VISTA - ***Visual Worlds***: *Temporal Analysis, Animation and Authoring*
LIX / CNRS, EPX

ÉCOLE POLYTECHNIQUE
*IP Paris*

# *Creative Graphics for Scientists*

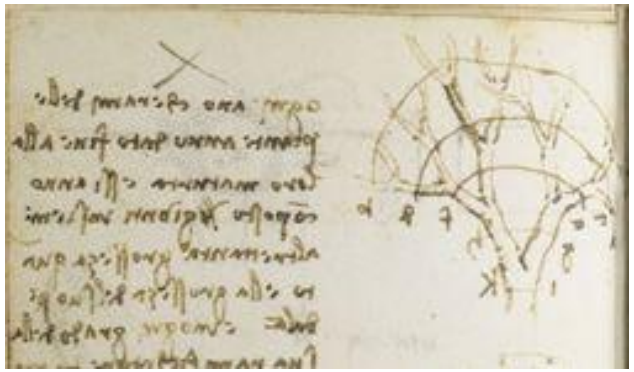
## *Could we use CG to support scientific thinking?*

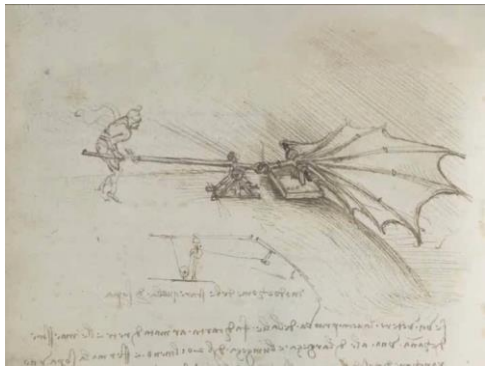
Marie-Paule Cani

Ecole Polytechnique, IP Paris, France

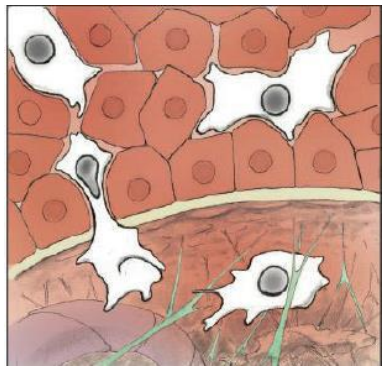
# *Motivation : Visual representations*

*Mandatory to understand and create!*





@ Leonardo da Vinci



@ Renaud Chabrier

**Representations in science**

- Help structuring ideas
- Increase the intuition on a phenomena

**But drawings are limited**

- 2D depiction only, for 3D+time
- Editing is difficult (only eraser!)
- Impossible to interact

# *Using digital images for scientific thinking?*

## Reconstruction of captured data

- Only shows a specific instance
- No possible interaction
- Does not help for abstraction

## 3D modeling software

Multiple trials and errors

- Vision from a scientist
- Explained to a trained artist

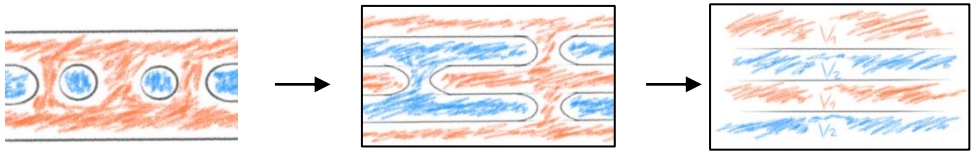
→ Tedious work

→ **Sterile, 3D illustrations**

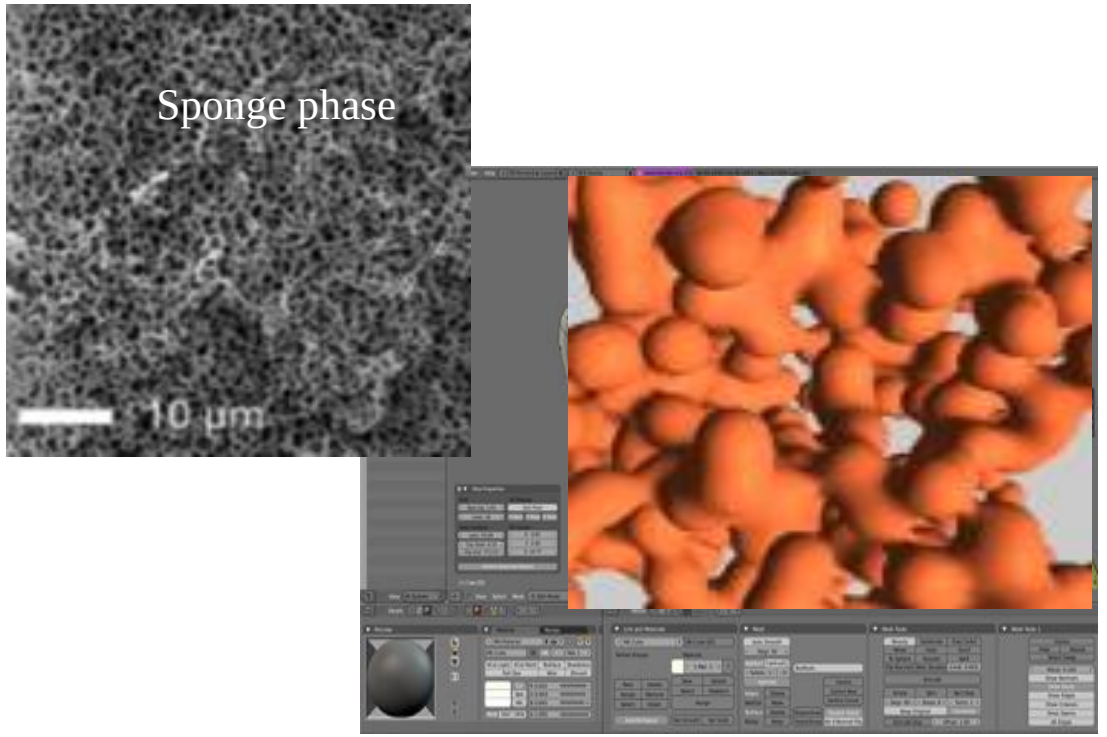
The scientist cannot interact & refine them !

**Example with Didier Roux, physicist**

Phase changes in liquid mixtures



Isolated bubbles → Sponge phase → Strip phase



# *In this talk : Creative Graphics*

## *Can **3D modeling** be extended to **Visual testbeds** in science?*



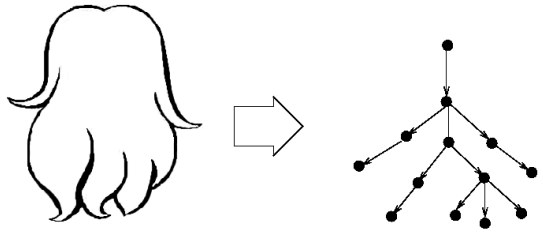
- Methodology
  1. **Interactive simulation** : Multi-models, embedding **knowledge**
  2. **Expressive design of shapes & distributions** (need to **learn** from examples)
  3. **Extension to animation, narration, …**
- Applications: from geology, ecosystems, paleontology…. to biology!

# *Challenge 1 : Interactive simulation?*
# *Multi-models, embedding knowledge*

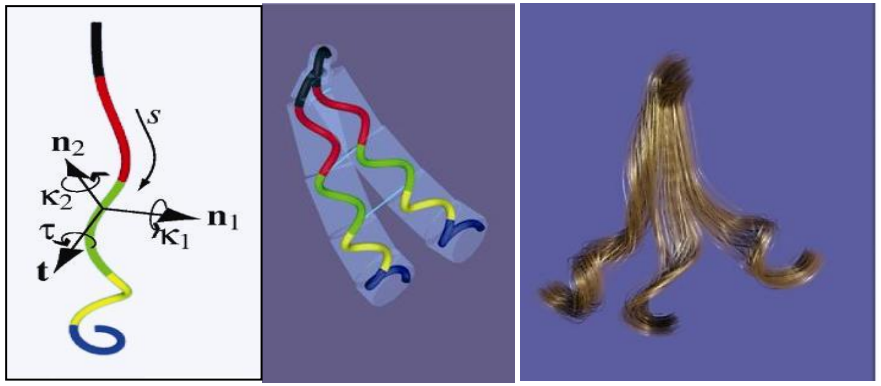
Specific methodology

**Decompose the problem**

- For each sub-phenomenon
  - ✓ Find the best representation
- Couple sub-models
- Adapt them to the needs
  - ✓ Space & time sampling
  - ✓ Switching models



Adaptive Wisp Tree



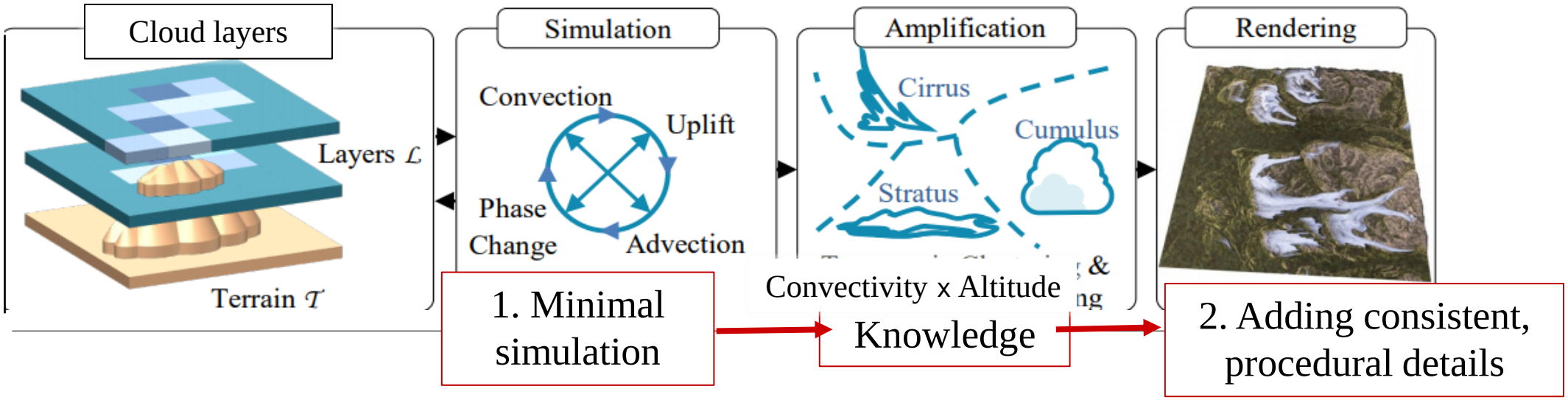

Super-helices Wisps Geometric strands

# *Recent application: Interactive simulation of skyscapes*

**Atmosphere :** difficult to simulate!

- Fluid (+ temperature, + moisture), interacting with water bodies & terrain (**wind**)
- Huge simulation domain (50 km² x 10km)
- Fine sampling to capture **clouds** -- water vapor condenses in moisture-saturated air

