Procedural generation of underwater landscapes

Marc Hartley, PhD student

LIRMM, University of Montpellier, France

Supervisors:

Fiorio Christophe,

Faraj Noura,

Godary-Dejean Karen

Why virtual environments?

- For cinema,
- Video games,
- Simulators,
- …

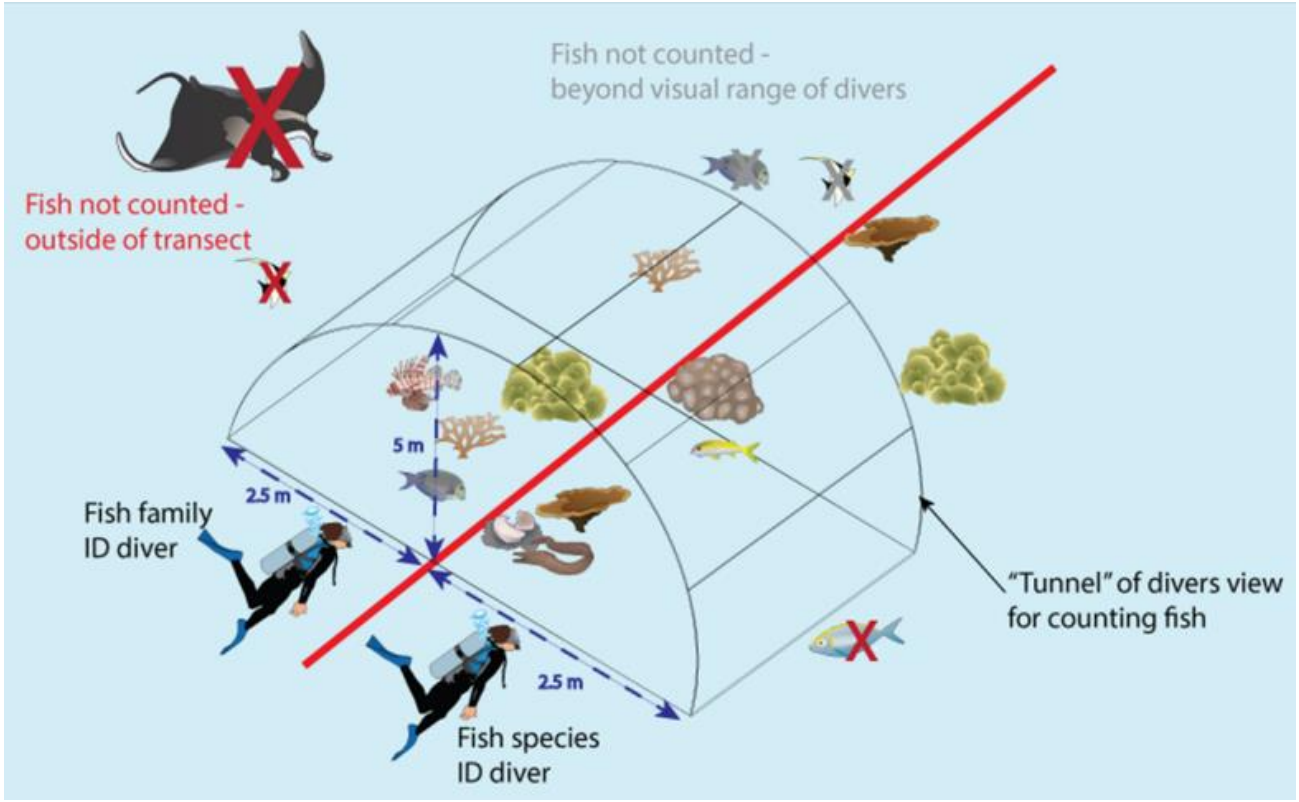
Avatar : The Way of Water (2022). By J. Cameron

Red Dead Redemption II (2018). Rockstar Studio

Pierre Ecormier-Nocca et al.. Authoring Consistent Landscapes with Flora and Fauna. ACM Transactions on Graphics, Association for Computing Machinery, 2021

Global project: Simulator for underwater exploration of robots

- For the study of marine biodiversity



Global project: Simulator for underwater exploration of robots

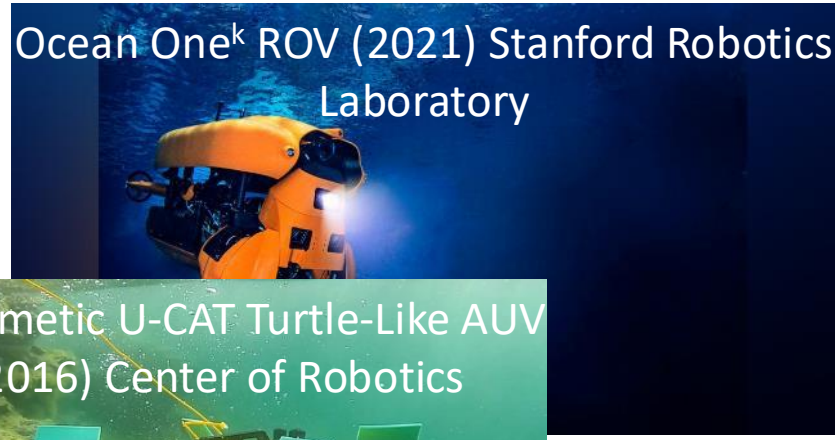
- Human divers:
  - Long,
  - Expensive,
  - Dangerous,
  - Perturbation of the wildlife
  - A lot of paperwork

