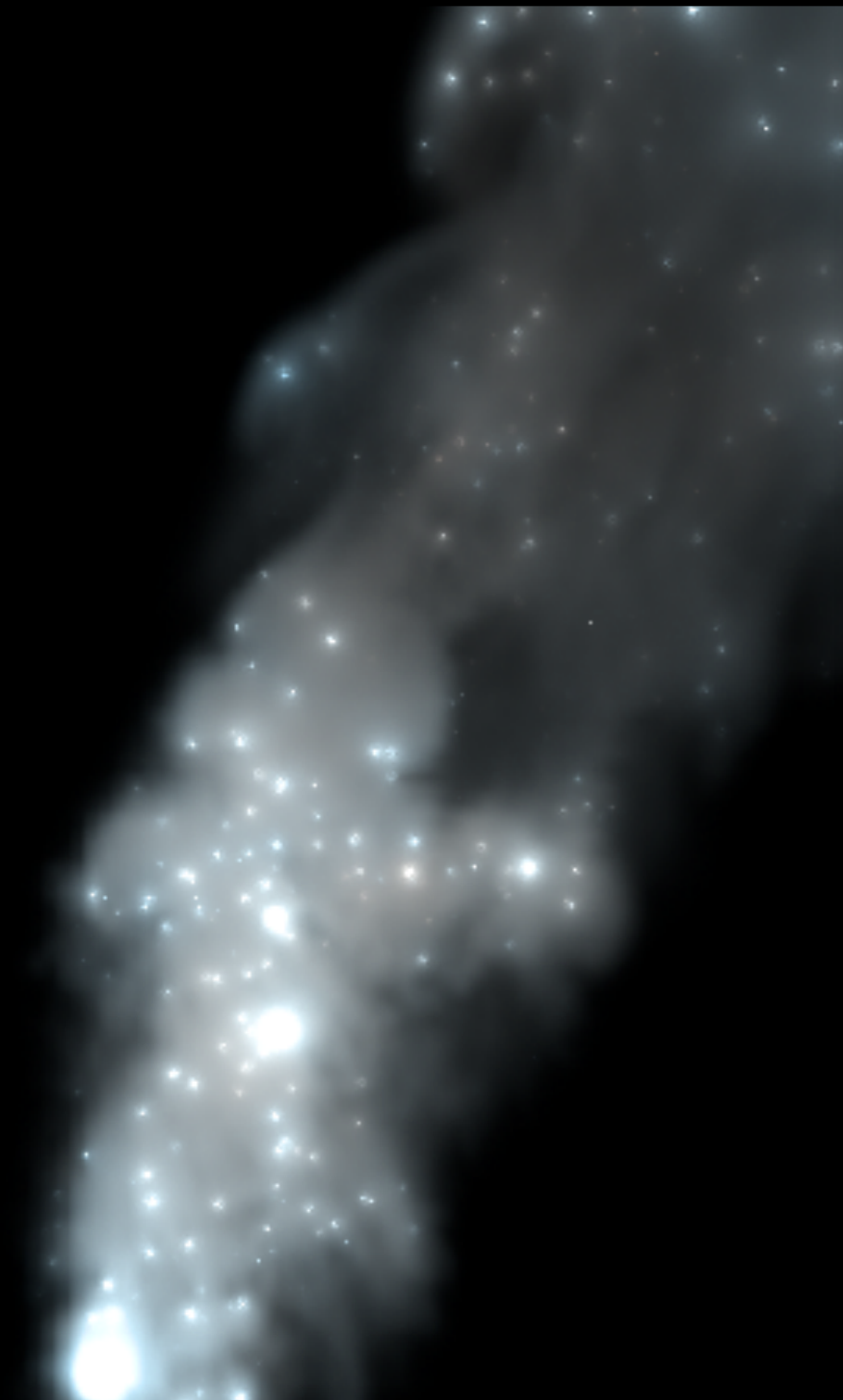
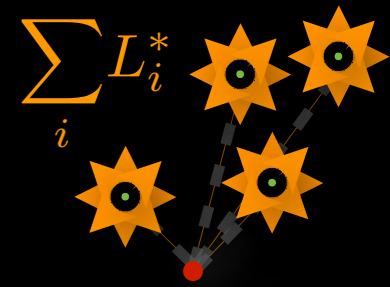
Méthodes de lumières virtuelles



$$L_{i+}(\mathbf{x}, \omega) \approx \sum_i \frac{\Phi_i}{r(\mathbf{x}_i)^2} V(\mathbf{x}, \omega_i) p_r(\mathbf{x}, \omega_i, \omega)$$

Lumières ponctuelles virtuelles (VPLs)