**Our solution: Multi-model**

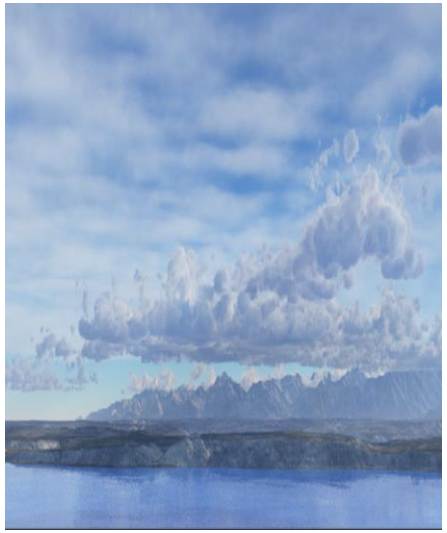


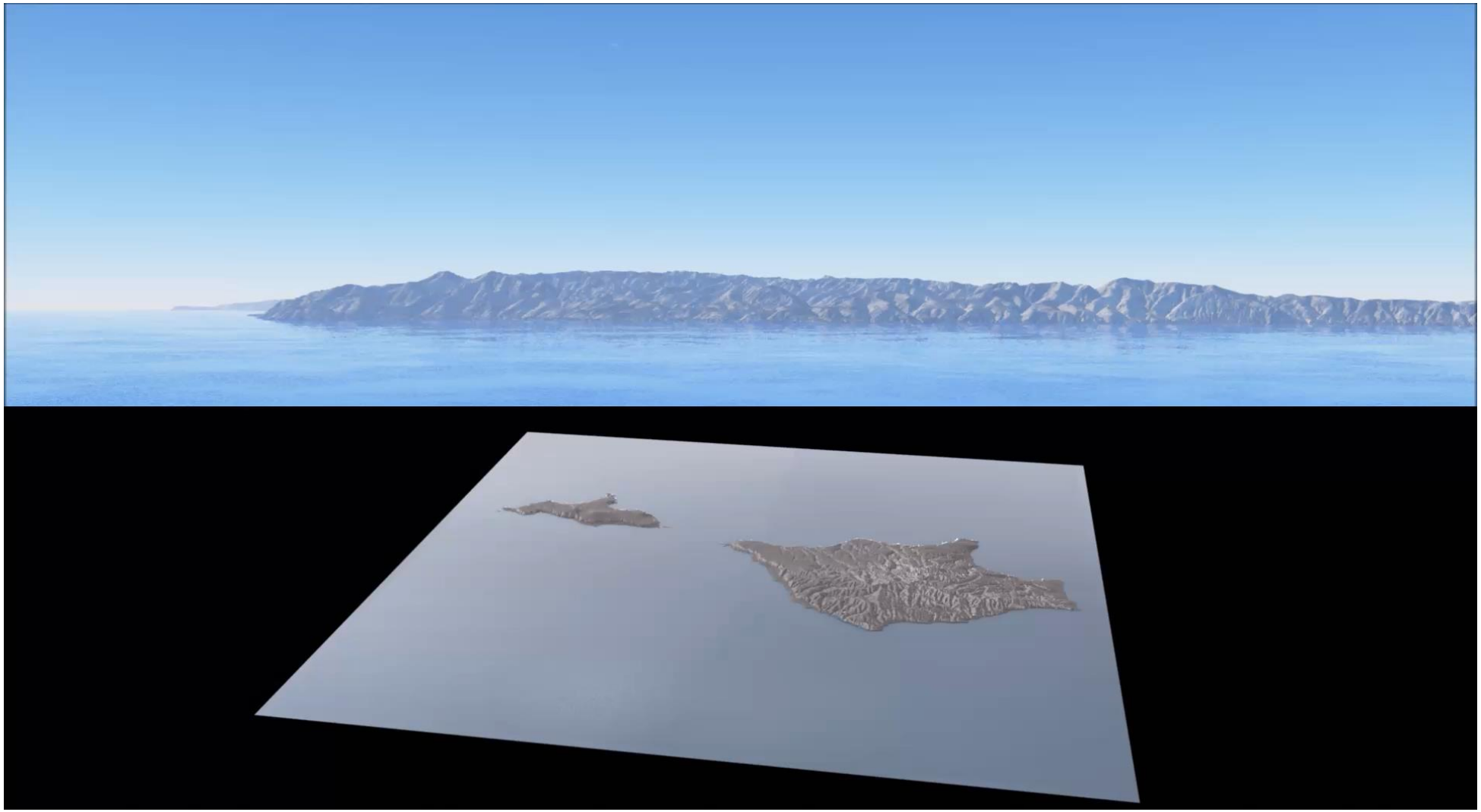
# *Results: Skyscapes with wind & clouds*

*[Vimont EG 2020]*

Simulation 5K cells
- terrain 50km$^2$
- 4 cloud layers
(10km)

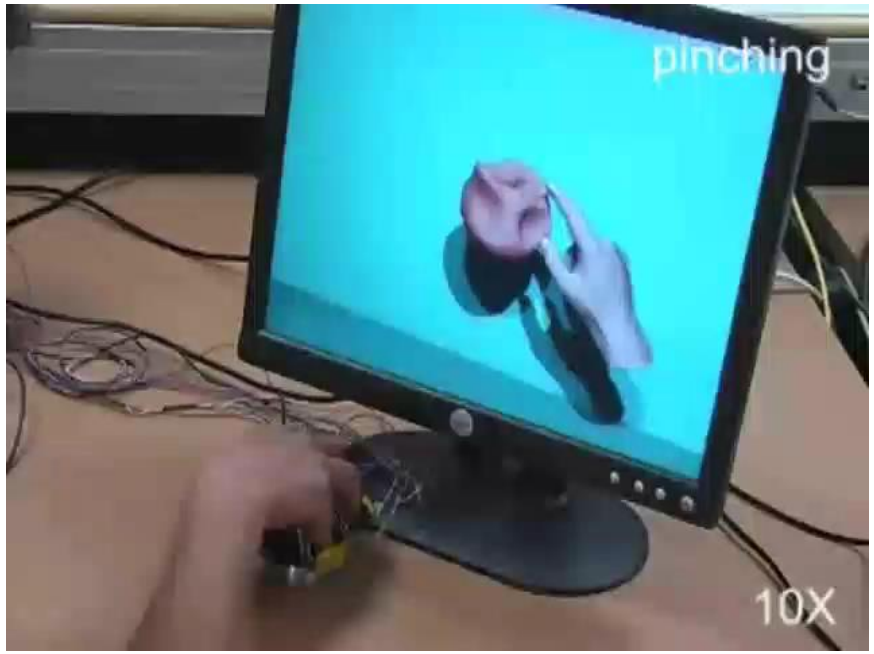
Interactive results
- 3 sec per frame





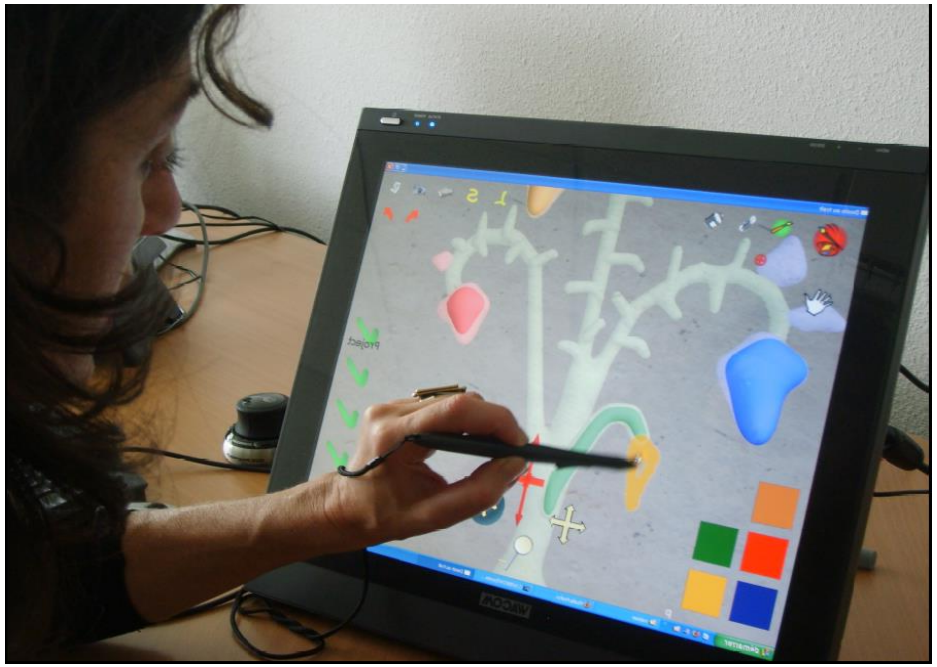
- **Islands:** Convective uplift → Cumulus
- **Windy mountains:** Dynamic uplift → Stratus

# *Challenge 2: Flow in digital creation?*
# *Expressive shape design, based on intuitive gestures*




**Sculpting virtual clay**

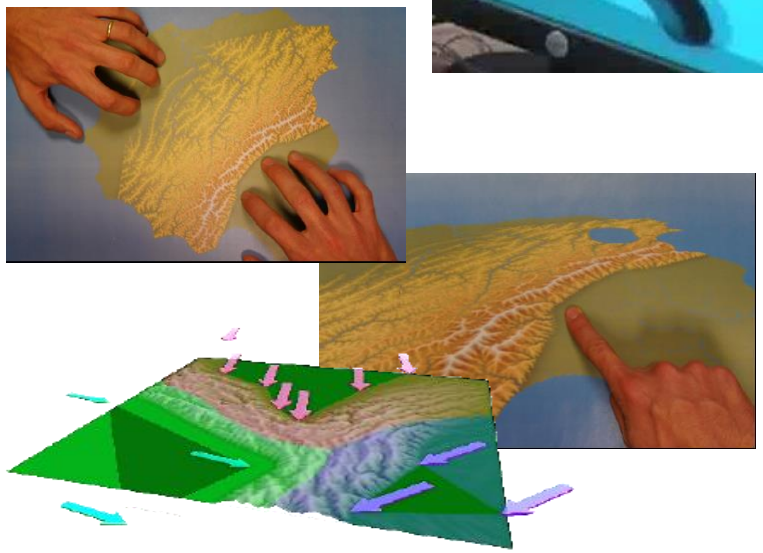
*Layered clay model + Hand navigator*
*[Dewaele 2004- Kry 2010]*



**Sketching in 2D to create in 3D**

*« Matisse » [Bernhardt 2008- Zanni 2013]*
*https://www.lix.polytechnique.fr/vista/software.html*

# *Expressive design of mountain ranges?*
## *Collaboration with Jean Braun (morphogeologist)*



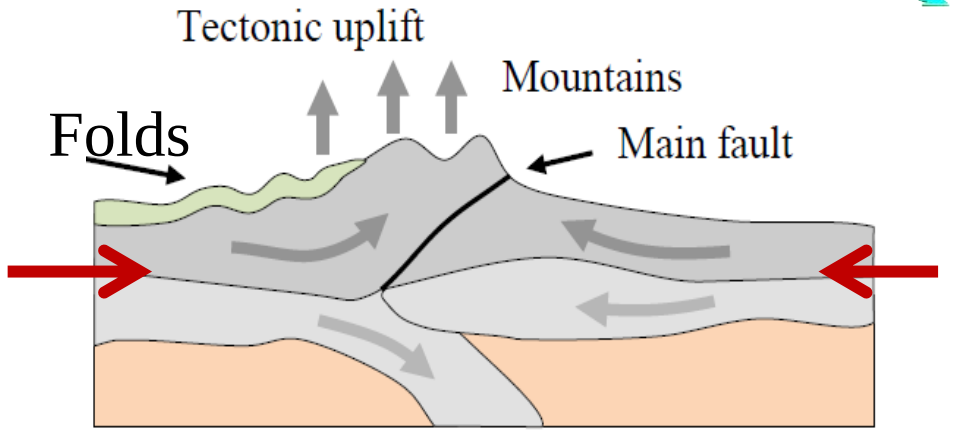
Could we sculpt mountains as if they were clay?

- Using a multi-touch table!