Source: Schultz et al. (2019). Arctic marine ecology benchmarking program: Monitoring biodiversity using scuba

Dianne et al. *A comparison of temperate reef fish assemblages recorded by three underwater stereo-video techniques*, 2005

Global project: Simulator for underwater exploration of robots

- Using robots:
- … remotely operated:
  - Cables can be a big problem
- … autonomous :
  - Terrains are complex
  - Lots of noise and perturbations on sensors
  - Not sure if the robot will ever come back

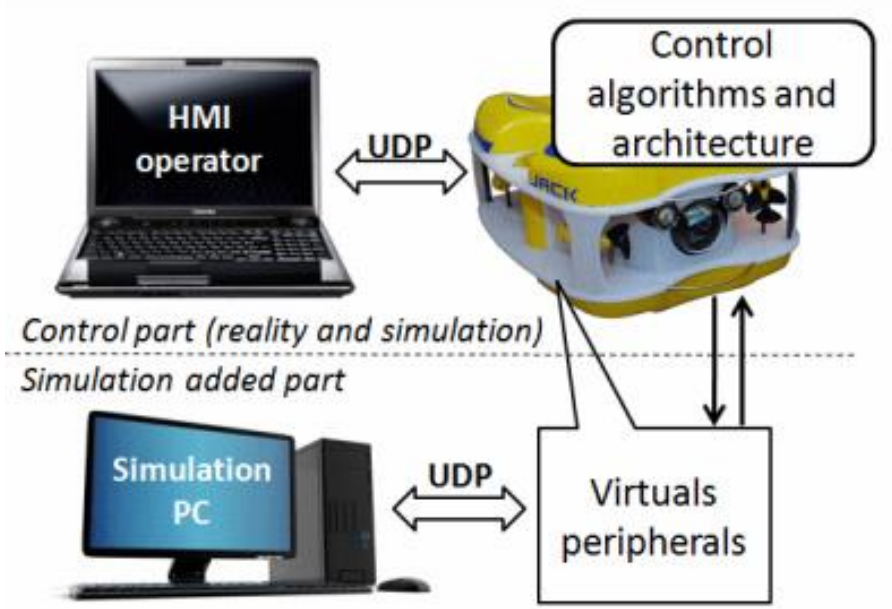

Ocean One^{k} ROV (2021) Stanford Robotics Laboratory


Biomimetic U-CAT Turtle-Like AUV (2016) Center of Robotics


REMI ROV-AUV (2017) LIRMM

Global project: Simulator for underwater exploration of robots

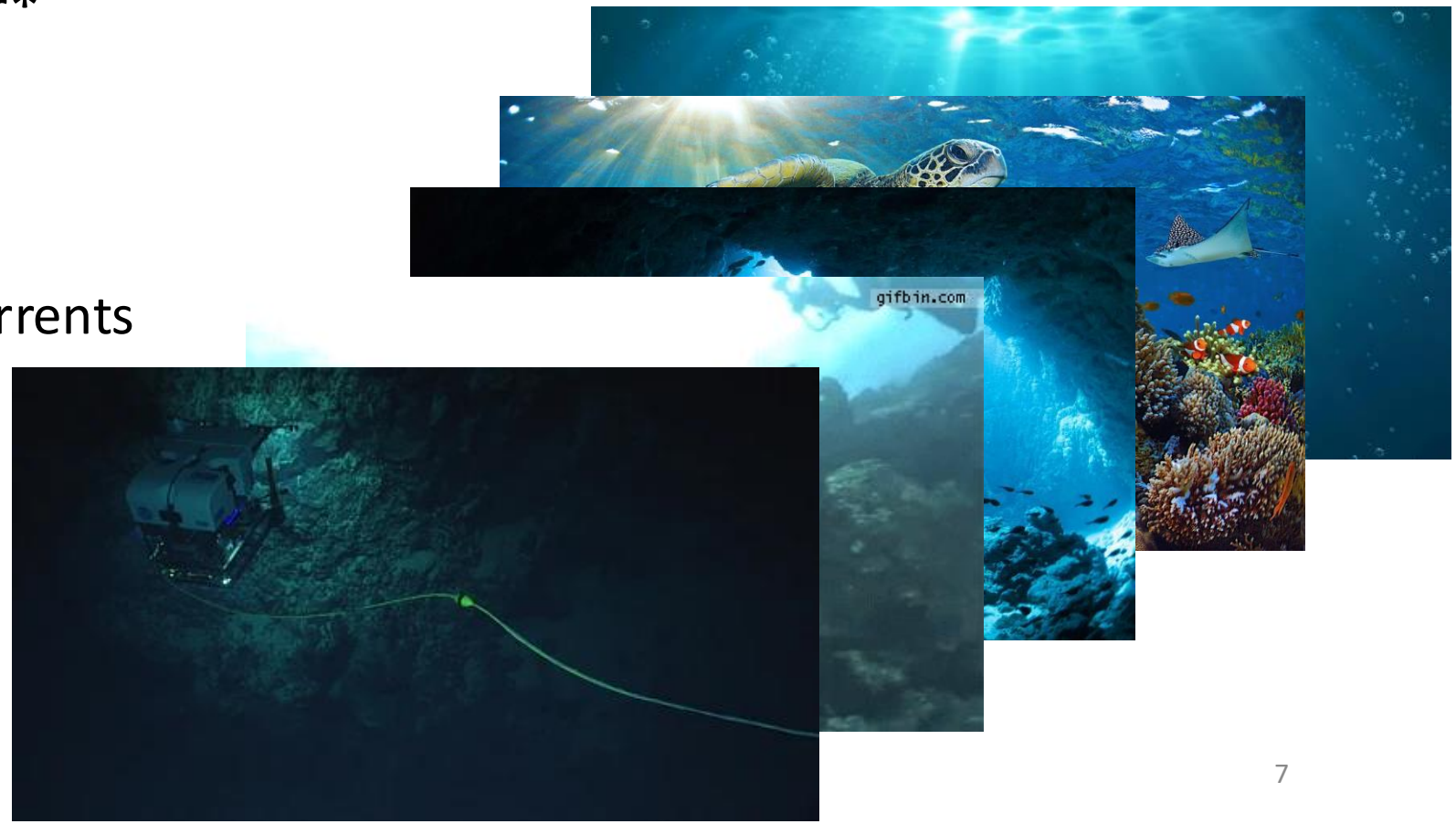
- Creation of a training camp for robots!