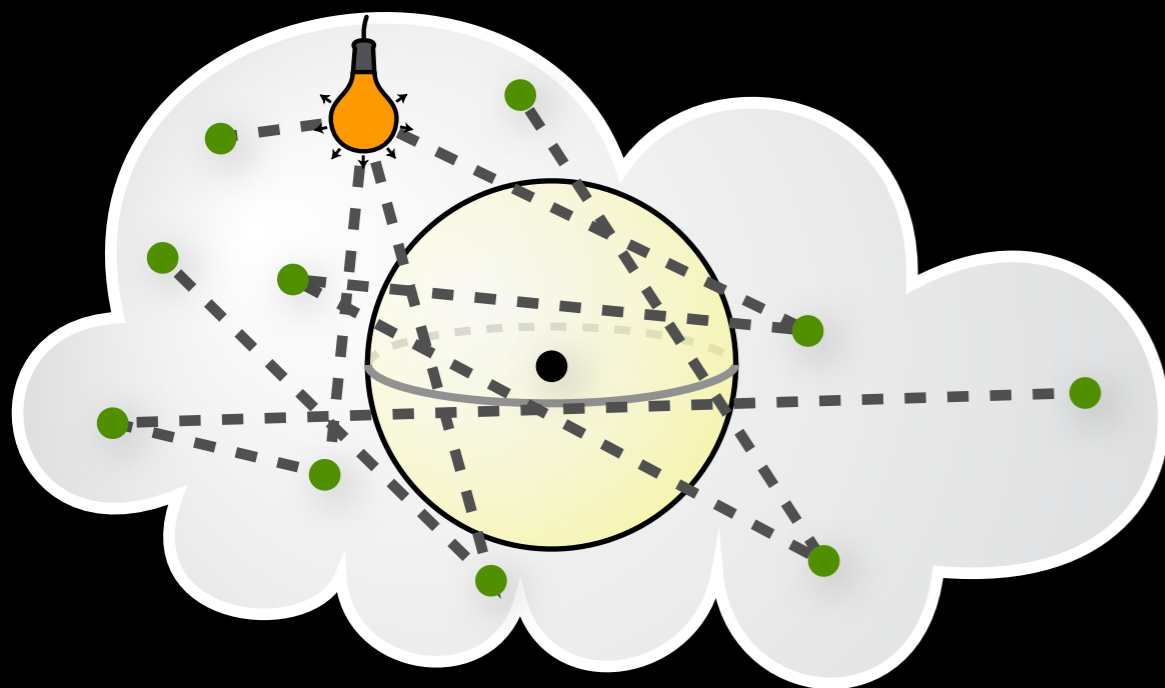
Méthodes de *lumières virtuelles*



L'artefact principale : les singularités volumétriques

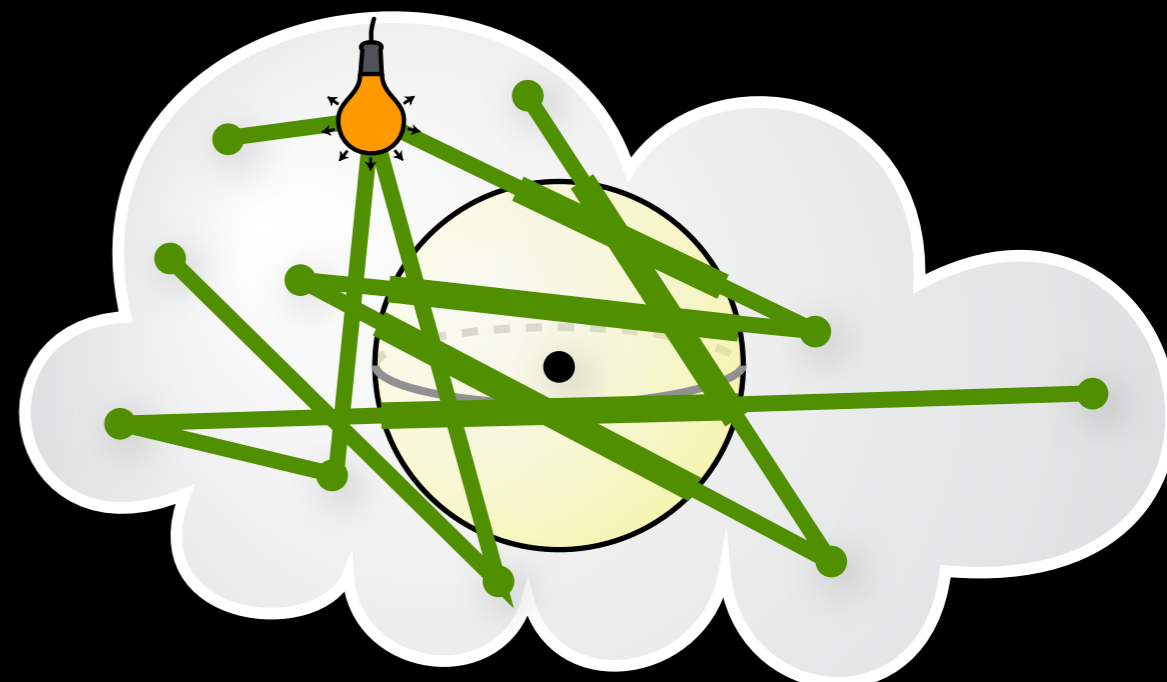
Lumières linéaires virtuelles

Photons



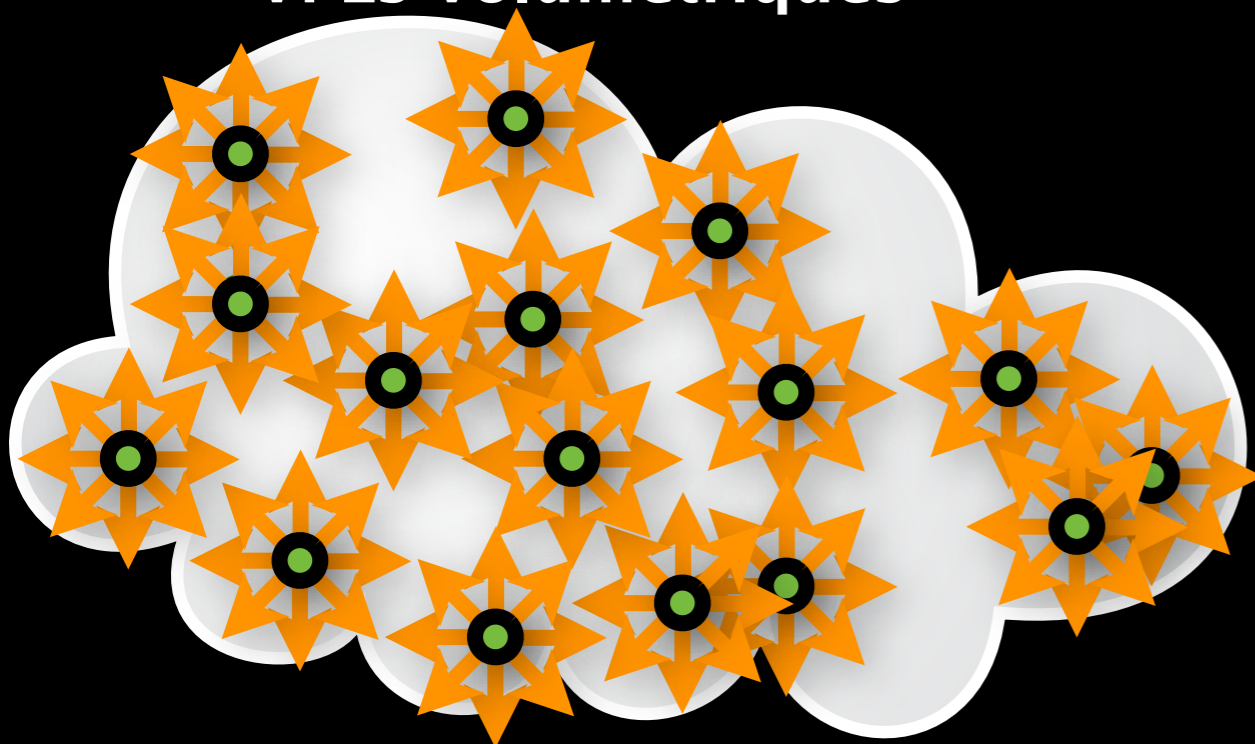
demandes beaucoup de photons

Photon Beams

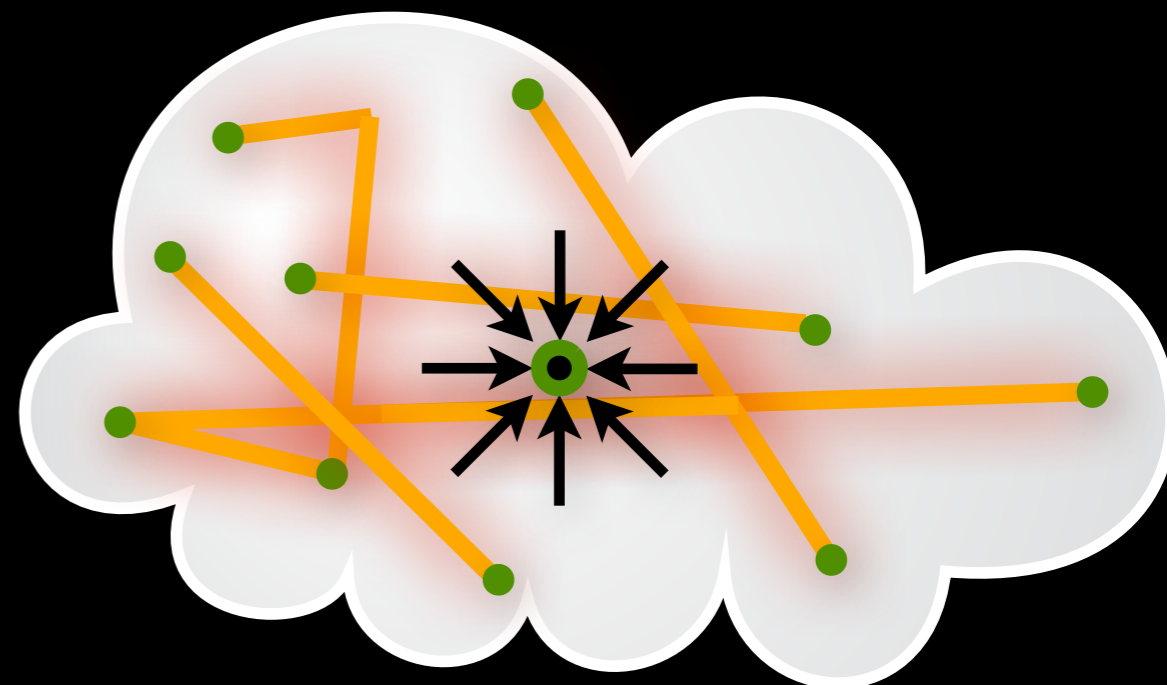


diffusion multiple inefficace

VPLs volumétriques