Collision between volumetric, tectonic plates

- Constant volume
- Folding layers

→ Vertical uplift



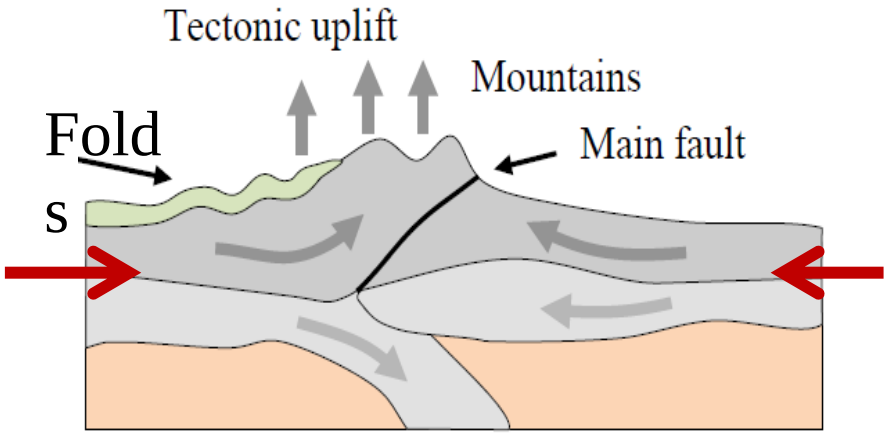

Erosion during uplift!

# *"Sculpting mountains"*

## *Sculpting metaphor on a knowledge-based multi-model….*

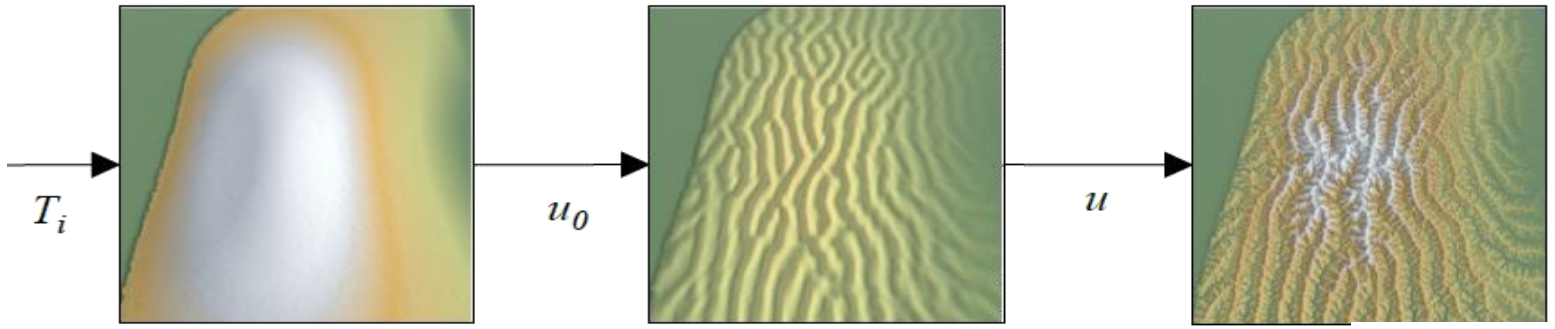
Sub-phenomena

- Constant volume
- Folds - wavelength fct of thickness!
- Erosion on top of uplift




Volumetric earth-crust model

- A multi-model coupling these phenomena



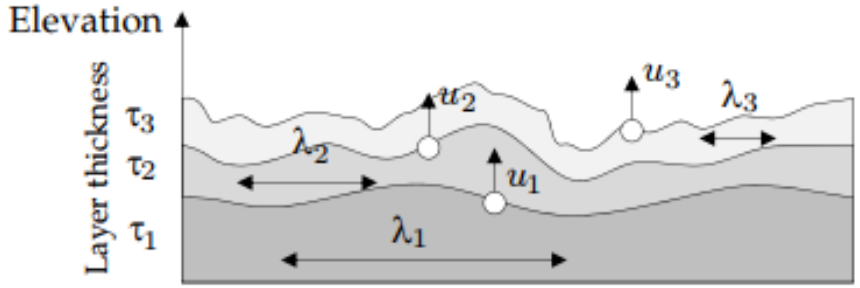

Crust as plastic material  Crust as layered sheets  Terrain (uplift + erosion)

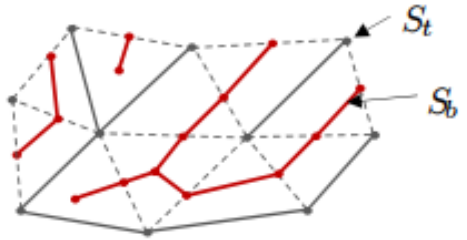
# *“Sculpting mountains”*

## *Collaboration with Jean Braun (morphogeologist)*

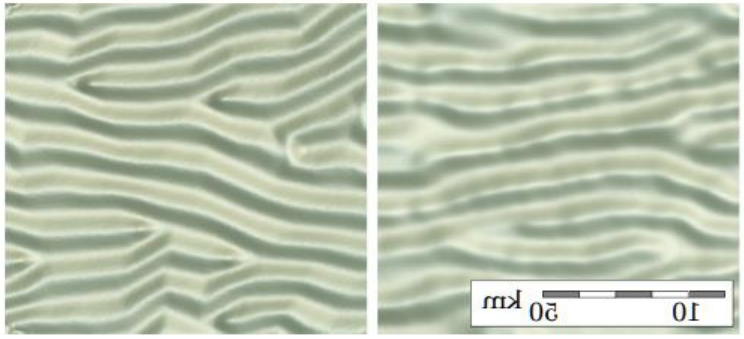
### *Procedural folding behavior*

- Fct of thickness & viscosity of sheets
- Can be computed procedurally!




→ Procedural modeling of fold skeletons over a mesh



← Simulation in Geomorphology

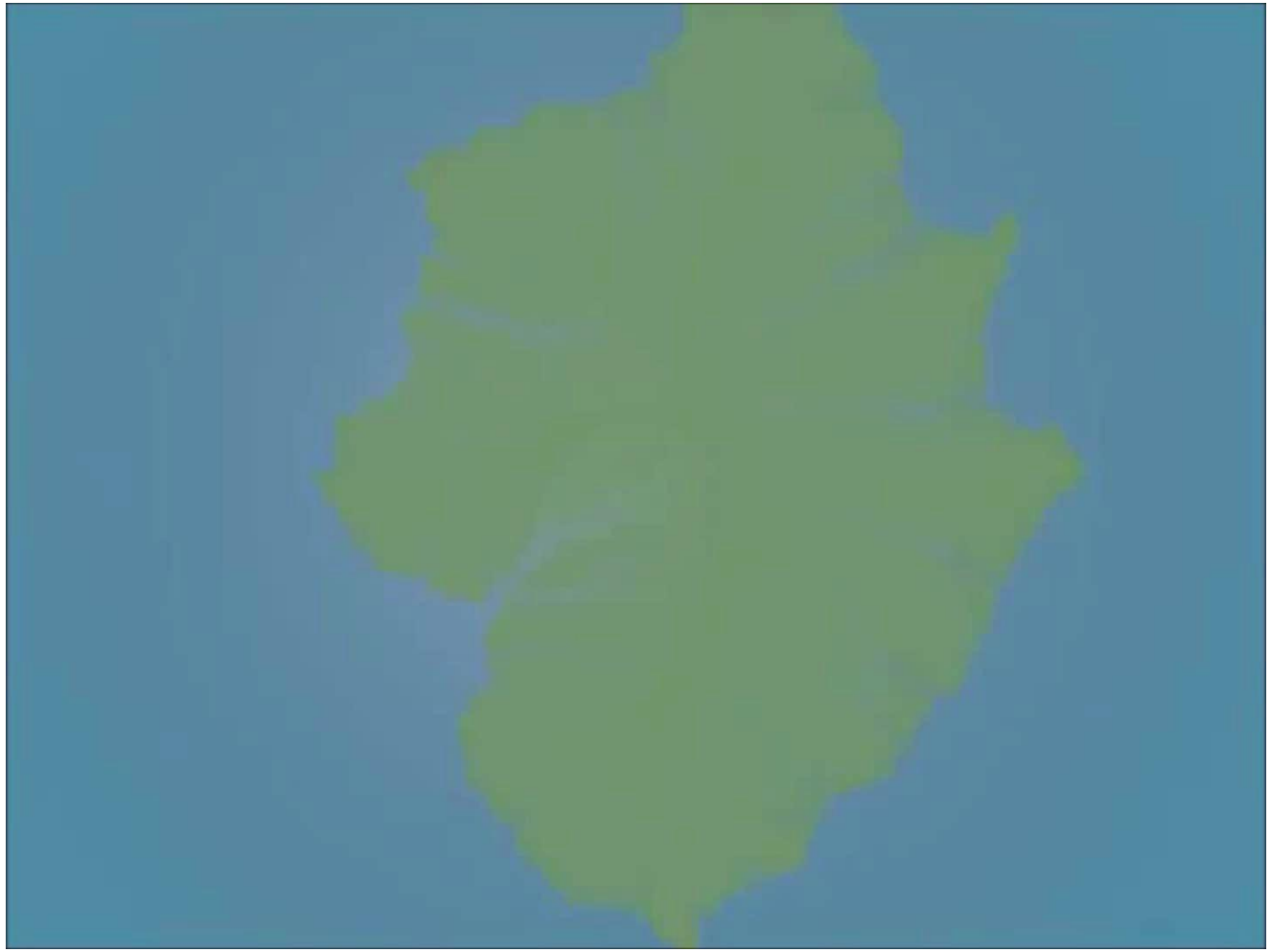
# *Sculpting mountains: Results*

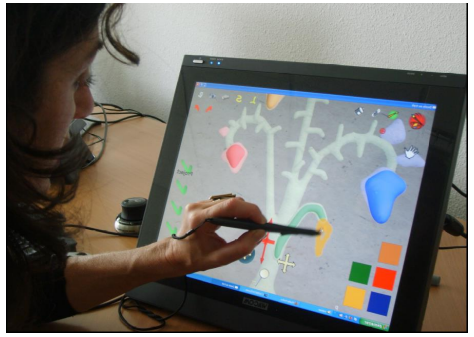
*[Cordonnier et a. IEEE TVGC 2018]*

Sculpting & display:

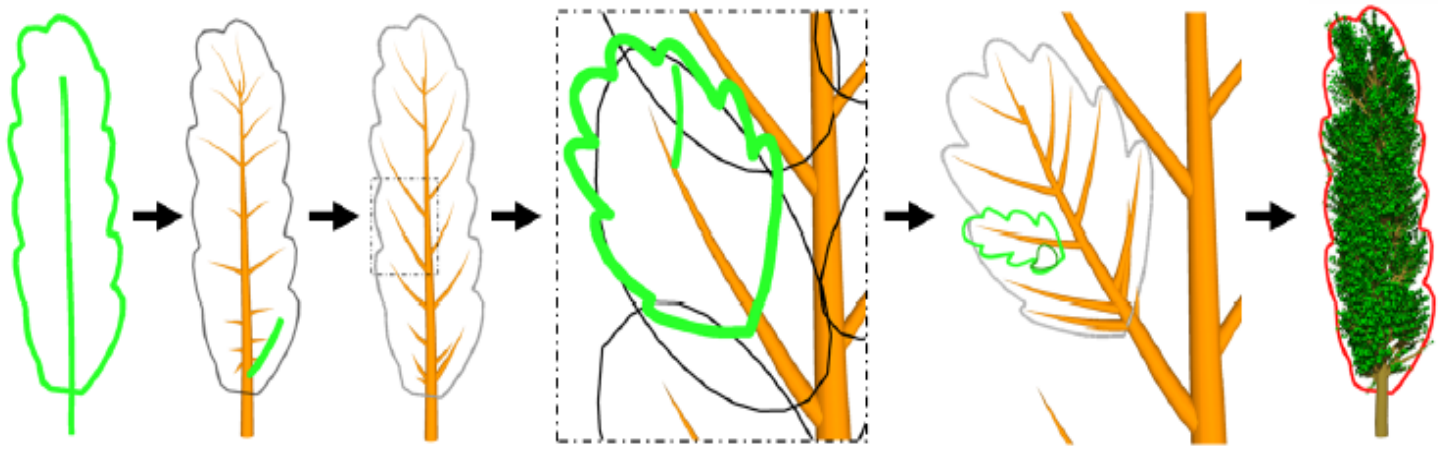
- multi-touch cube!