Source: Louis, Silvain, et al. *HIL Simulator for AUV with ContrACT*. 2019.

Difficulties of underwater generation compared to terrestrial generation

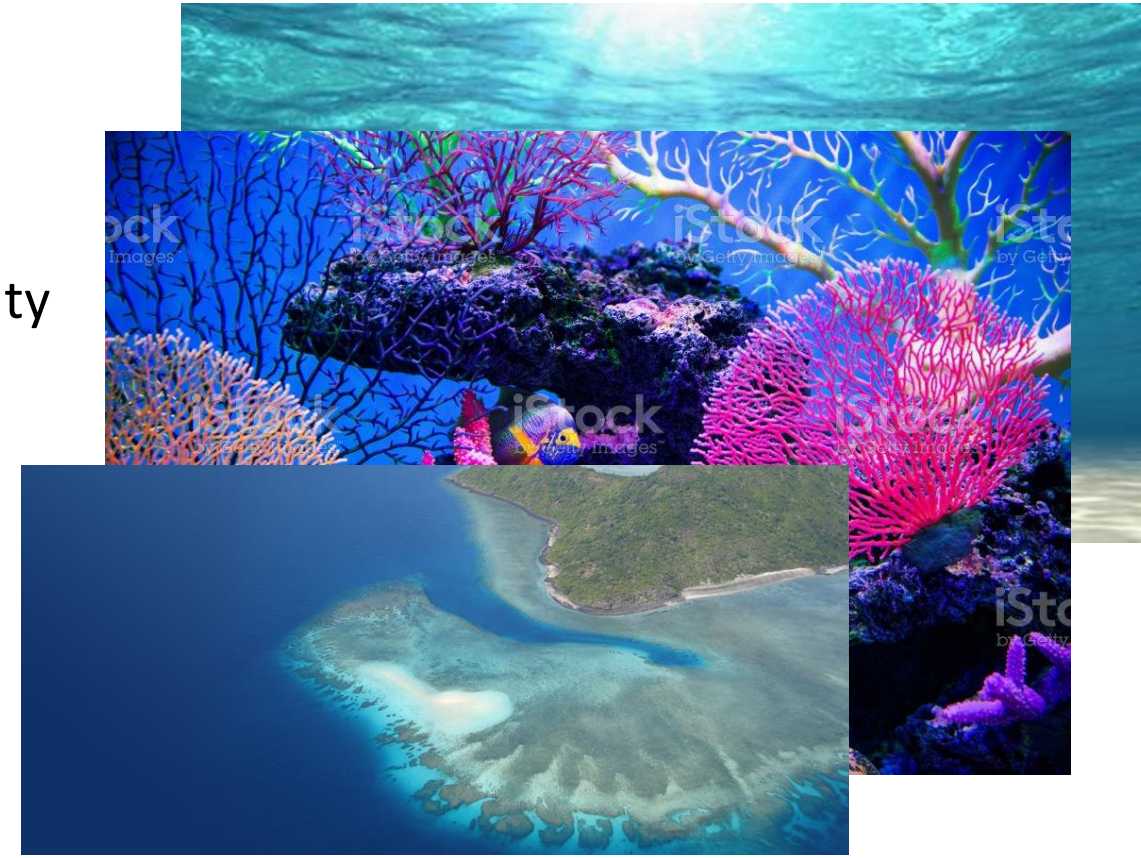
- A lot of works made for terrestrial since the '80s
- Nothing for underwater*
  - Water-filled vs. air
  - Different gravity
  - Notion of 3D
  - Importance of water currents
  - Lack of visibility
  - Difficulty in access



* «*at the best of my knowledge*»

More specifically, difficulties for coral islands

- Modeling of 99.9% of oceans: easy!
- Coral islands :
  - < 0.1% of ocean's surface, for 25% of biodiversity
  - Lack of observation instruments
  - Protected areas
- Geology mixed with biology
- Everything interacts with everything
- Physical simulations are too complex, not enough understanding