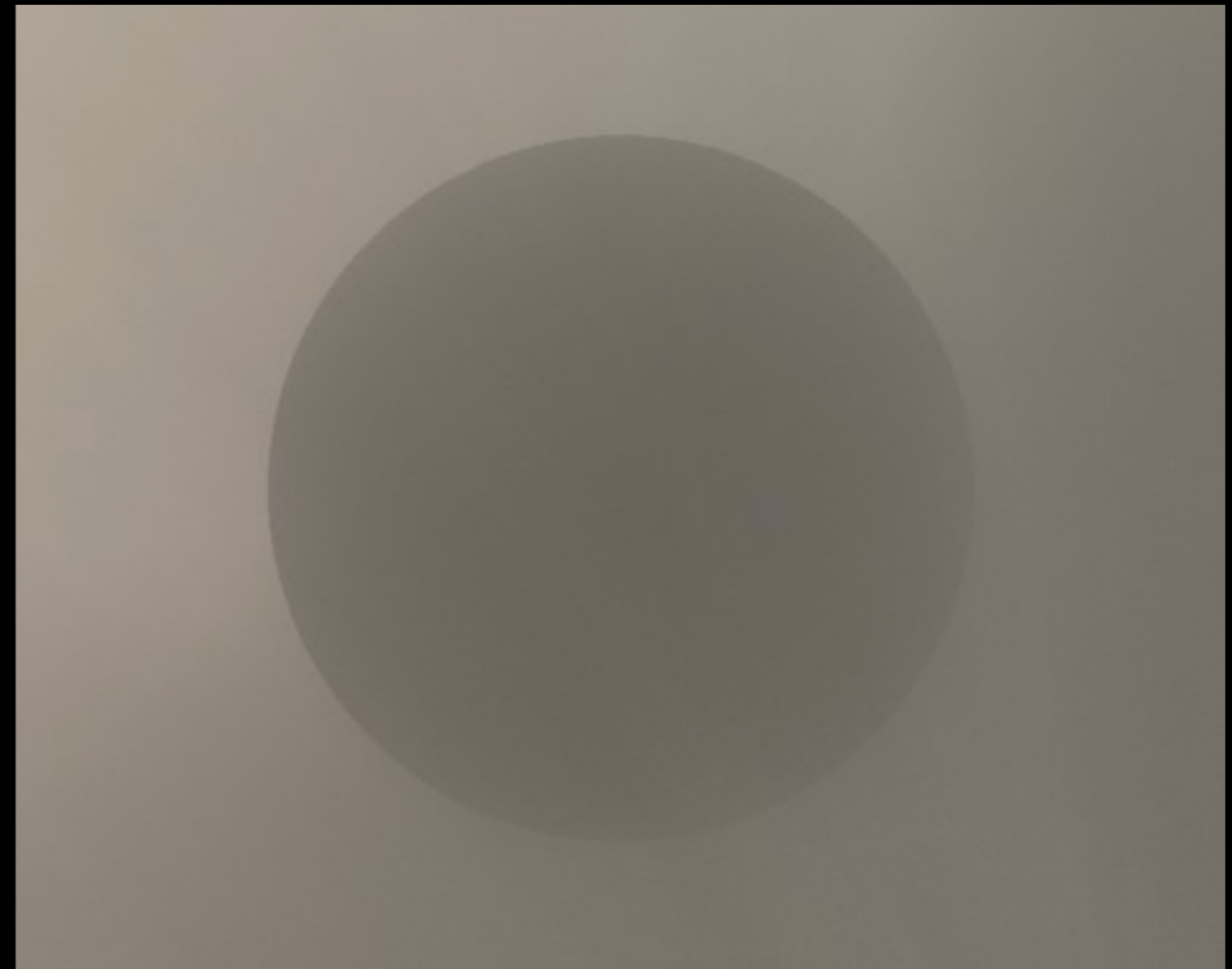
Lumières linéaires virtuelles



Lumières linéaires virtuelles



10^4 lumières ponctuelles

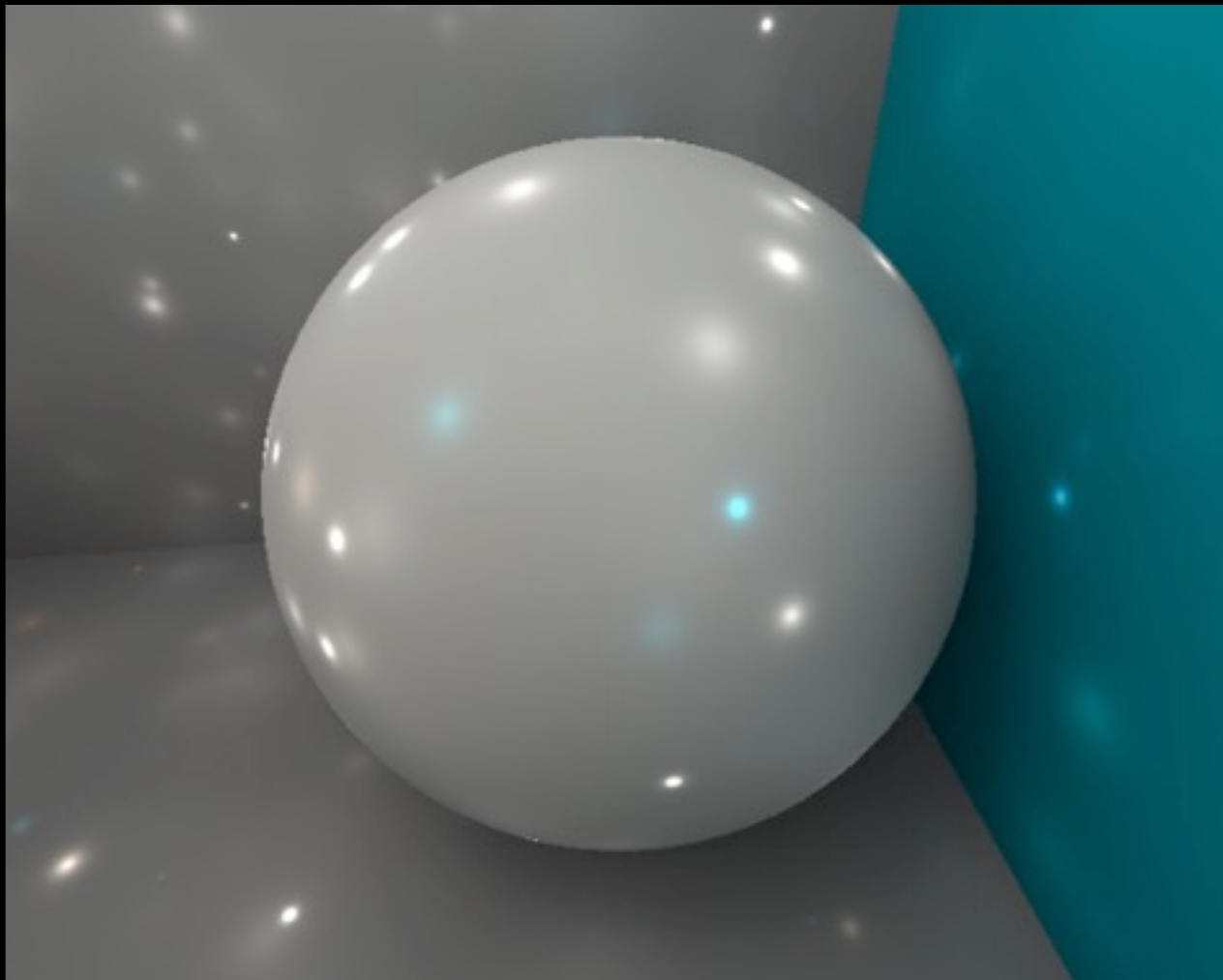


10^4 lumières linéaires

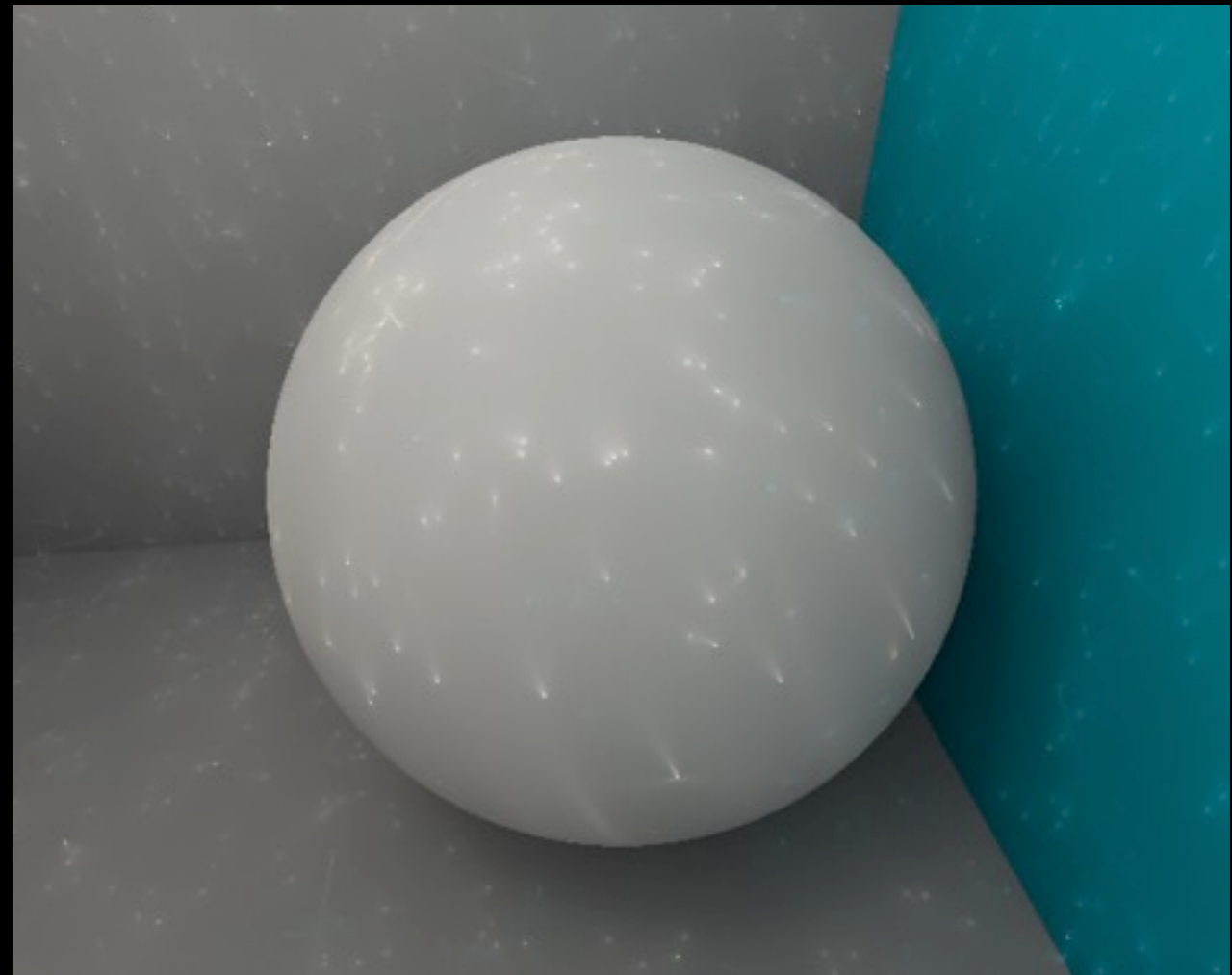


Lumières linéaires virtuelles

Bénéfices additionnels pour le transport de surface



10^4 Virtual **Point** Lights



10^4 Virtual **Beam** Lights





Jus de fruit
anisotrope (HG g = 0.55)