Salient soil layers on eroded cliffs





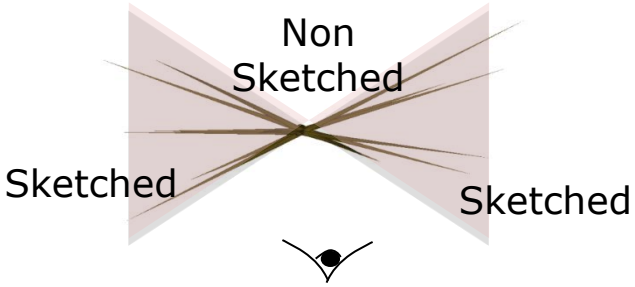
# *Sketching a biologically valid tree?*
# *Collaboration with CIRAD*



Inspirations
- Art
- Biology

Idea: Structure from silhouette!

→ build on **multi-resolution sketches**
- **Add knowledge**: perception, biology …



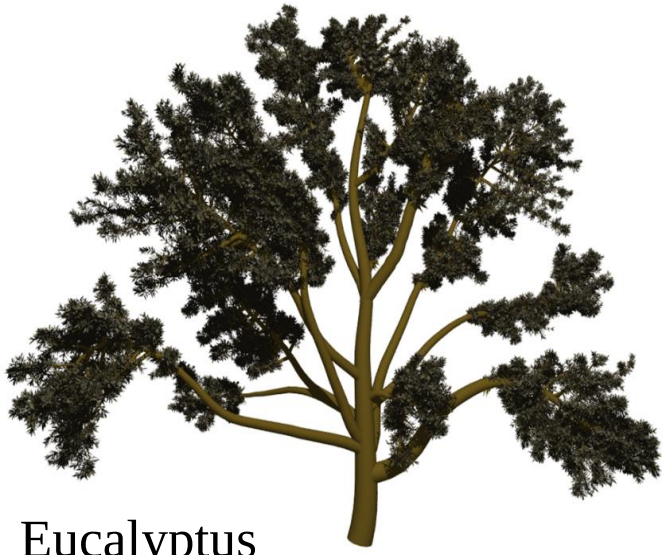

Plants phyllotaxis

## *Sketching + knowledge?*

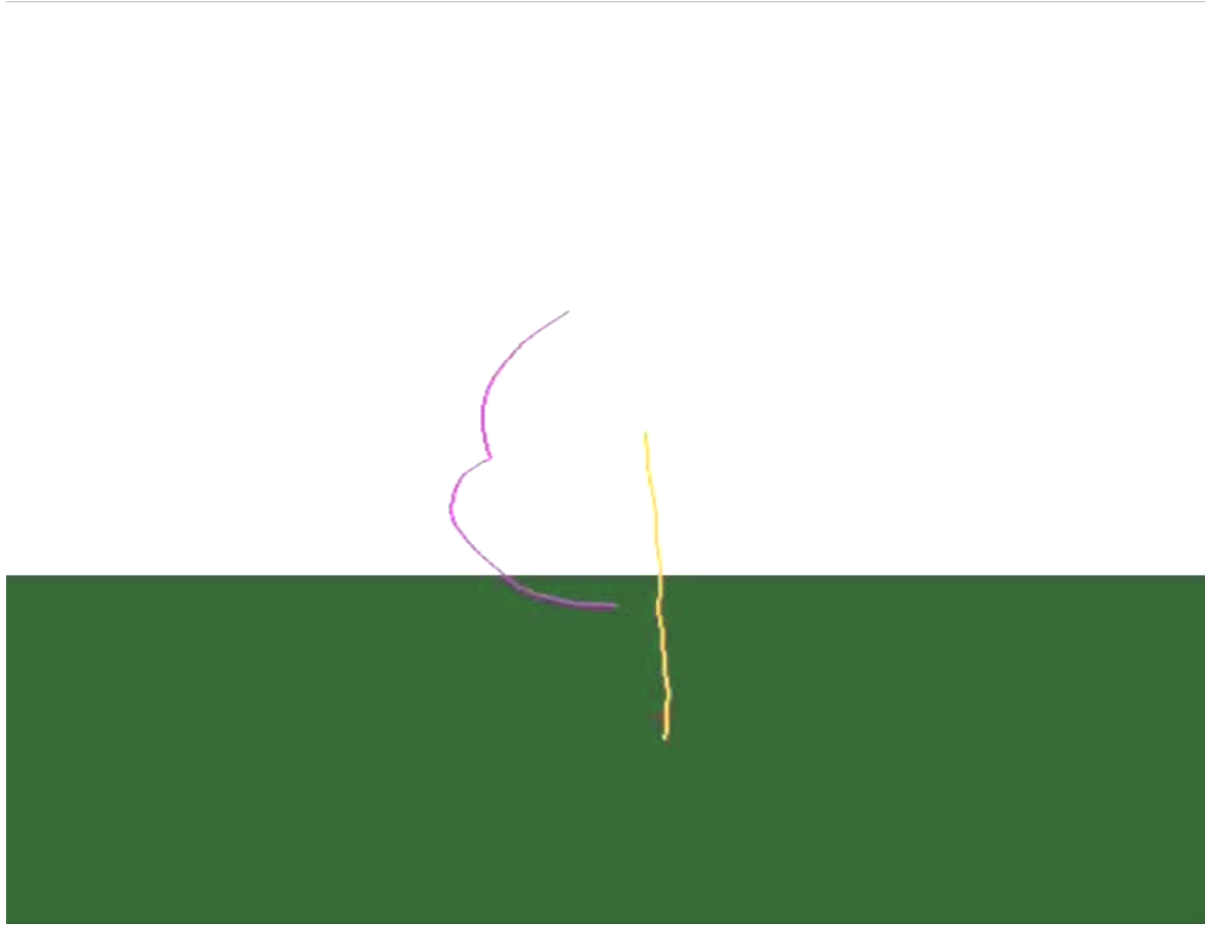
## *Example: designing a tree*

*[Wither et al. Eurographics 2009]*

- Results



Eucalyptus



**Statistics for sub-branches to be learnt!**

- Generalizing from sparse user input?

# *Expressive design of shape distributions?*

## *« Light learning » from examples*

**Nature is full of details**

- Too many elements for us to sketch them all

Fortunately, there are heavy self-similarities!

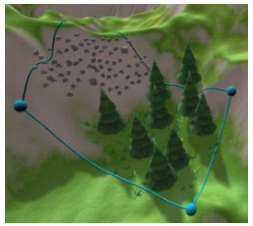
→ **Learning consistent distributions?**

- Light learning from
  - ✓User-defined examples
  - ✓Simulation results

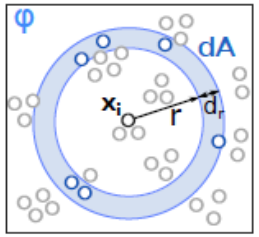
# *Light learning from examples?* *"World brush"*

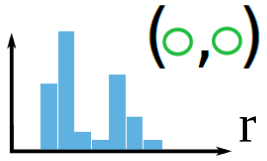
**Goal:** Designing consistent distributions of vegetation & rocks

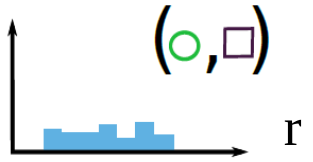
- Learning from **a single** user-defined exemplar



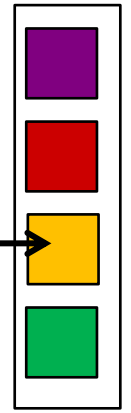
Learning



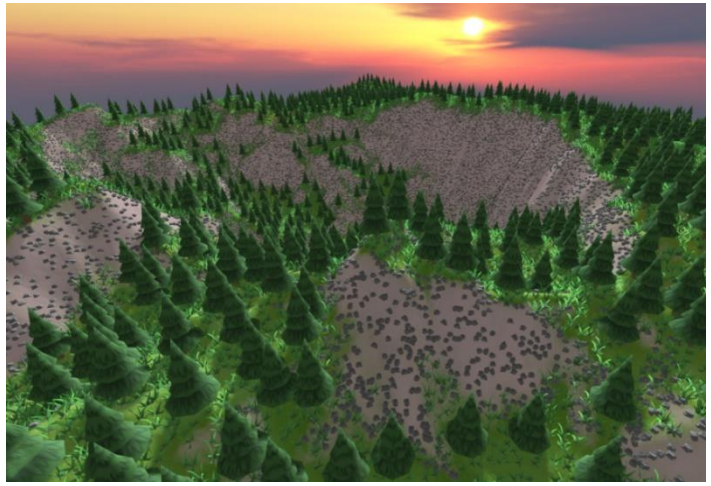




Distribution stored in a "palette"



- Color = {Statistics on distributions of objects}
  + correlations with slope, rivers, etc