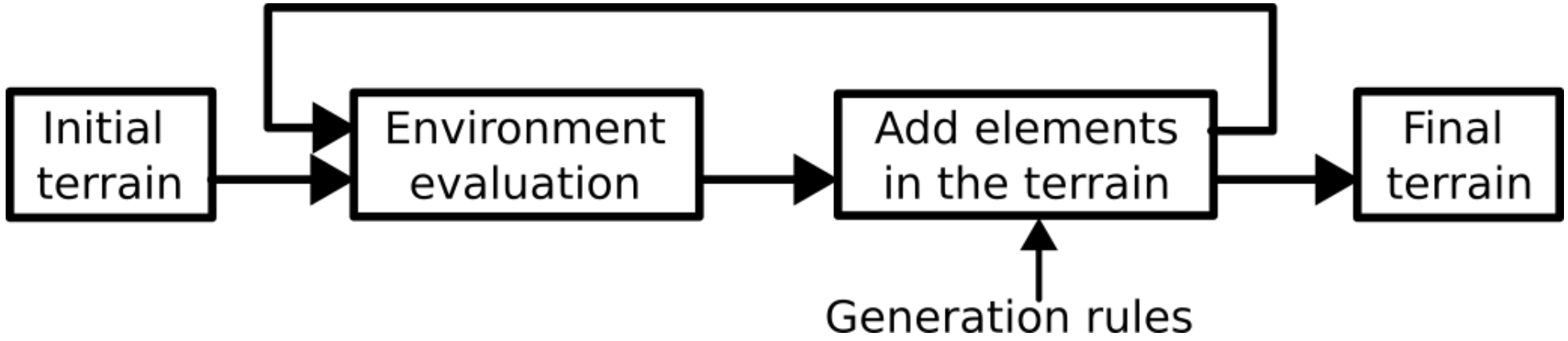


Darwin, C. (1842). *The structure and distribution of coral reefs - Chap I : Atolls or lagoon-islands*. In *The Structure and Distribution of Coral Reefs.*
Daly, R. A. . (1915). *The Glacial-Control Theory of Coral Reefs*. *Proceedings of the American Academy of Arts and Sciences.*
Davies, P. J., & Kinsey, D. W. (1977). Holocene reef growth -- One Tree Island, Great Barrier Reef. Marine Geology.
Droxler, A. W., & Jorry, S. J. (2021). The Origin of Modern Atolls : Challenging Darwin's Deeply Ingrained Theory. Annual Review Of Marine Science.
Liu et al. (2022). *The Formation of Atolls: New Insights From Numerical Simulations*. Journal of Geophysical Research: Earth Surface.

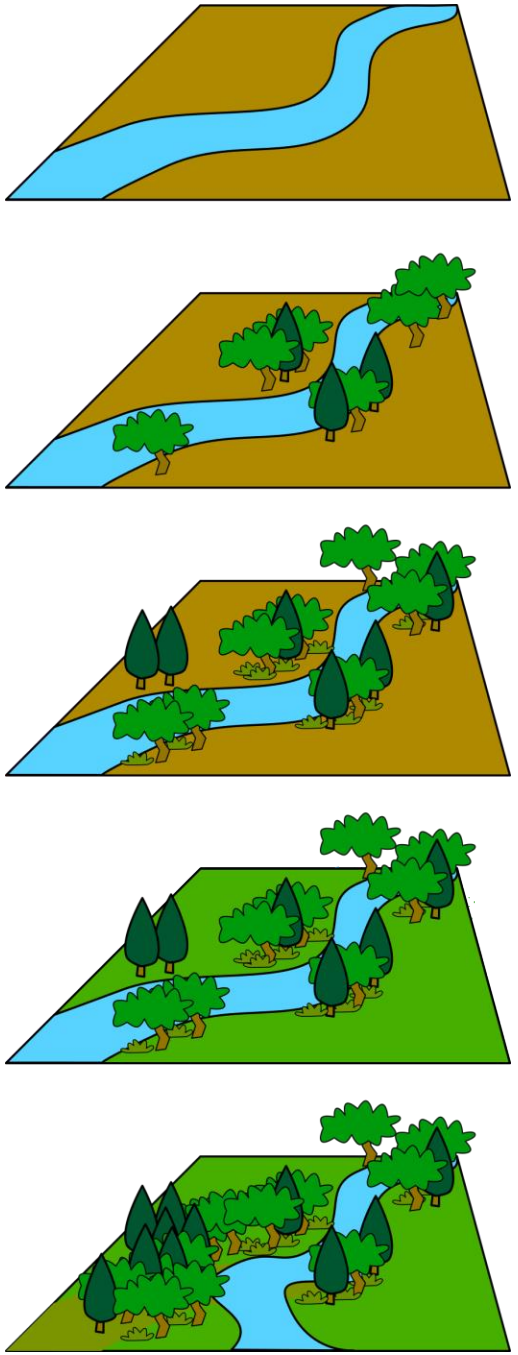
My method for procedural generation of landscapes

- Using "Environmental objects"
  - Construct the terrain using semantics
  - Simplify the representation
- Generation rules
  - Interactions between Objects and the environments defined by experts' knowledge
- Phenomenlogy
  - Provides an abstraction from physical simulations

Pipeline


Initial terrain
Environment evaluation
Add elements in the terrain
Final terrain
Generation rules