Rendu surfacique
Photon Mapping



Diffusion simple
Photon Beams



Diffusion multiple

Diffusion multiple

Lumières linéaires
virtuelles

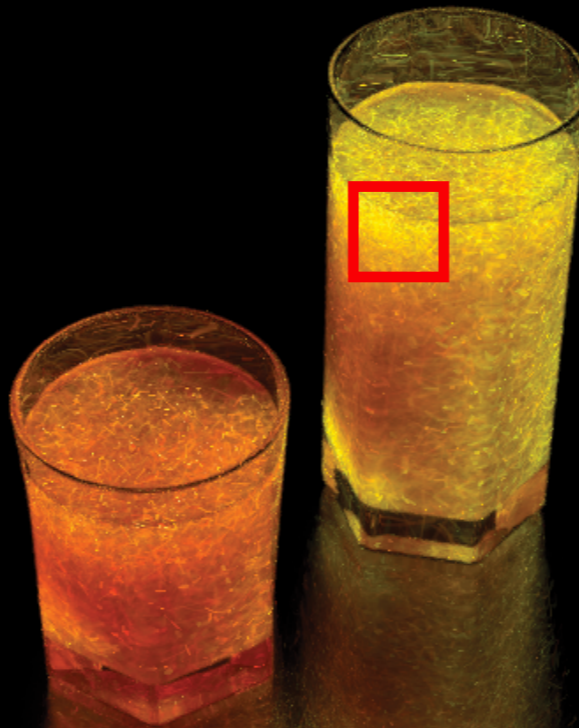


60 s

1200 s



Photon Beams

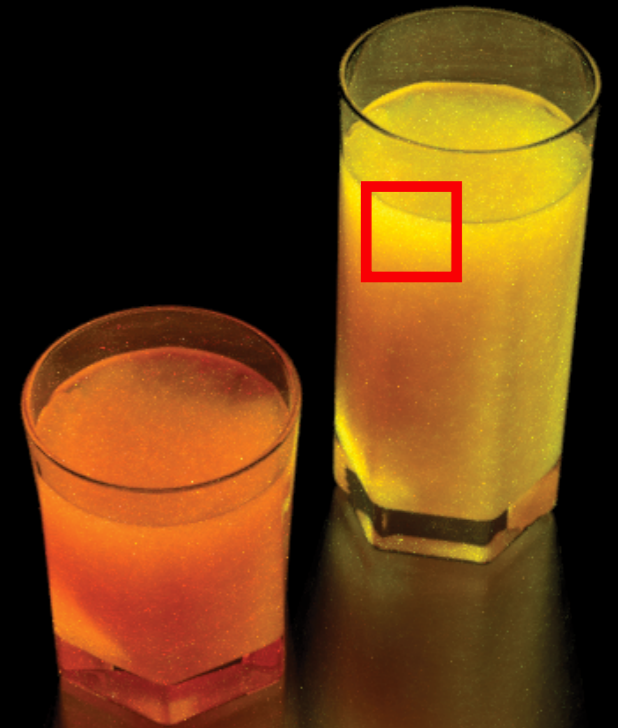


60 s

1200 s

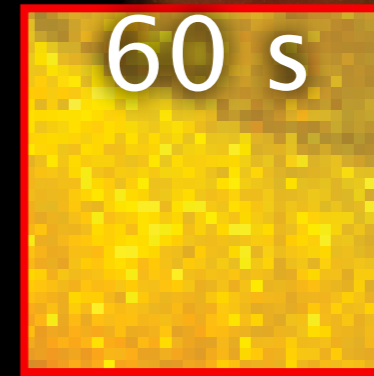


Lumières ponctuelles
virtuelles



60 s

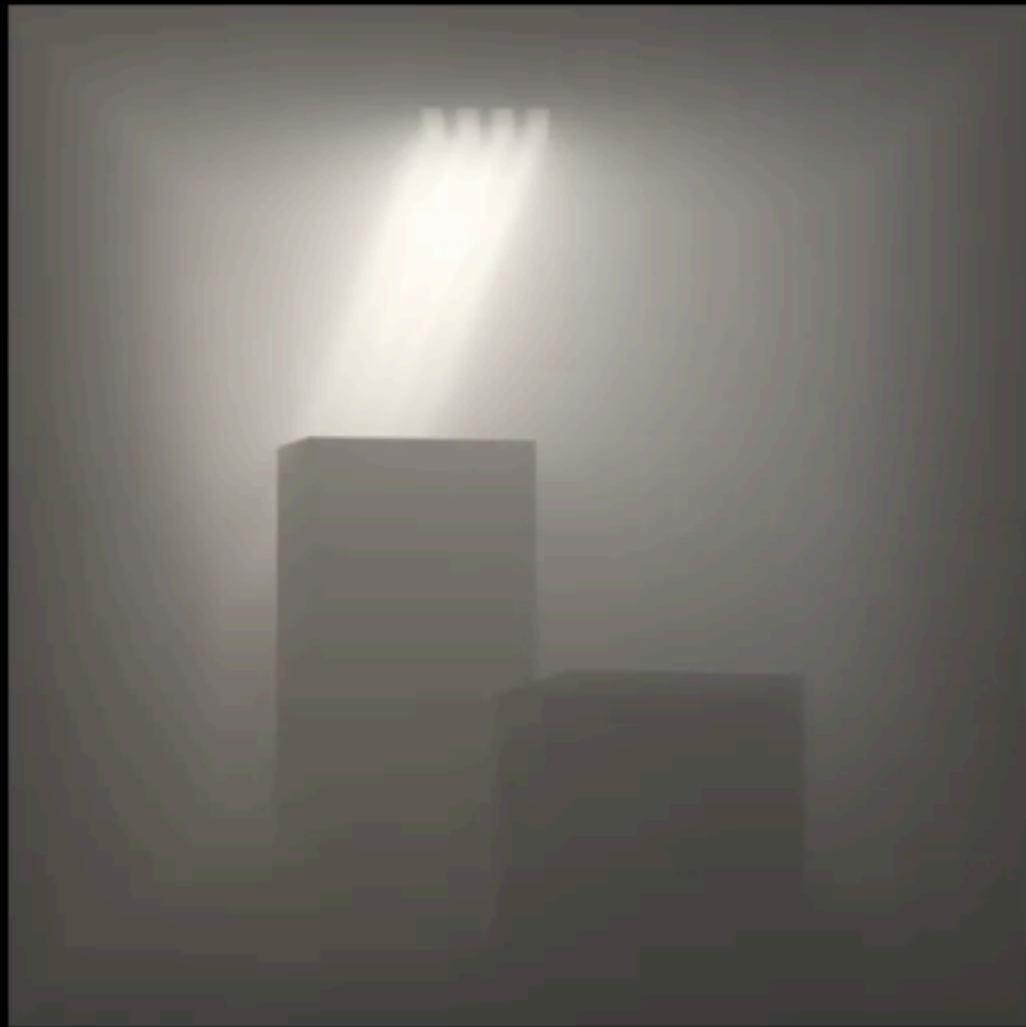
1200 s



EGSR
2012 2012

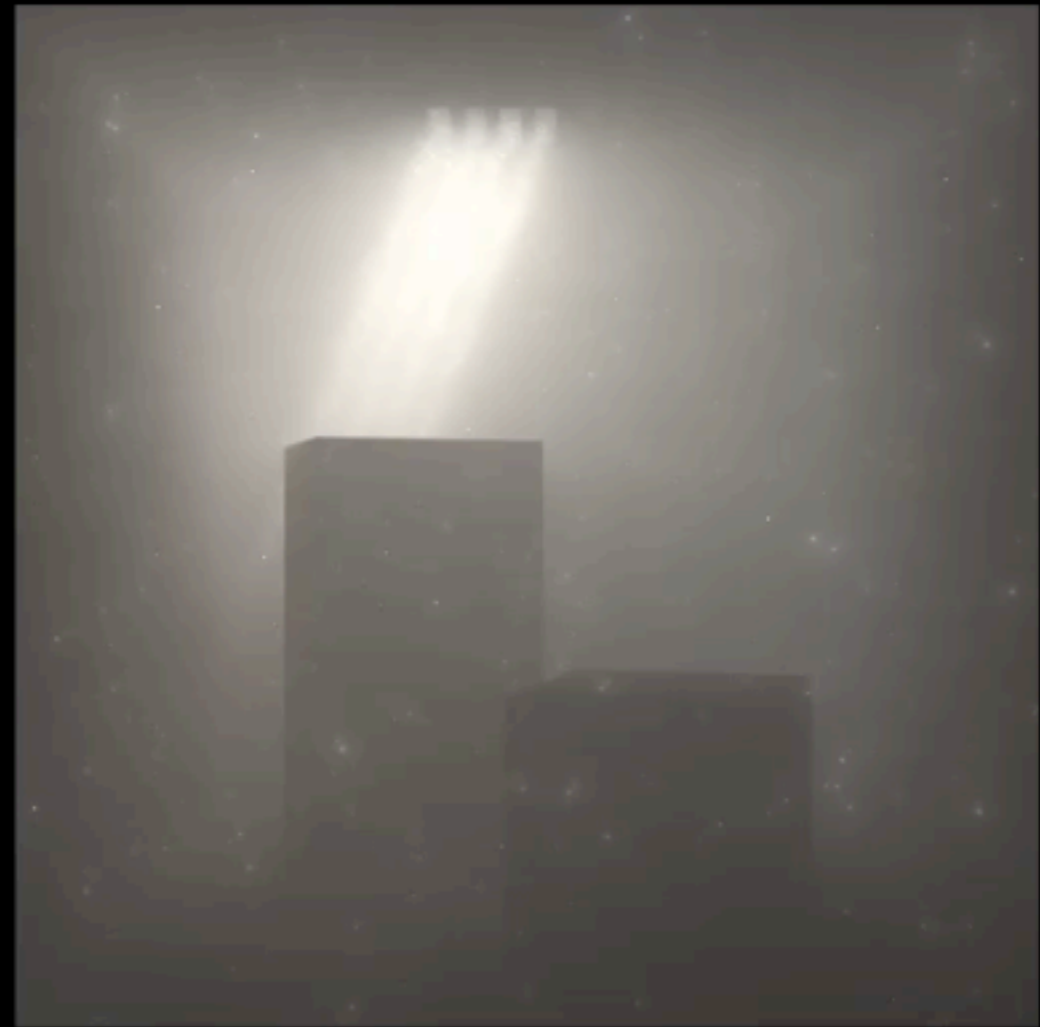
Cohérence temporelle

LVLs



1 minute/frame

VPLs



1 minute/frame



2012

EGSR

2012



Manipulation de la lumière dans les volumes

Rapunzel



2011a



©Disney



©Disney

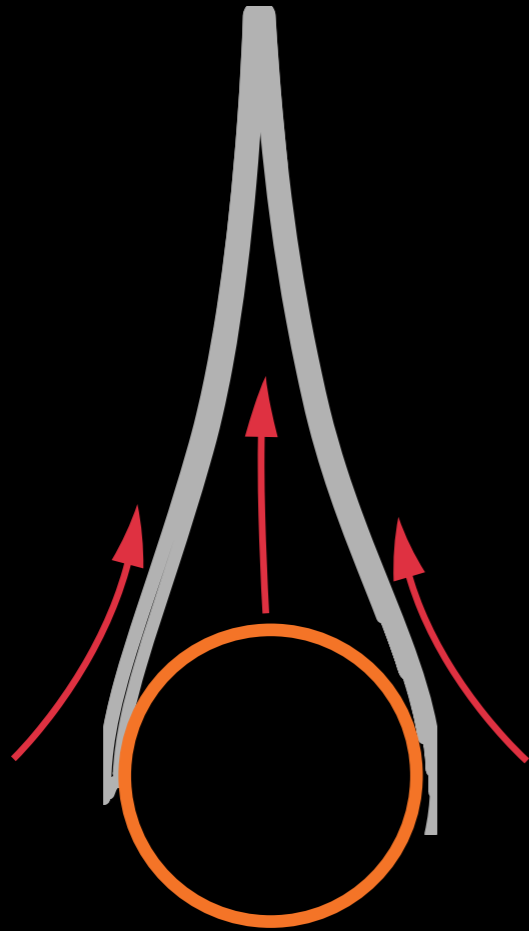


©Disney



2011a

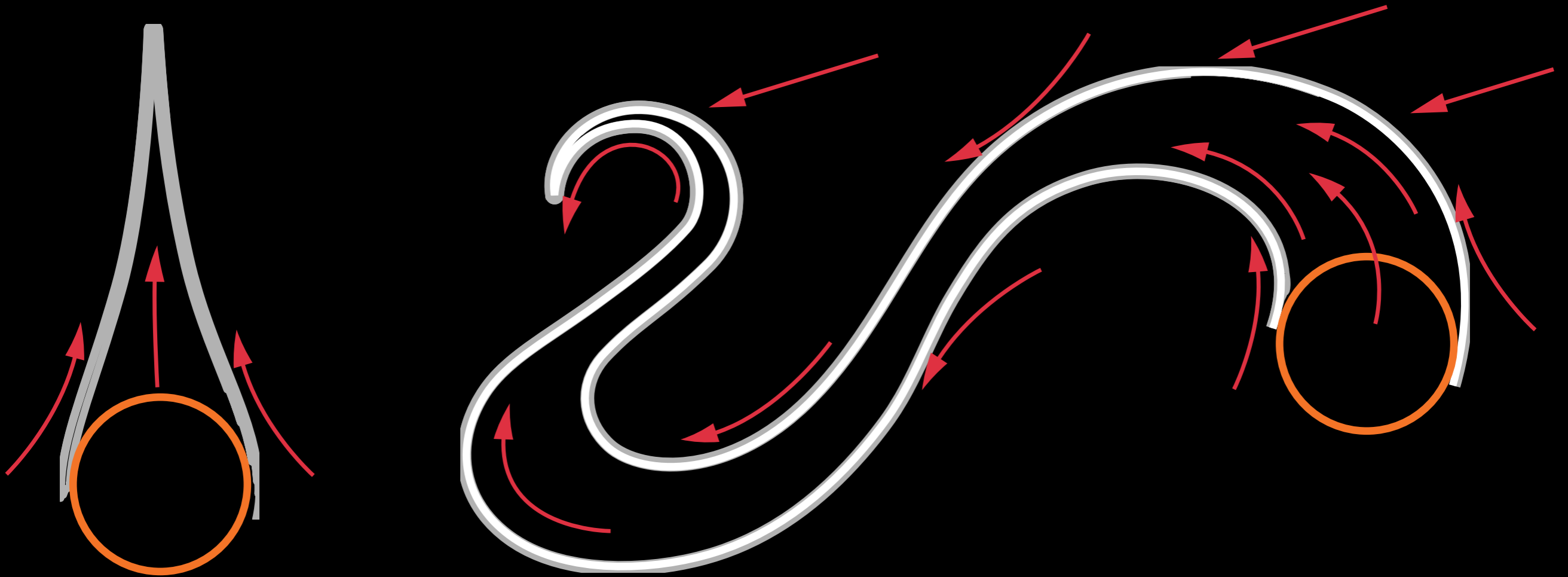
Diffusion artistique



Esquisse de la forme
(peut-être avec des annotations)