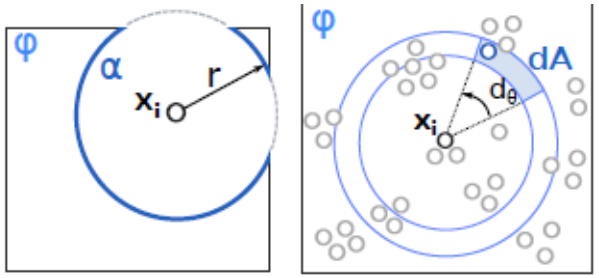
**Expressive design**

- Pipette + Painting + gradient
- Sculpting & Transfer tools

# *Result: Expressive design of consistent distributions*

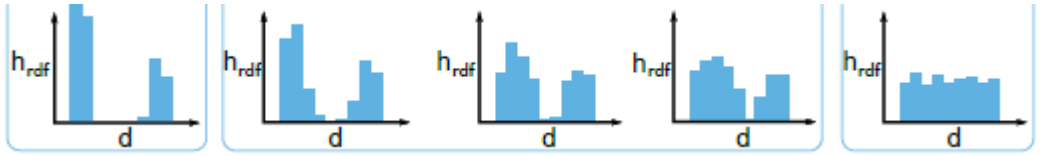
## Contributions

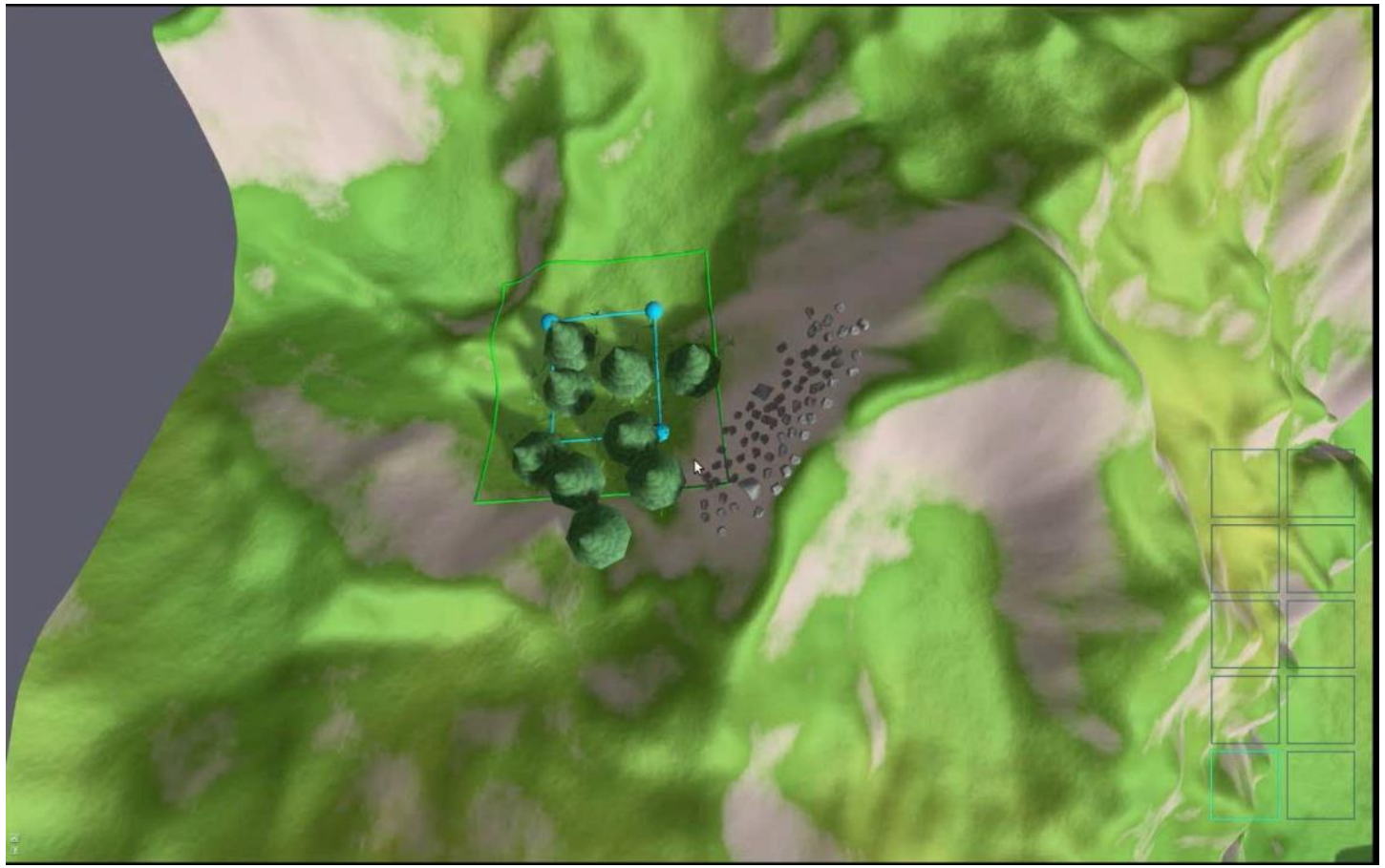
- Handling small examples
- Angular distributions




- Distributions “gradient”

Optimal mass transport!

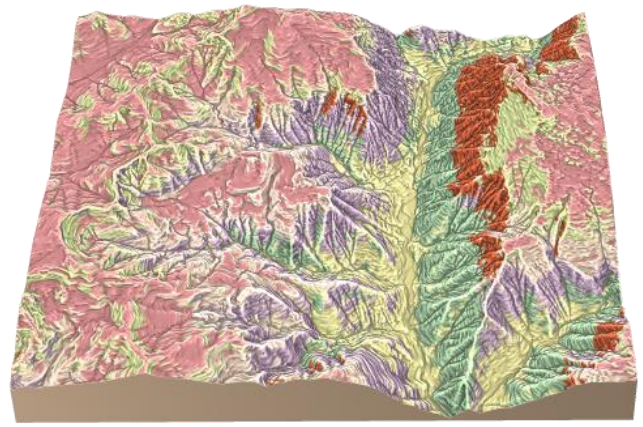


*[Emilien et al. SIGGRAPH 2015]*

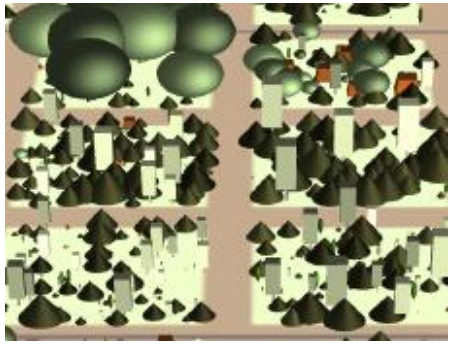
# *Realistic ecosystems ?*

# *Learning from Simulation results !*

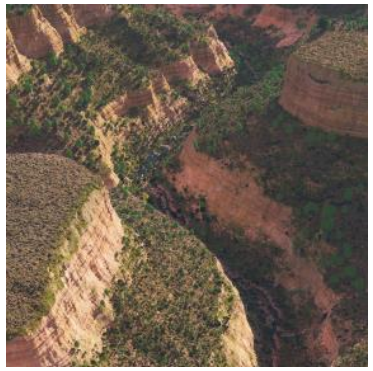


Idea: Combine simulation with world-brush

- Multi-dimensional terrain clustering
- Sand-box ecosystem simulation for each cluster
- Learn statistics
- Synthesis: Semantic brushes: age, density…



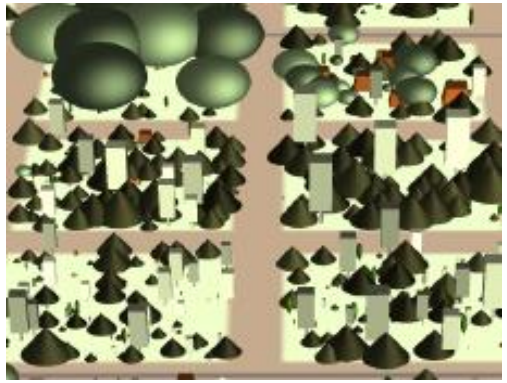
Sand-box
100x100m



*[Gain et al. EG 2017]*

# *Realistic ecosystems ?*

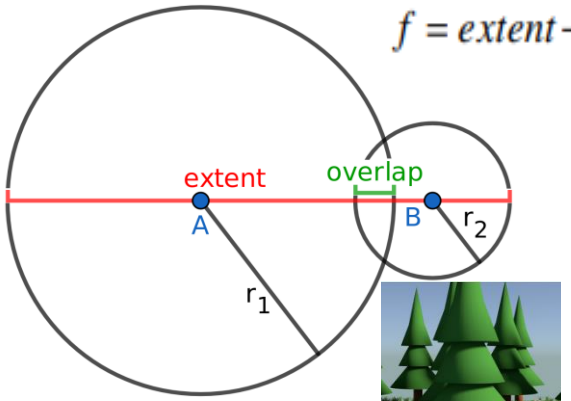
# *Learning from Simulation results !*



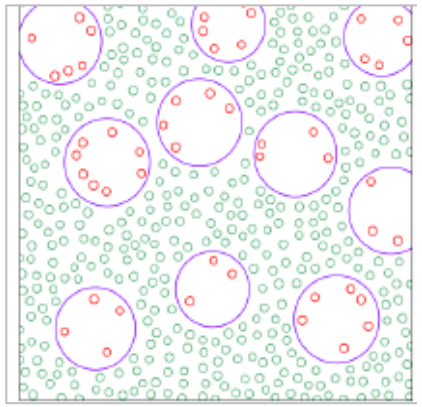
## Challenge: Distributions of overlapping discs!

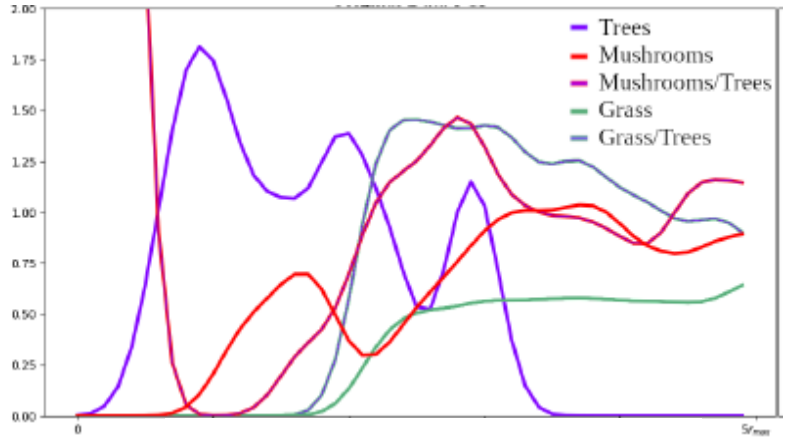
- Extend Pair Correlation Functions (PCF)
- A new, normalized metric for disks $f_{norm} = normalize(f)$

  → Distinguishes disjoint ($f_{norm}>3$), tangent ($f_{norm}=3$), overlapping, nested ($f_{norm}<1$)




$$f = extent - overlap + d + r_1 - r_2$$






Pair correlation functions

*[Ecormier-Nocca at al. Eurographics 2019]*

# *Application to Visual testbeds in sciences ?*

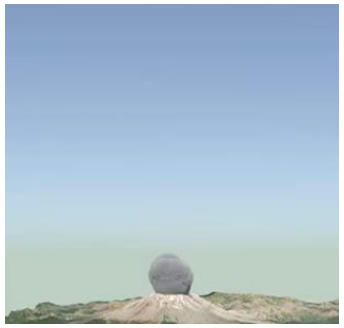
→ Allow scientists to share, refine and interact with the visions they have in mind!

**Our scale…**

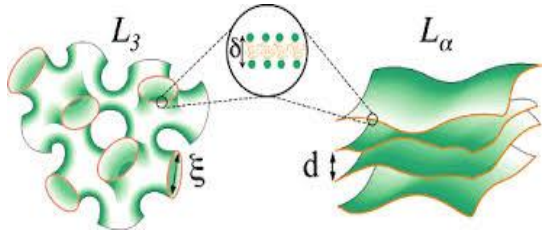
Ecosystems

Geology

Volcanology



**Other scales**




Physics

Biology




@Renaud Chabrier

## Creative media

1. Interactive simulation embedding knowledge
2. Expressive design of shapes and distributions
3. *Extension to the design of Animation & Narration*

# *Bio-sketch : A new medium for interactive storytelling*

## Extended distributions

- Sketching 3D environments
- Distributions of nested shapes

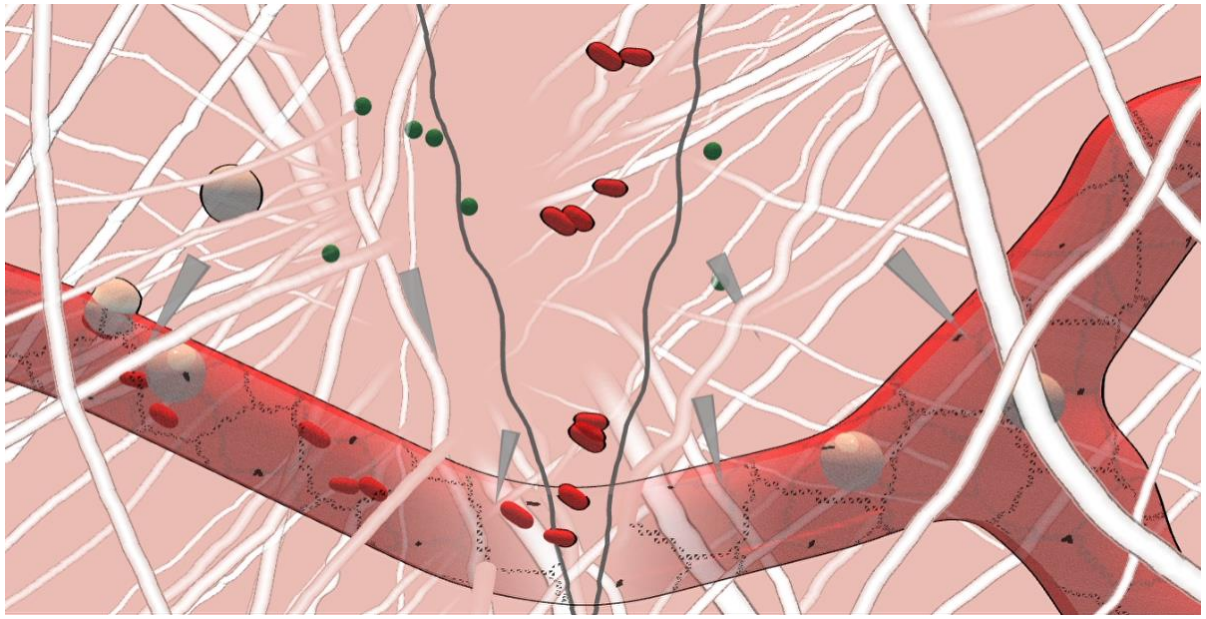
(surface, volume)