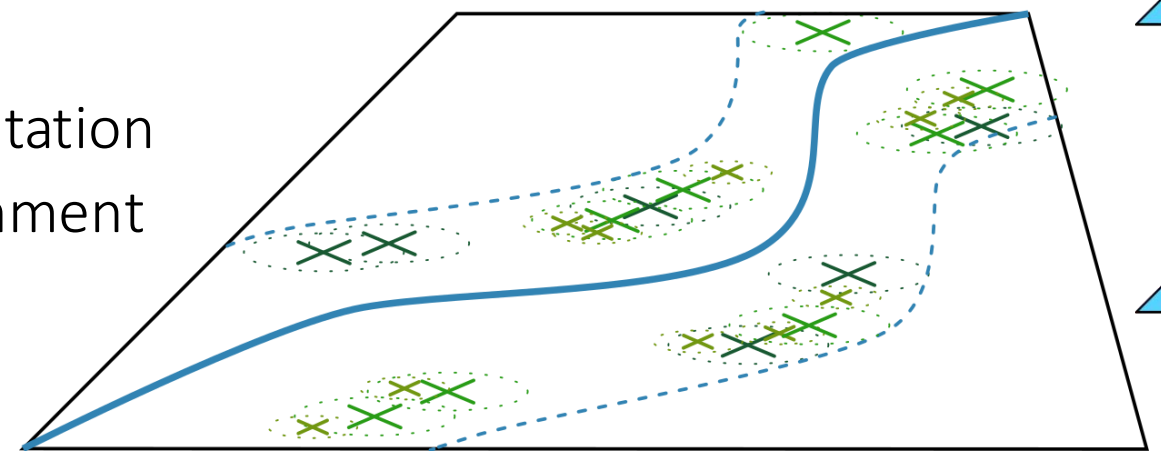
Environmental Objects

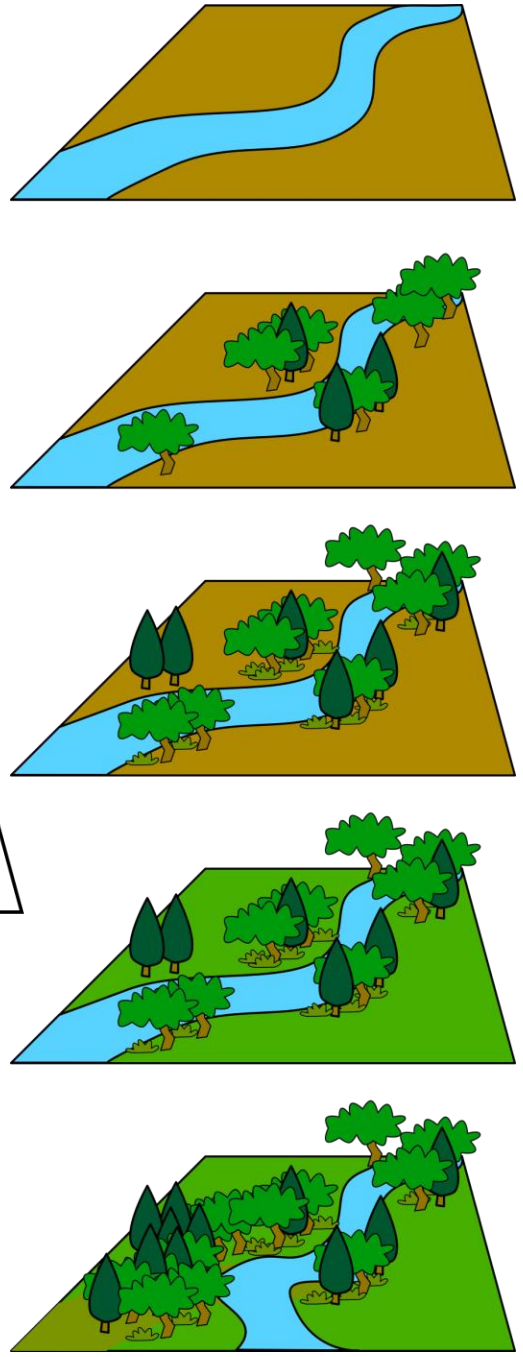


Grosbellet et al. (2016) *Environmental Objects for Authoring Procedural Scenes*.

Environmental Objects

- Defined by:
  - A skeleton
  - A geometric representation
  - Effects on the environment
  - A generation rule