Ces schémas sont inspirés par Gilland [2009]

Diffusion artistique



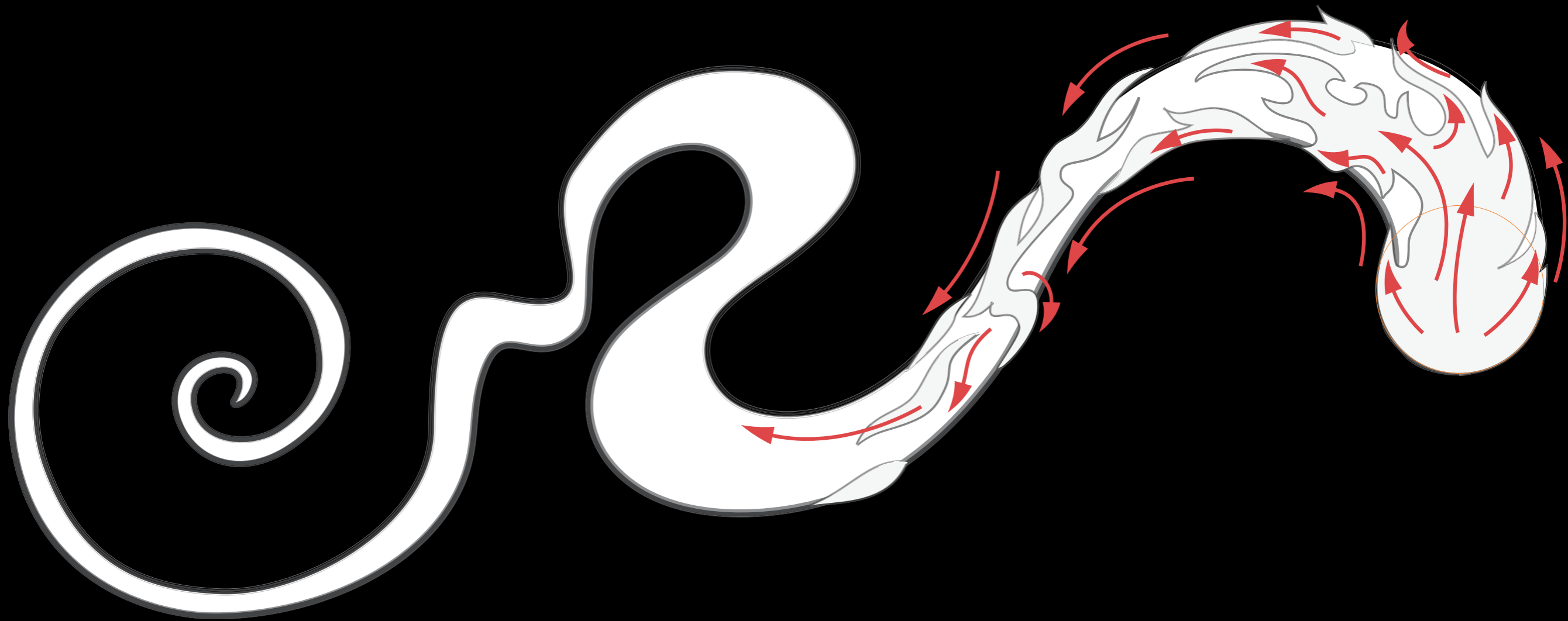
Esquisse de son évolution

Ces schémas sont inspirés par Gilland [2009]



2011a

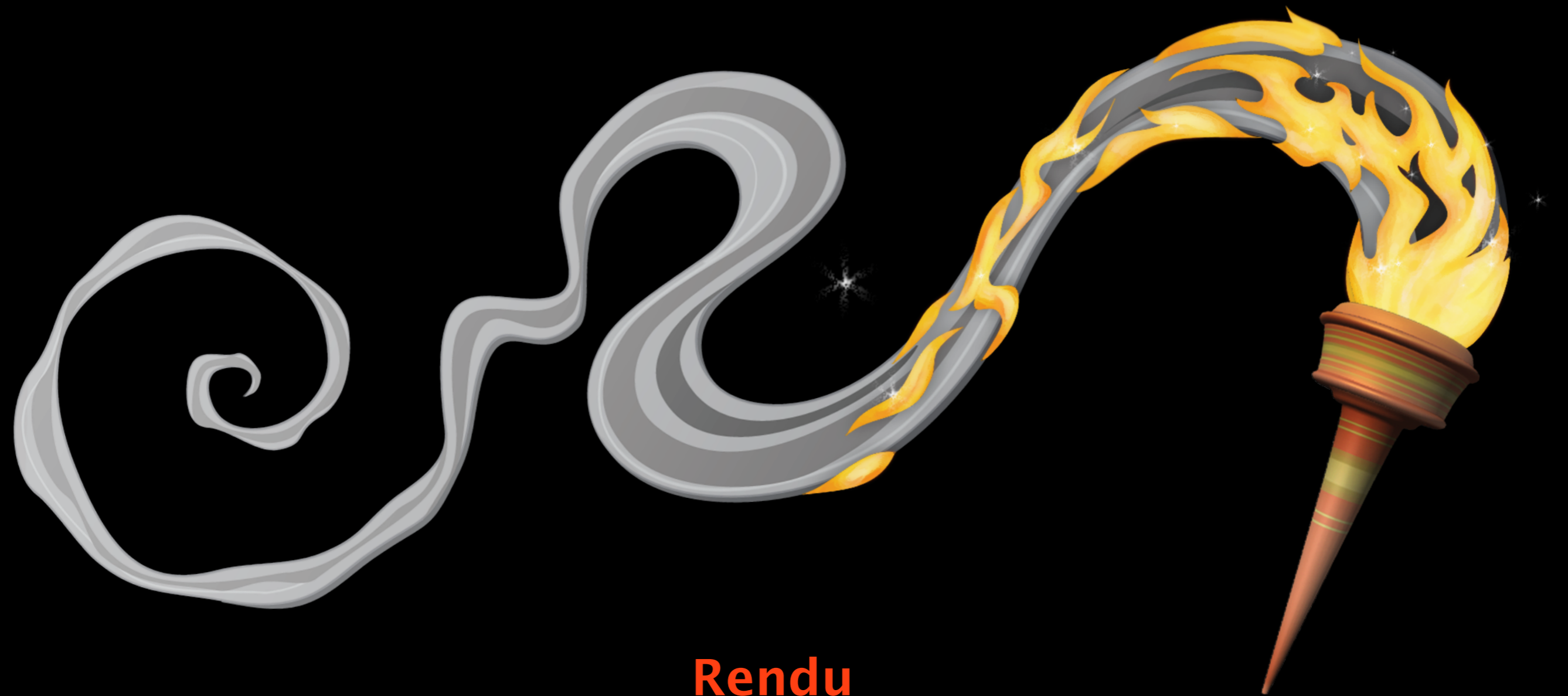
Diffusion artistique



Ajout de détails

Ces schémas sont inspirés par Gilland [2009]

Diffusion artistique



Rendu

Les workflows d'artistes ne respectent pas ce processus

Ces schémas sont inspirés par Gilland [2009]



2011a

Alerte : spoiler!