## Sketching motion

- Sketch-based motion design
- Specifying deformations

## Narrative design

- Triggering events along a timeline



Case study: An infection (cut through tissues)
**Collaboration with J-L Coll (IAB)**

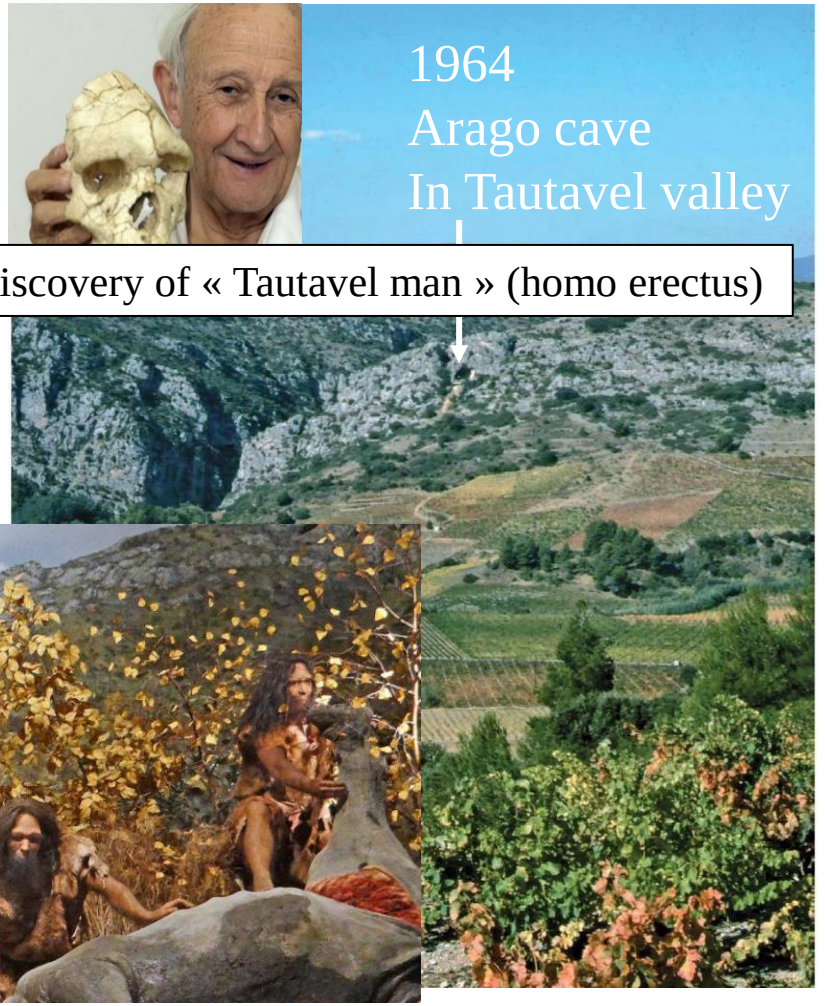
# ***Bio-sketch*** *[Olivier et al. VCBM 2023]*

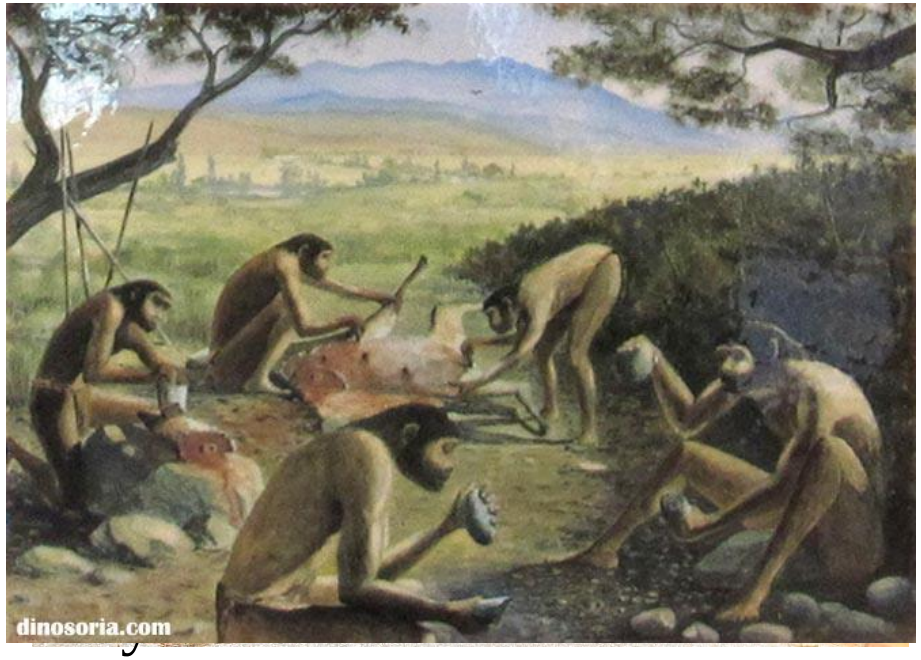
# *Application: An experimental testbed for Paleontologists?*

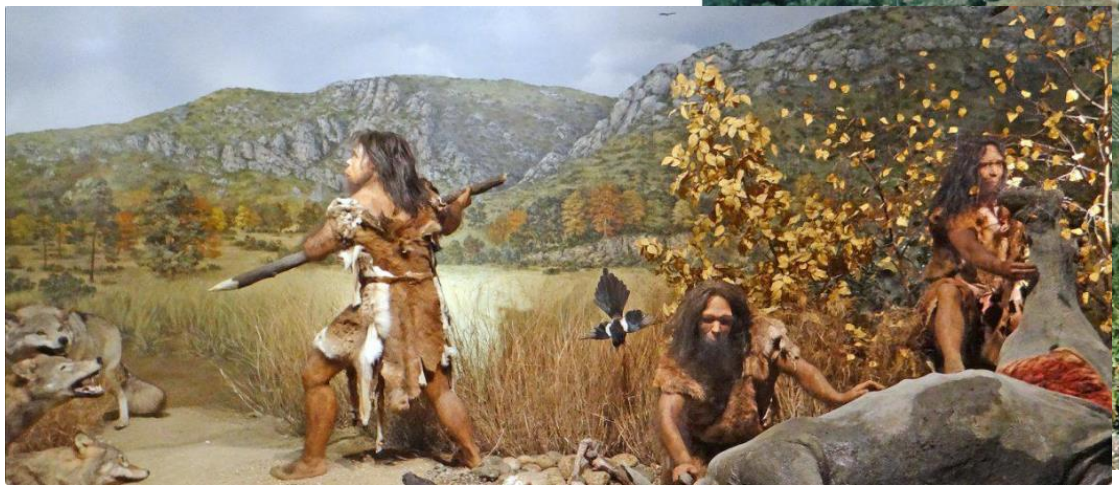
2017: Meeting **Henry de Lumley,** French paleontologist

- Pluri-disciplinary team studying past ecosystems

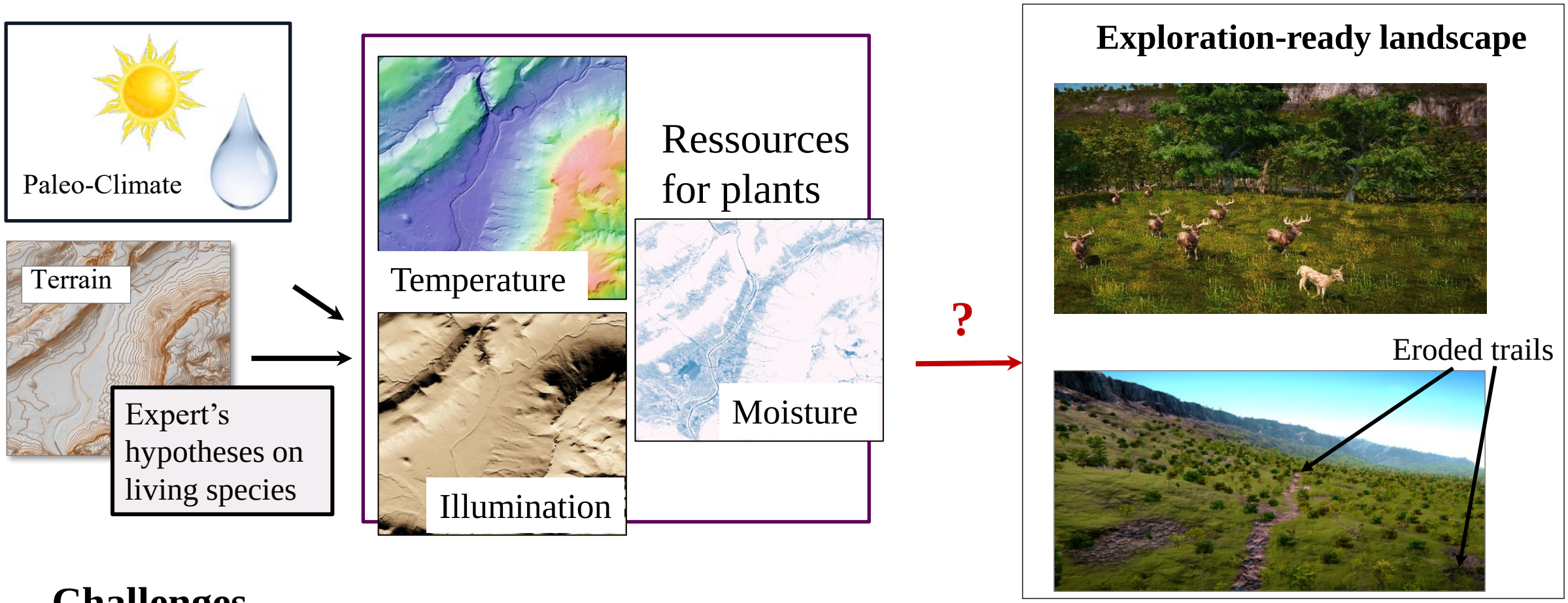
→ Can we help them **« see » their models**?



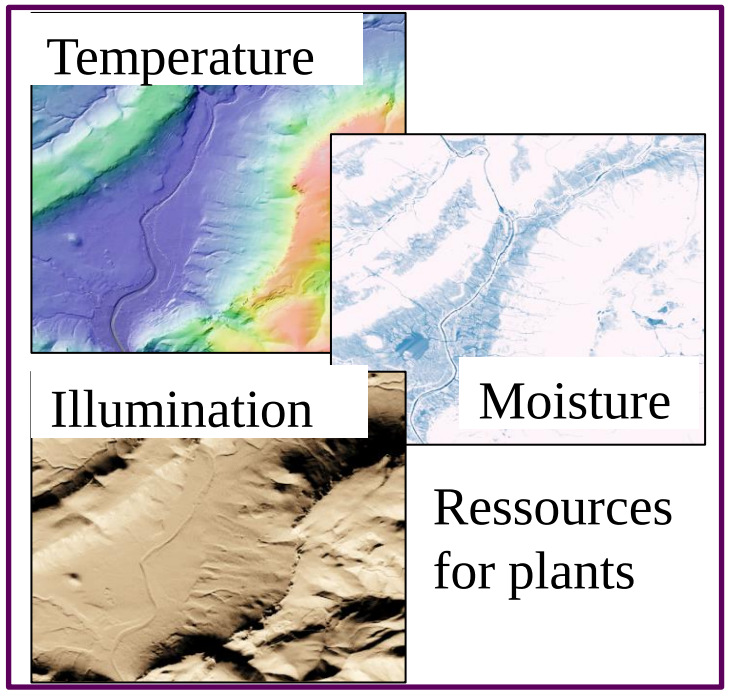
# *Authoring a consistent landscape with flora & fauna ?*