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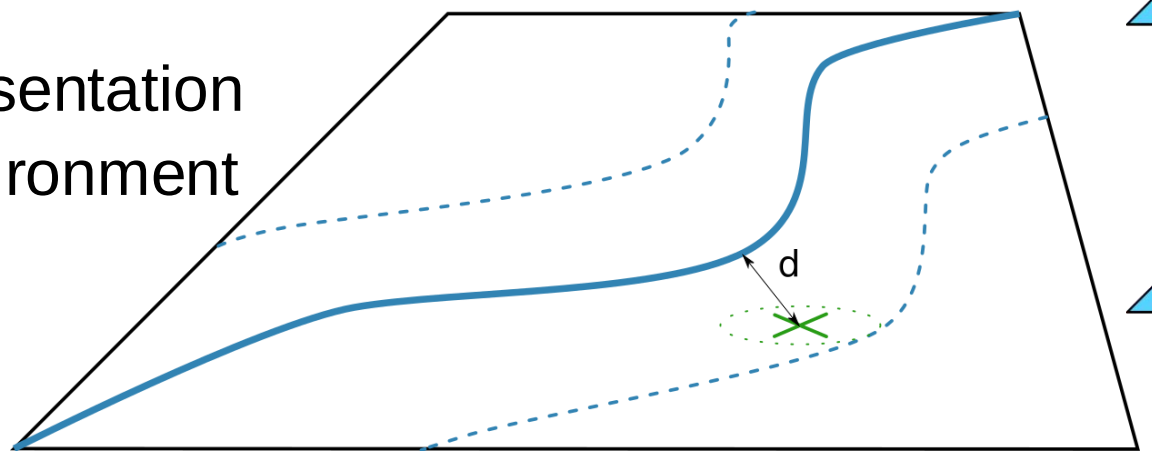
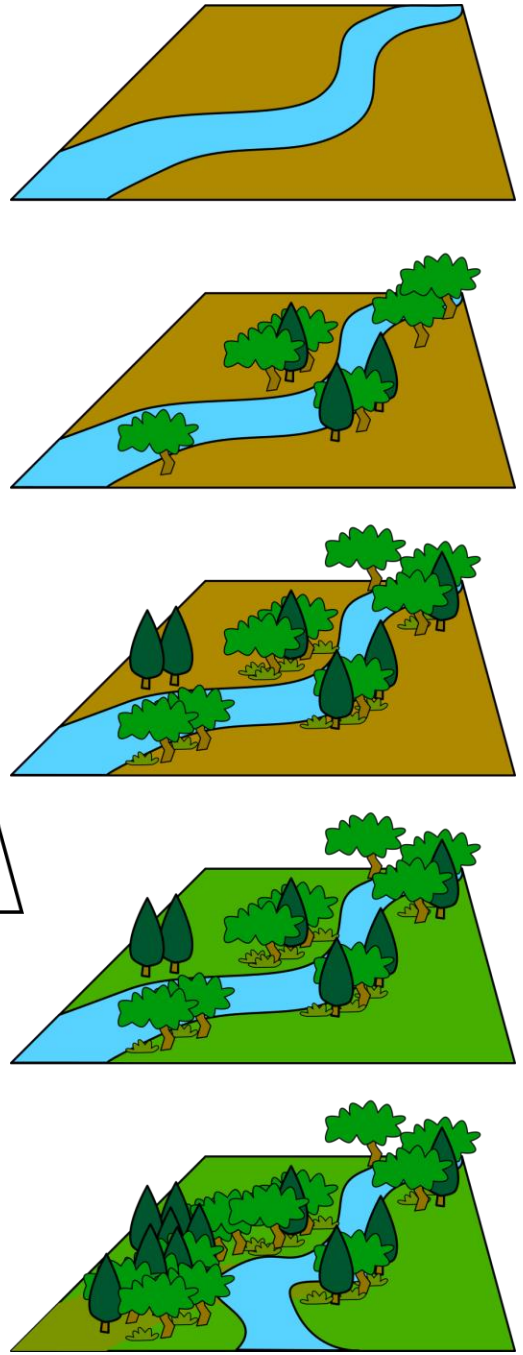