©Disney

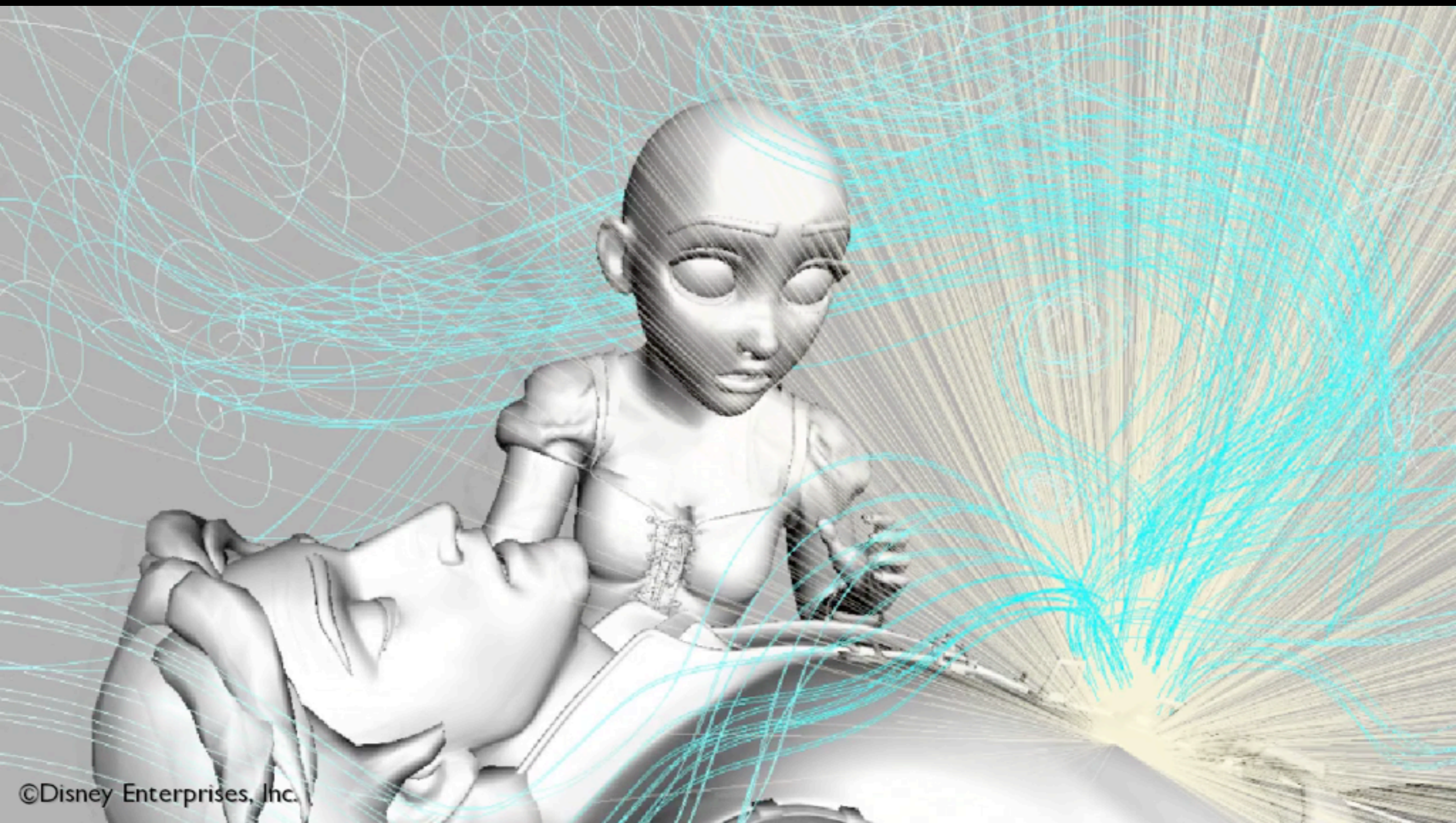


©Disney

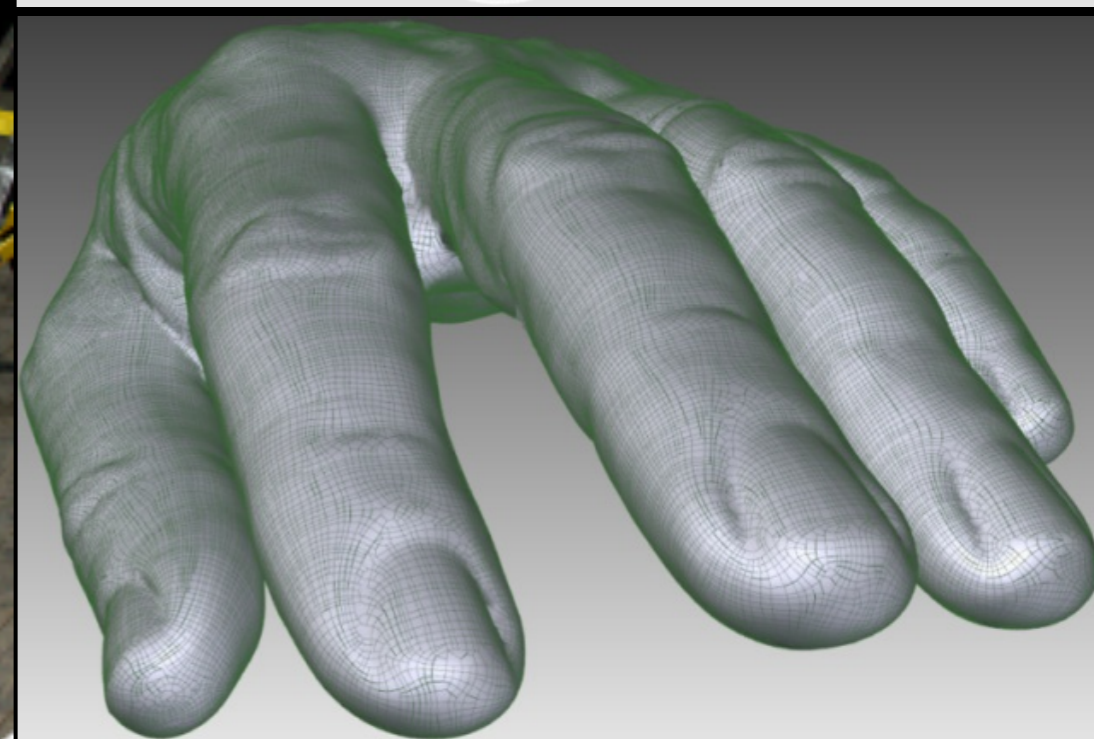
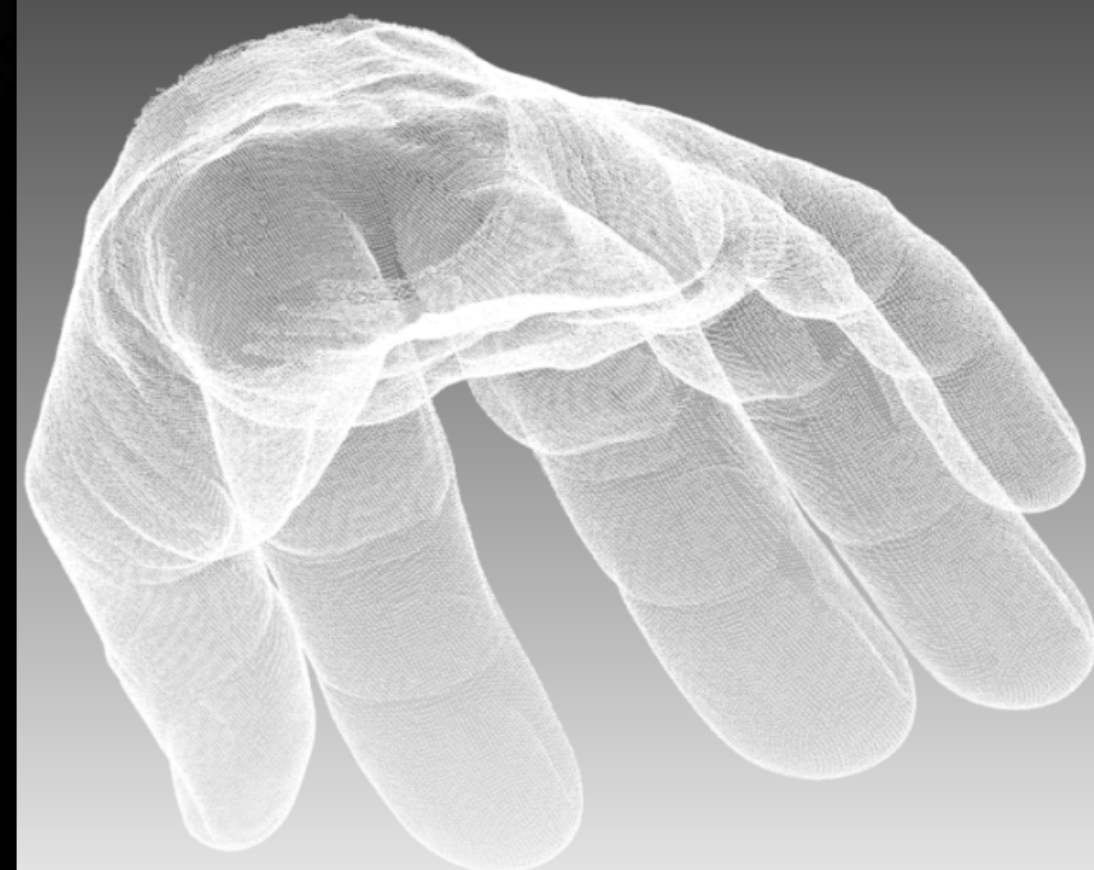
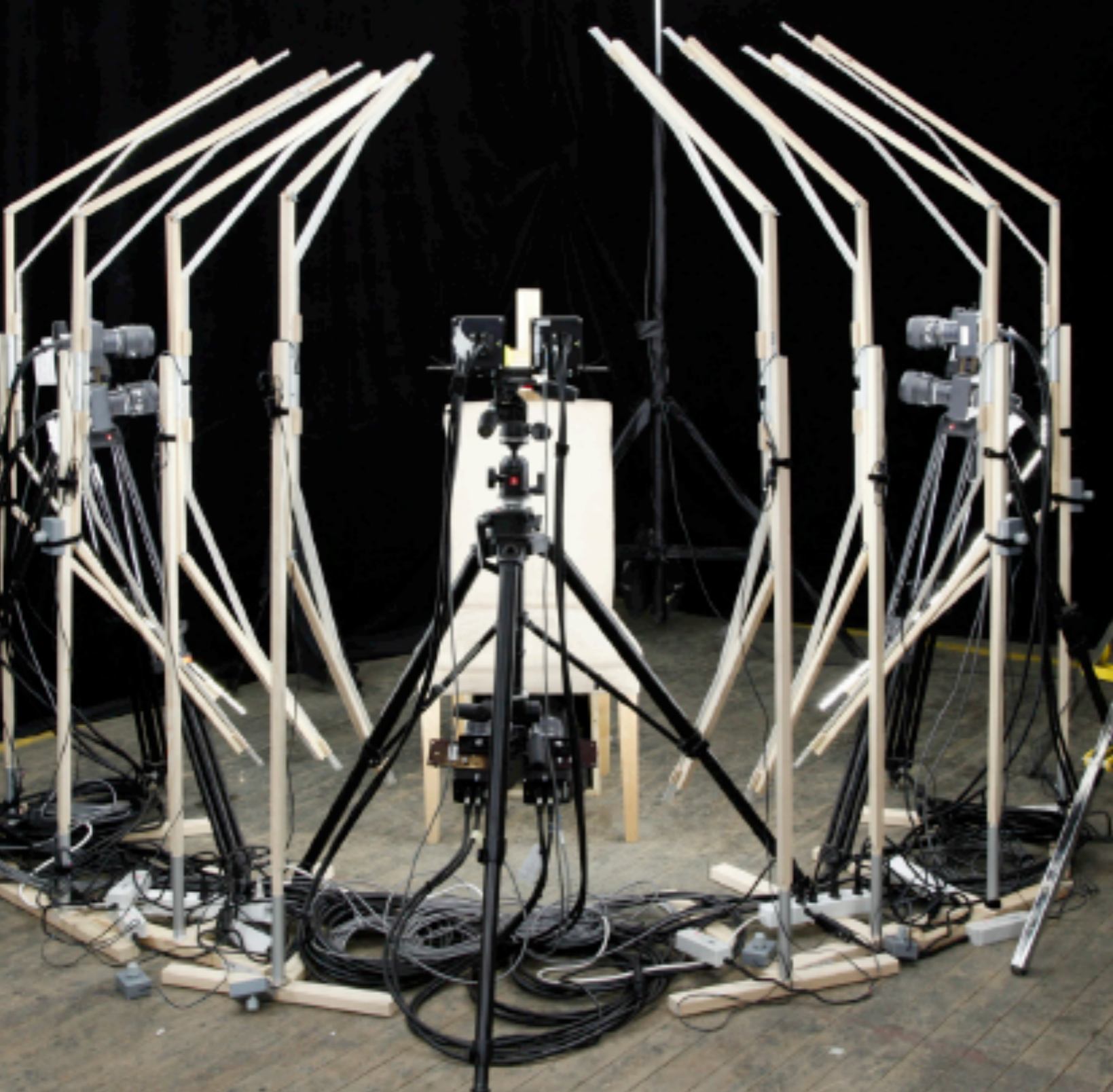