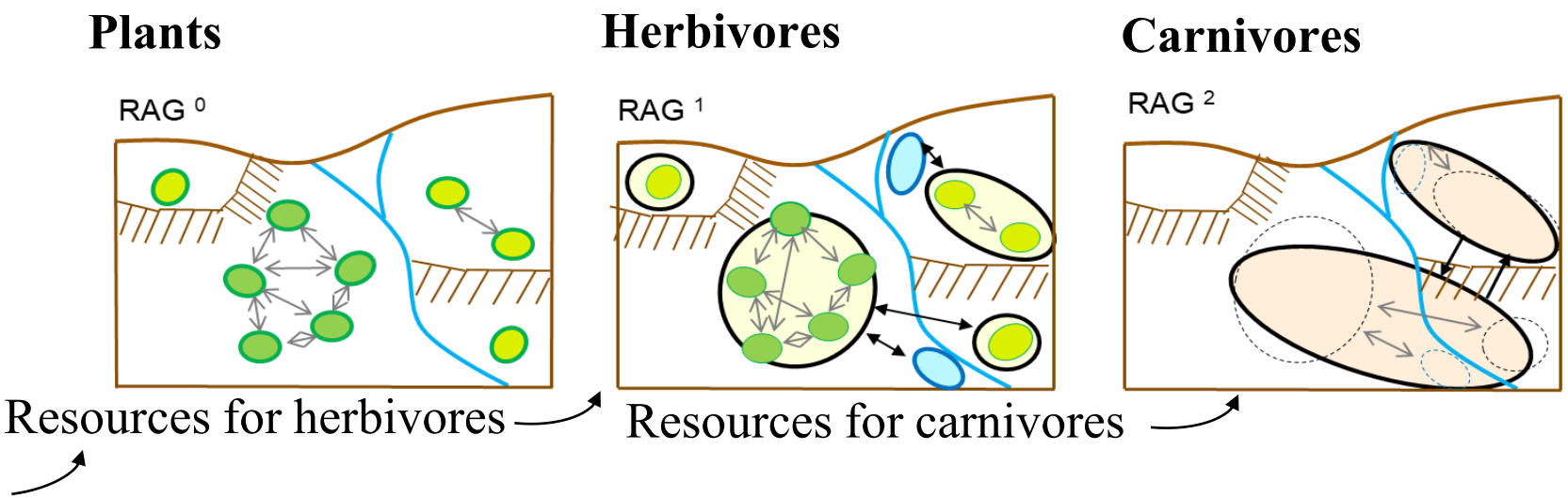



## Challenges

- Need for authoring (species proportions, painting on maps - according to knowledge)
  - ✓ Pray-predator simulation would fail matching these hypotheses!
- Need for precise embedding plants + animated animals (on daily paths)

# *Key idea: Progressively instantiate species up the food-chain*

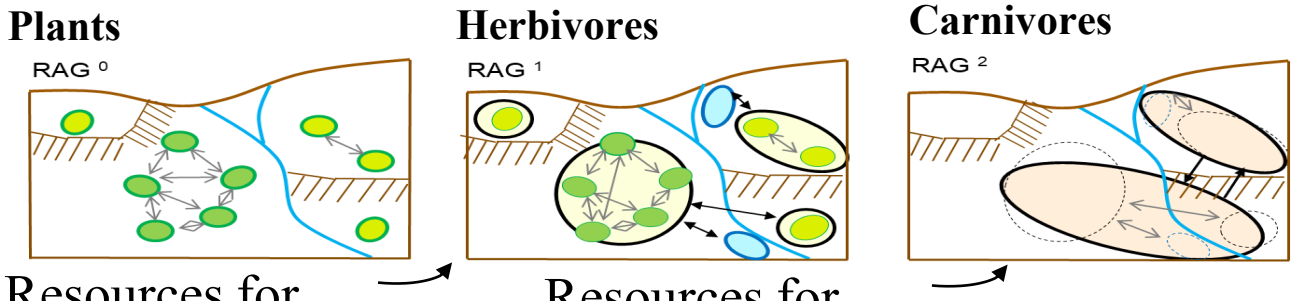



**How to account for knowledge on species proportions?**

- Quasi equilibrium state hypothesis
  - ✓ Species can only eat the « surplus » produced by their resources

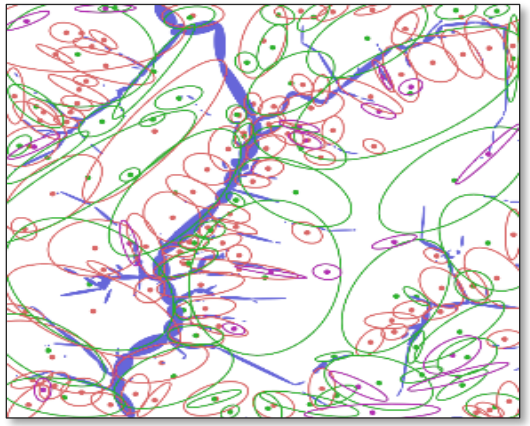
# *At each food chain level….*



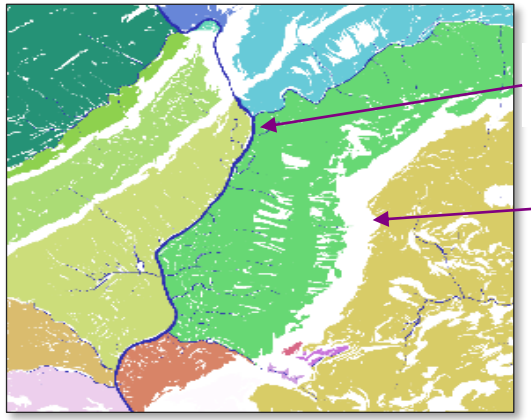

Resources for herbivores

Resources for carnivores

## Compute resources access graph



Resources

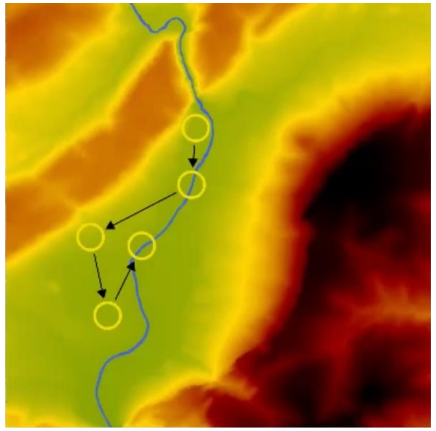



«Confinement areas»

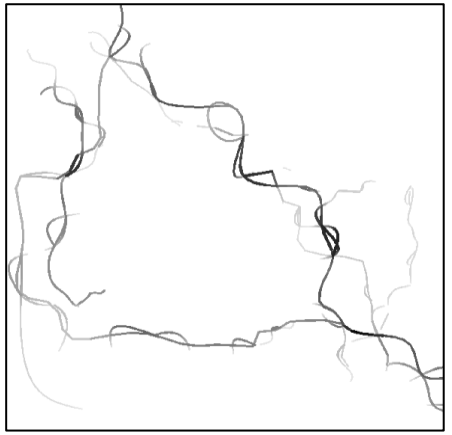
## Greedy competition algorithm

- Until no more resources remain
  - Instantiate the best species as to improve the matching with input proportions