$$f(p) = |dist(riviere, p) - 10m| - 100 \times hydratation(p)$$



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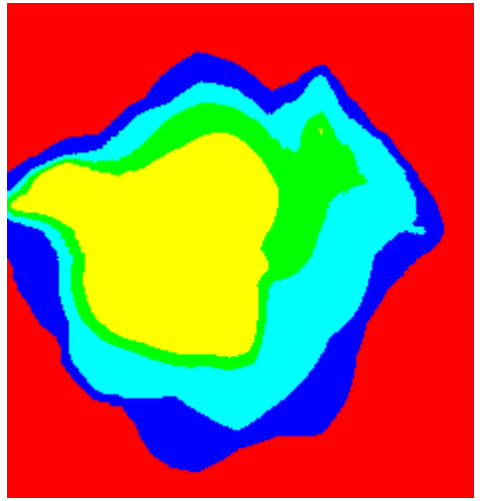
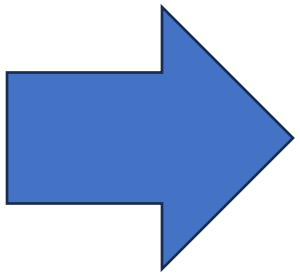
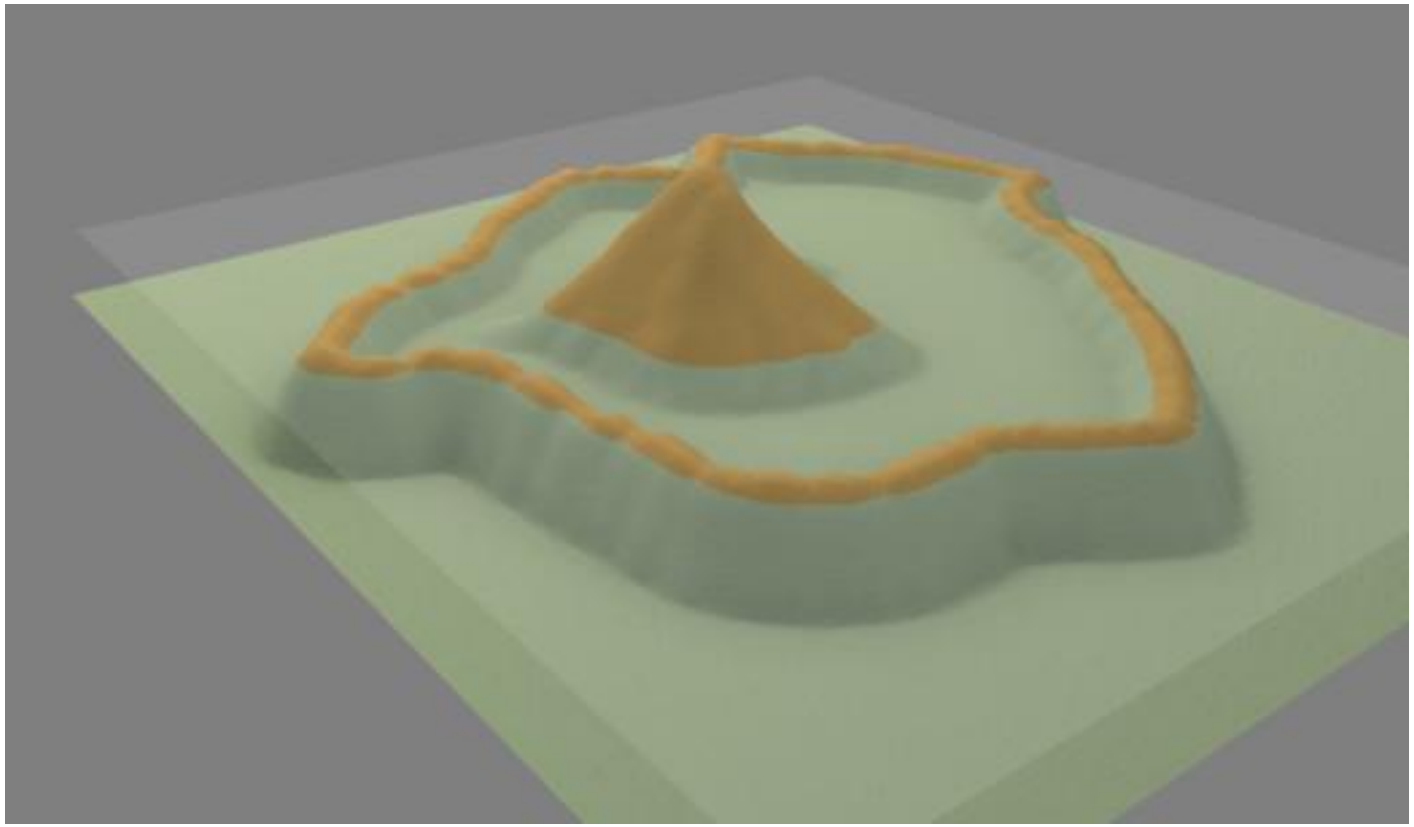
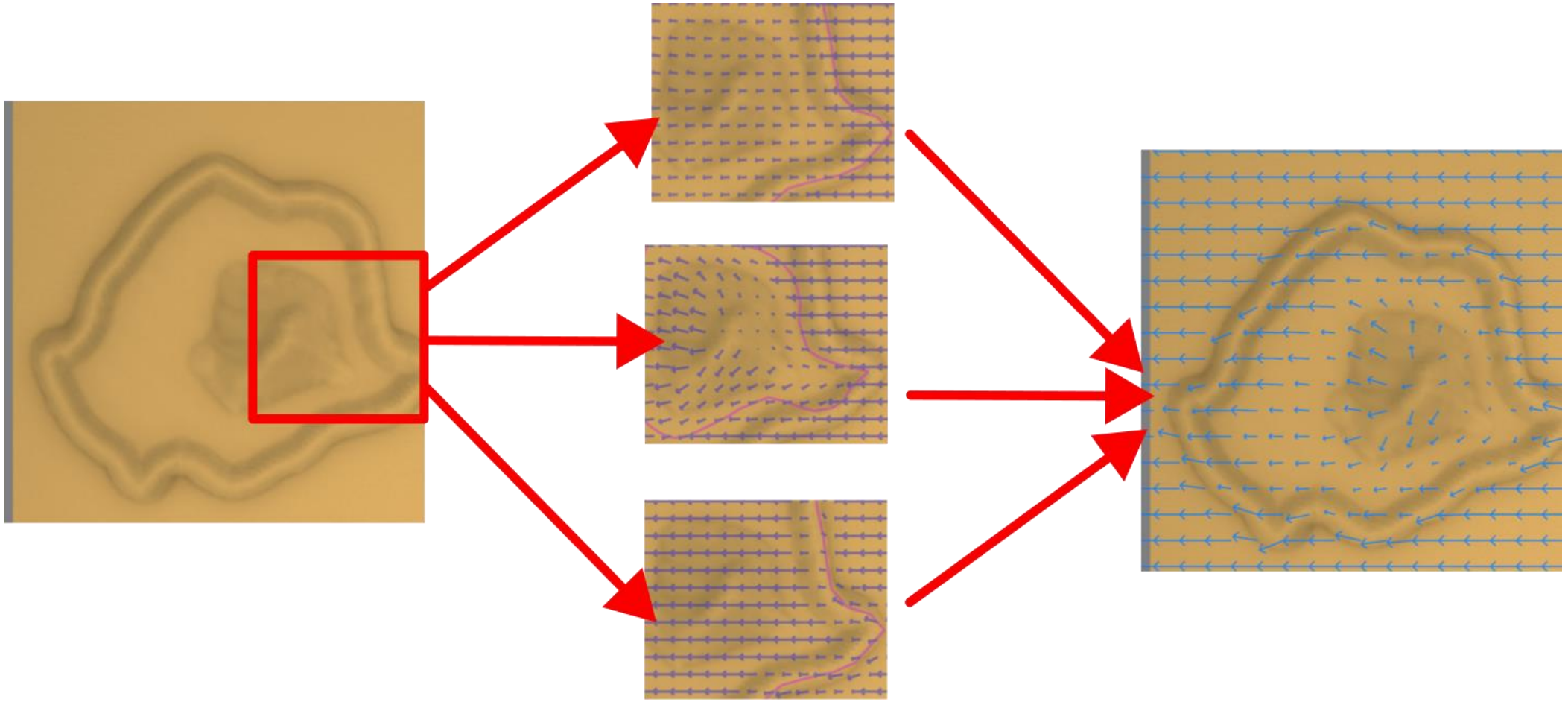
Initial terrain