2011a

Diffusion artistique



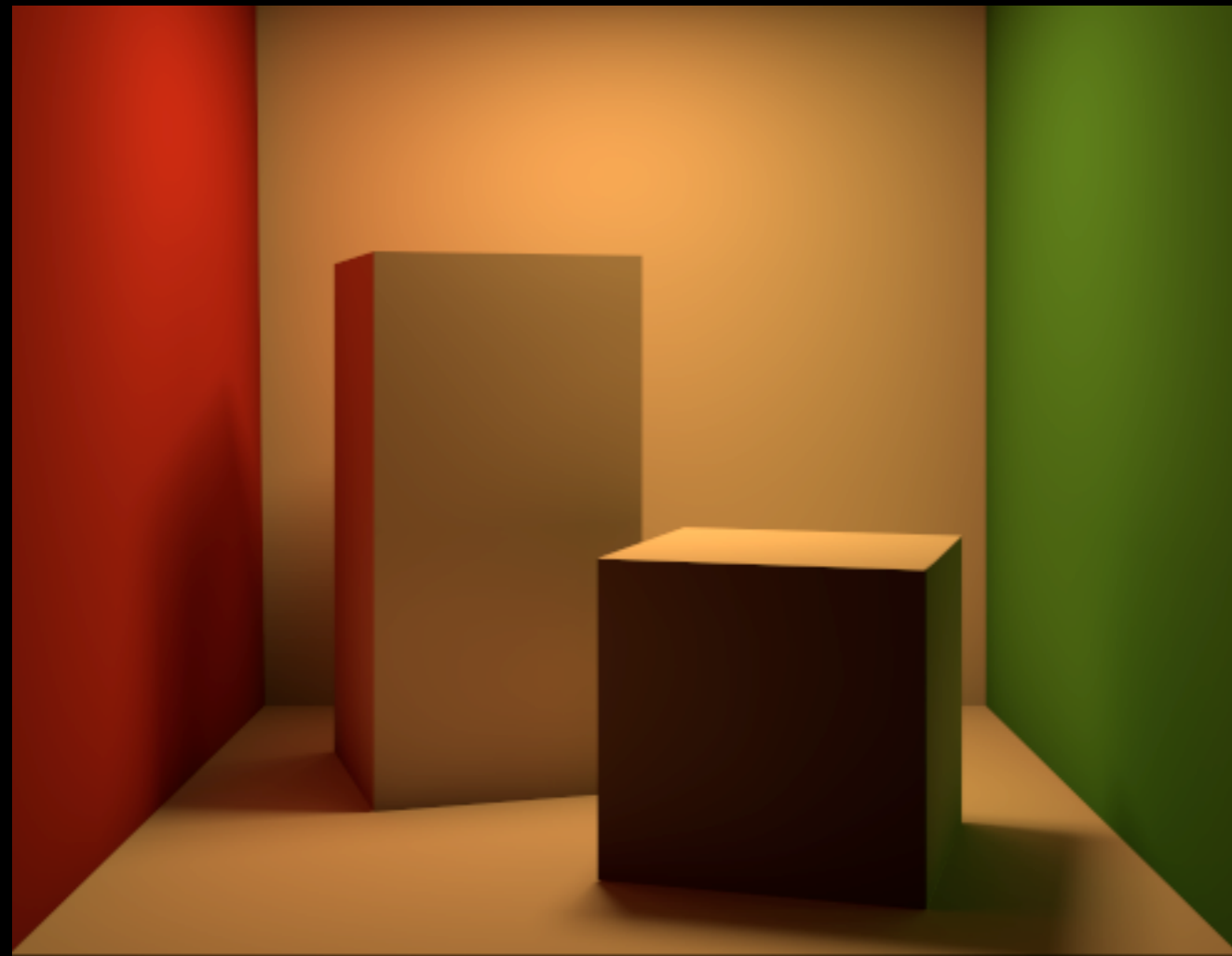
©Disney Enterprises, Inc.



Capturer le monde réel
avec la lumière

Les données alimentent l'innovation

La disponibilité des objets virtuels de haute qualité nous pousse à **innover** afin d'améliorer le **réalisme**



Marriage entre les données et la simulation



La lumière comme outil de capture

Peut-on remplacer la modélisation manuelle en



controllant et en interprétant la réflexion de la lumière



2014a

Capture de visage



**géométrie de haute
qualité**



**données radiométriques
pour le rendu**



2014a



Travaux futurs

1. Où et comment peut-on tricher?



Rendu hors ligne

Temps de rendu : **8m18s**

Mémoire : **1.28GB**



Notre approximation interactive

Temps de rendu : **16ms**

Mémoire: **300MB**

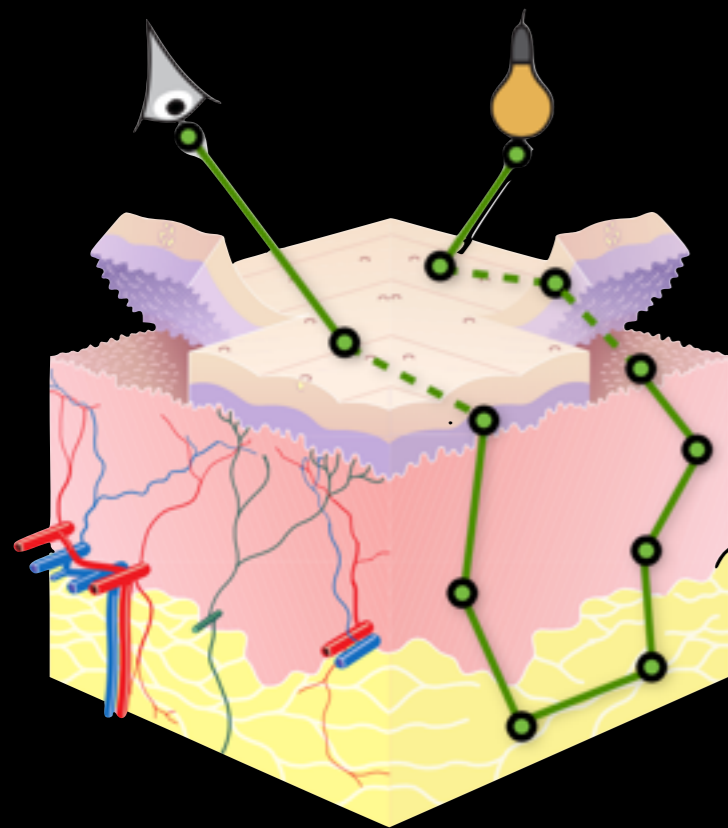


Radiosity Results

DIRECT + AMBIENT X AO

HPG
2014

2. Capteurs de profils de diffusion passifs



3. Reproduire la réalité – apparence et au-delà



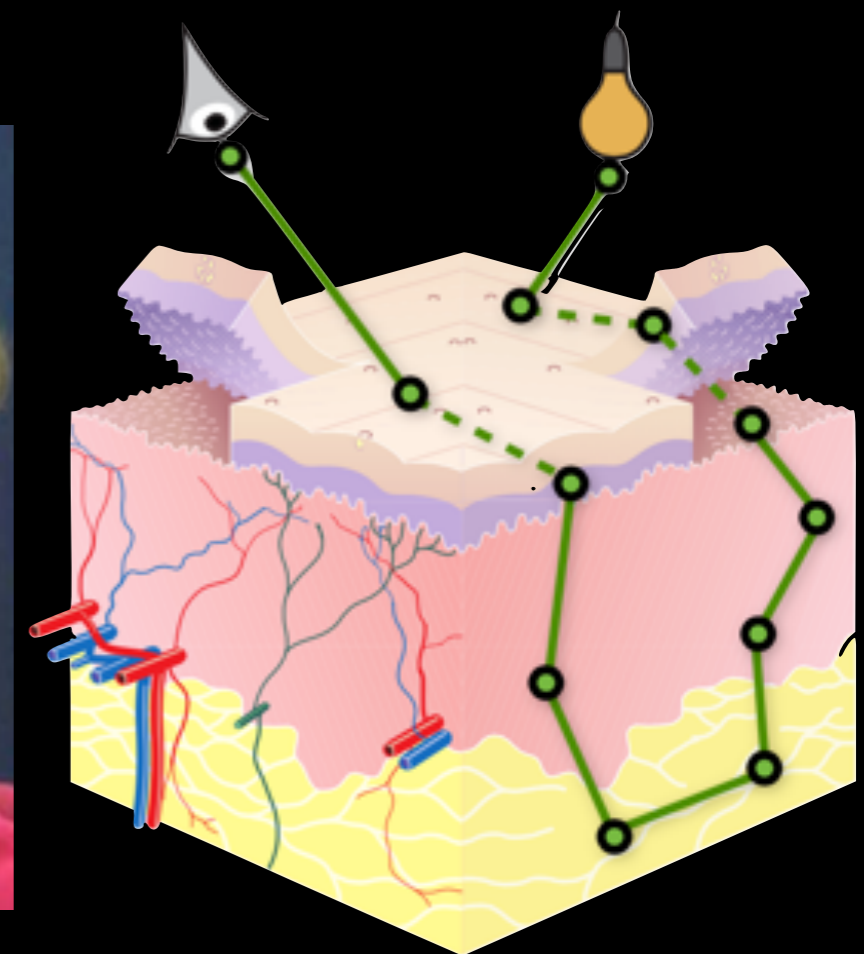
[Papas et al. 2013]

2. Capteurs de profil de diffusion passifs

La disponibilité des paramètres de réflexion pour des matériaux inorganiques a facilité notre compréhension

Avez-vous déjà vu un acteur virtuel avec un rendu qui était véritablement convaincant?