From the herd terrirories & needs



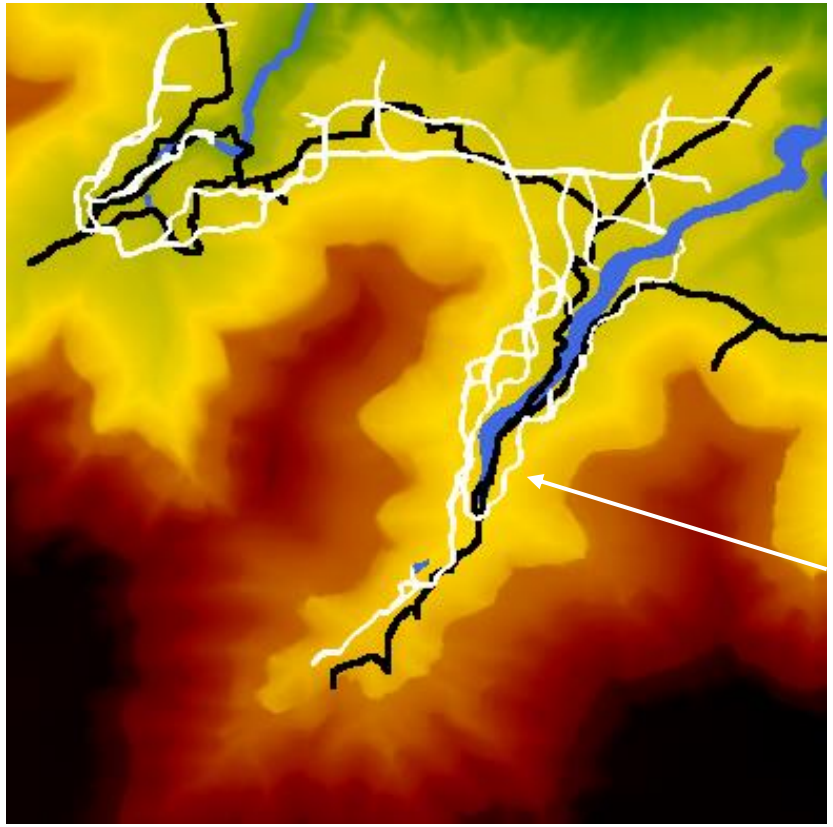
Daily planning



Eroded trails

## *Validation on a current ecosystem*

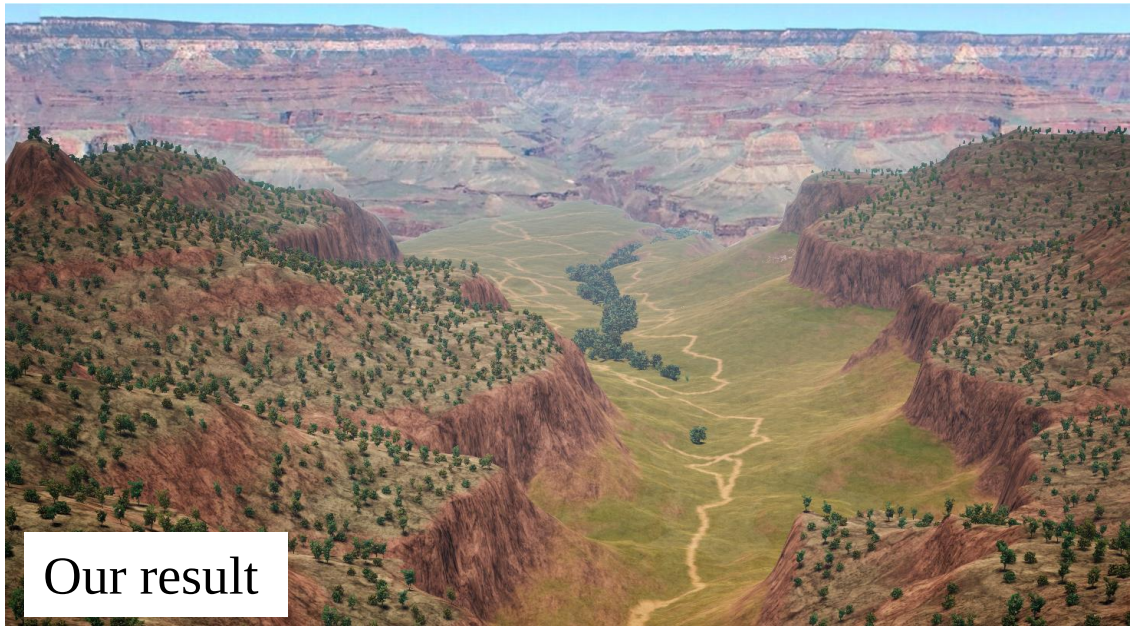
# *Bright Angel valley*



Actual trails

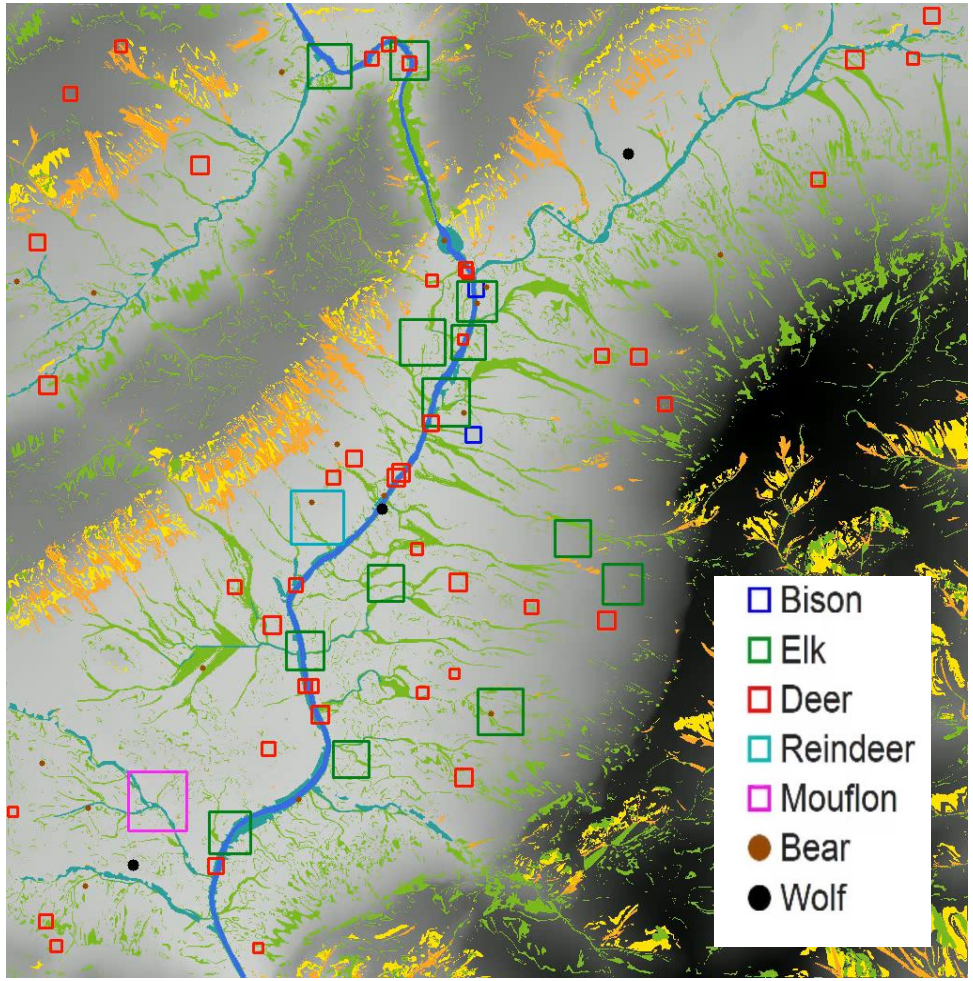
Our trails

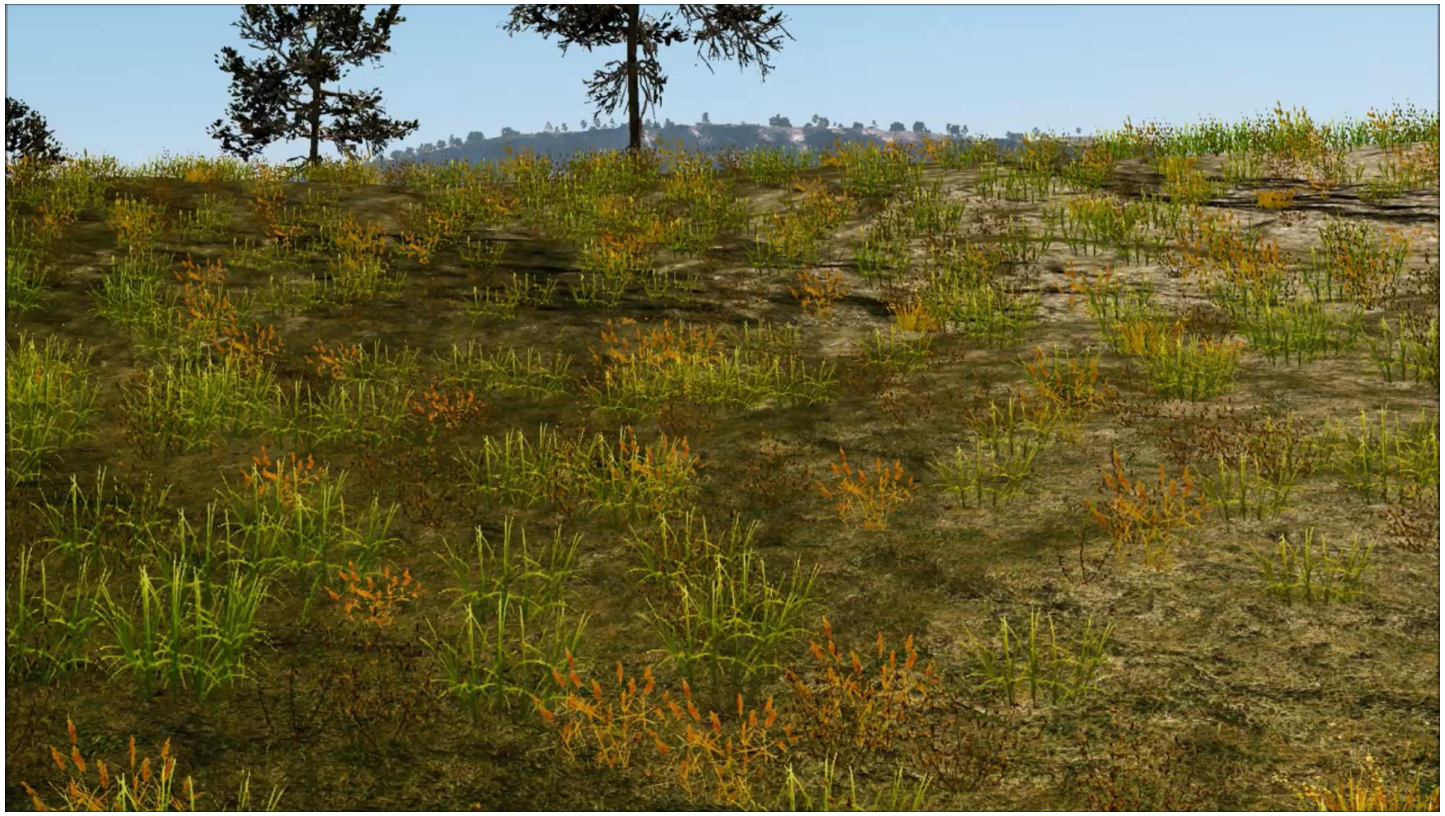
Comparison with satellite data

# *Results: Tautavel valley 450 000 years ago*

Accelerated herd motion on a map vs. Interactively exploring the environment



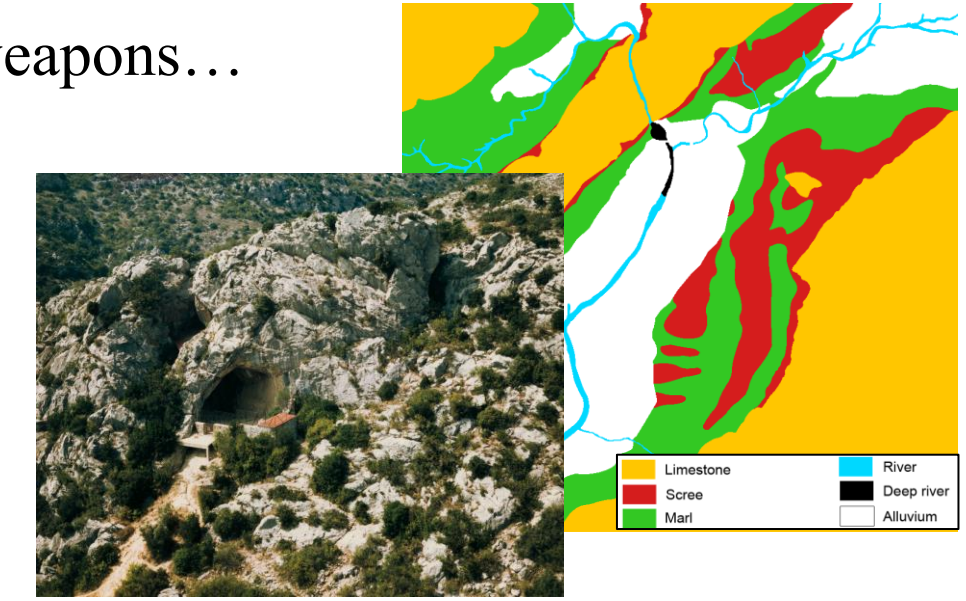



*[Ecormier-Nocca et al, SIGGRAPH 2021]*

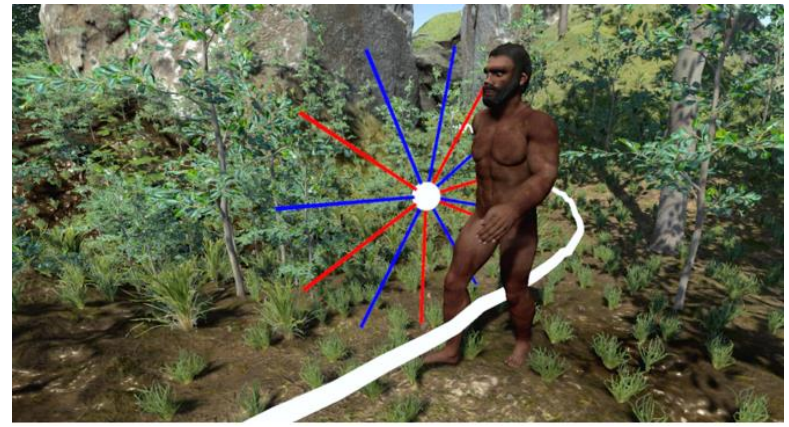
# *Simulator for pre-human mobility? (Paleomob 3D)*

- Hunting, carrying food, fetching stone for tools & weapons…

1. **Coarse Level: Motion planning**
   - Maps: ground type, slope, vegetation
   - Goals for a typical journey
     - Path & time taken to gather resources?




2. **Fine level: 3D pre-human locomotion**
   - Adapting captured motions to a different morphology
   - Moving silently through instable grounds & vegetation
   - Retrieving hunting gestures & strategies
     - *Deep reinforcement learning!*

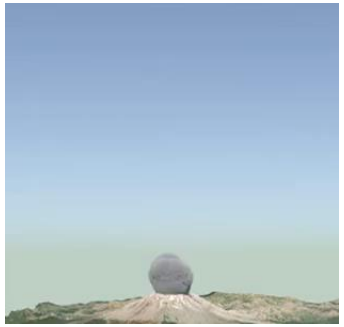


# *Conclusion*
# *Creative graphics can help scientists refine their mental visions!*

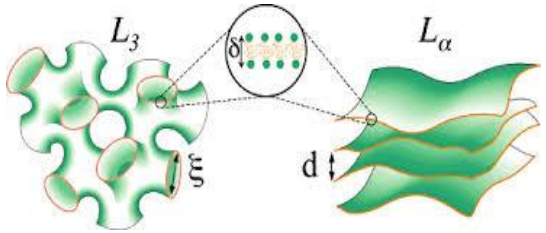
Ecosystems

Geology

Volcanology



Physics




Biology




**Future**:

- Multi-scale distributions, shapes of any dimension
- Sketching Motion, Deformation + Narrations
- On the fly combination of knowledge & learning

In contrast with “Creative AI”, smart models **to make us, humans, more creative!**

# *Thanks a lot*

to my

- Students
- Colleagues
- Collaborators

To the audience!