- la capture non-invasive de profil de diffusion venant des objets organiques nous aidera à plus rapidement atteindre cet objectif



3. Reproduire la réalité – apparence et au-delà



3. Reproduire la réalité – apparence et au-delà



Greg Petchkovsky

3. Reproduire la réalité – apparence et au-delà



Greg Petchkovsky

... avec du prototypage interactif

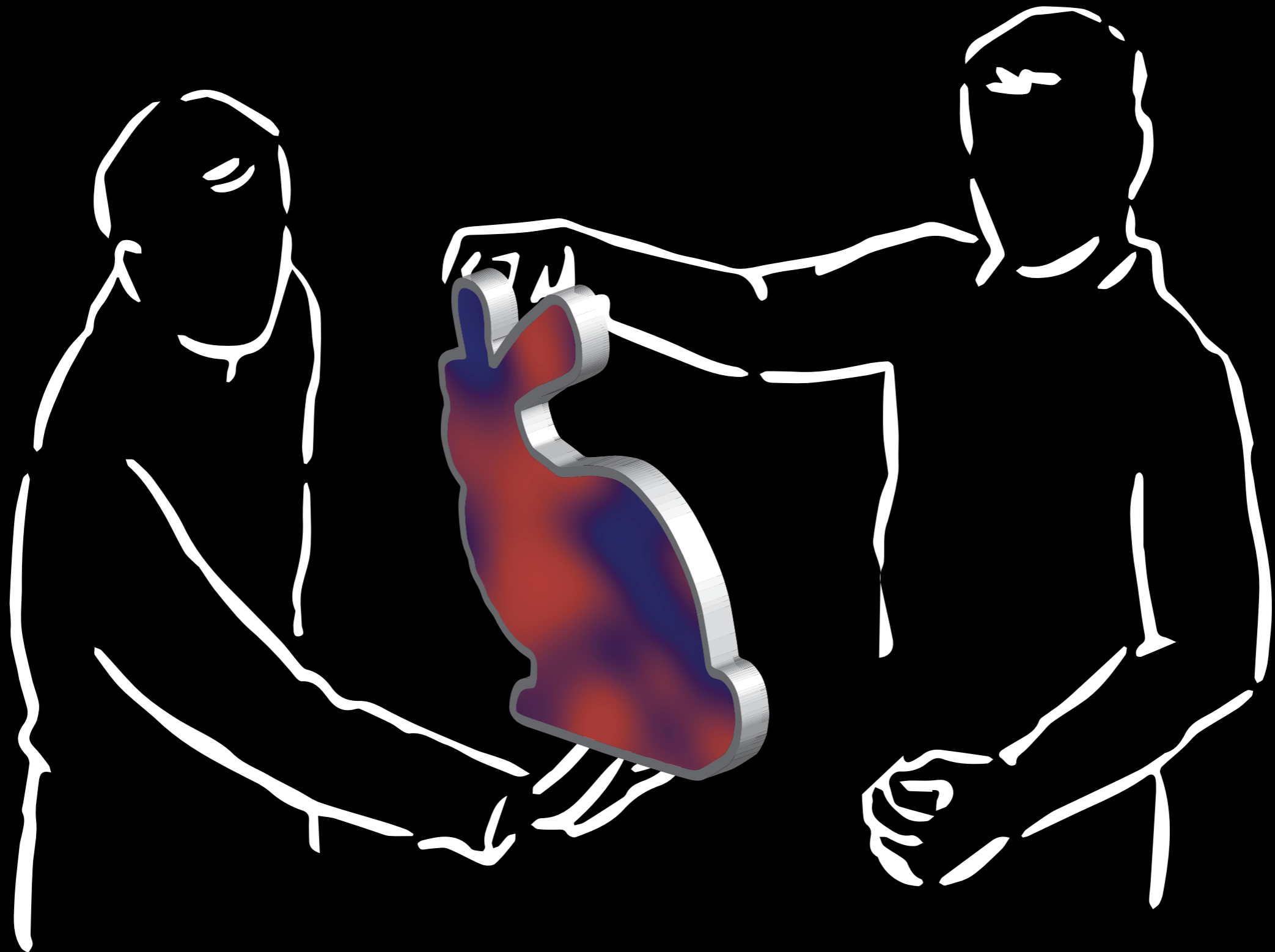
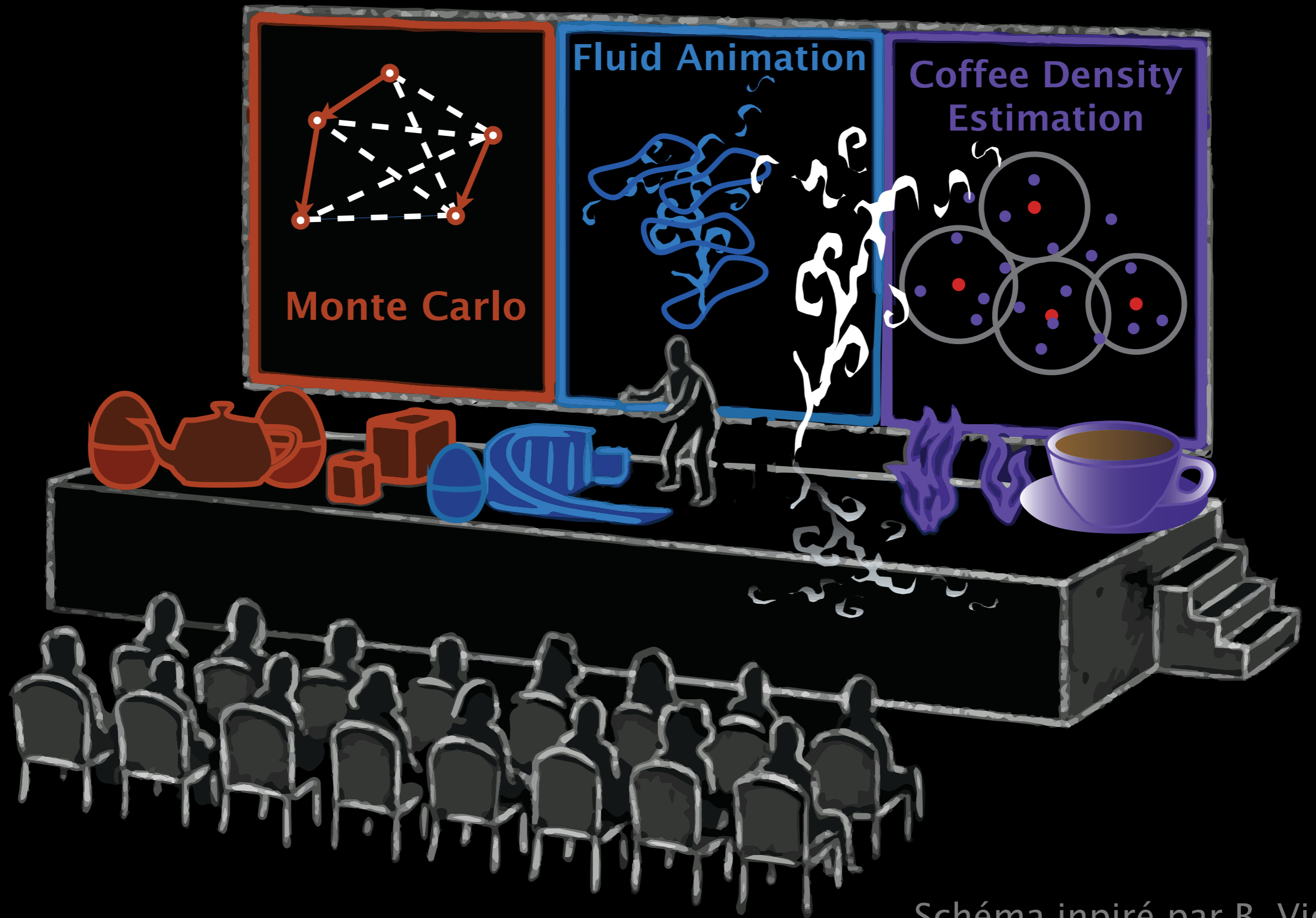


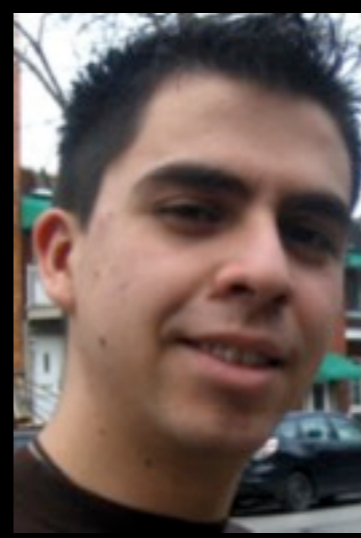
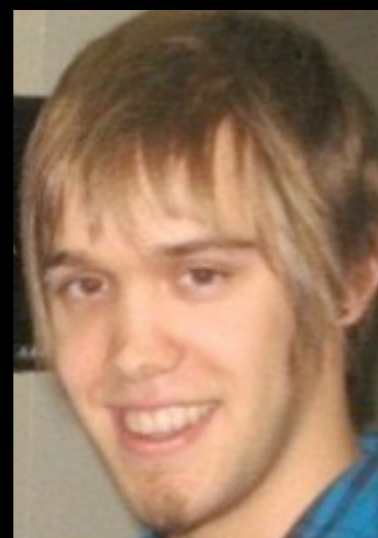
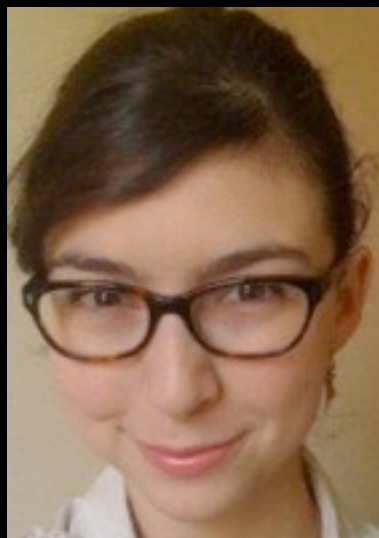
Schéma inspiré par B. Victor

Communication par création



Équipe de recherche

Université 
de Montréal



Collaborateurs et leurs institutions



Merci et bonne soirée

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