Current state – Updating the water flow



The reef and island deviate the water flow
and lagoon slow it down

Current state – Adding new objects

Add a first passe

Multiple other passes

Add beaches

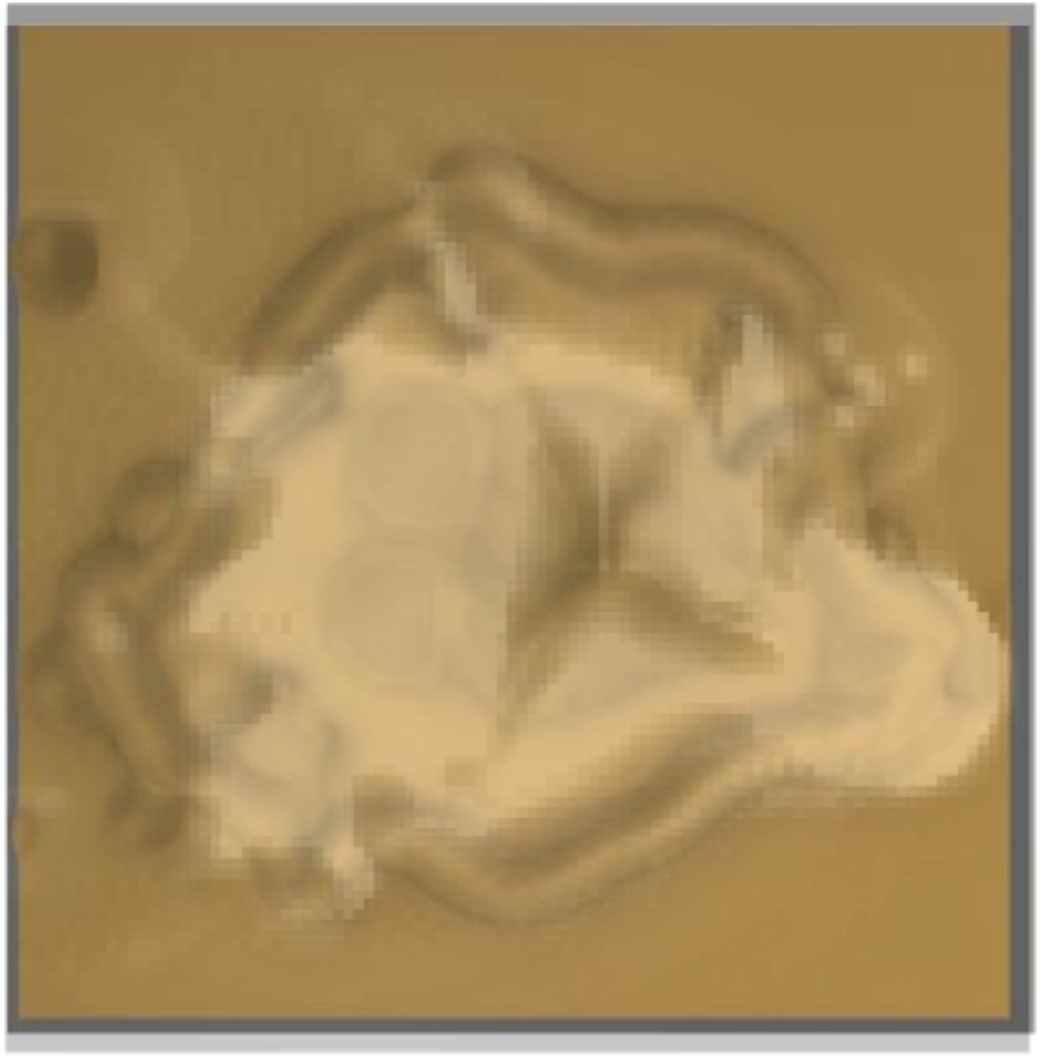
Add *motus*

$$f_{passe}(\mathbf{p}) = \langle N_{reef}(\mathbf{p}), \vec{v}_{current}(\mathbf{p}) \rangle * 10 - dist(\mathbf{p}, reef)$$

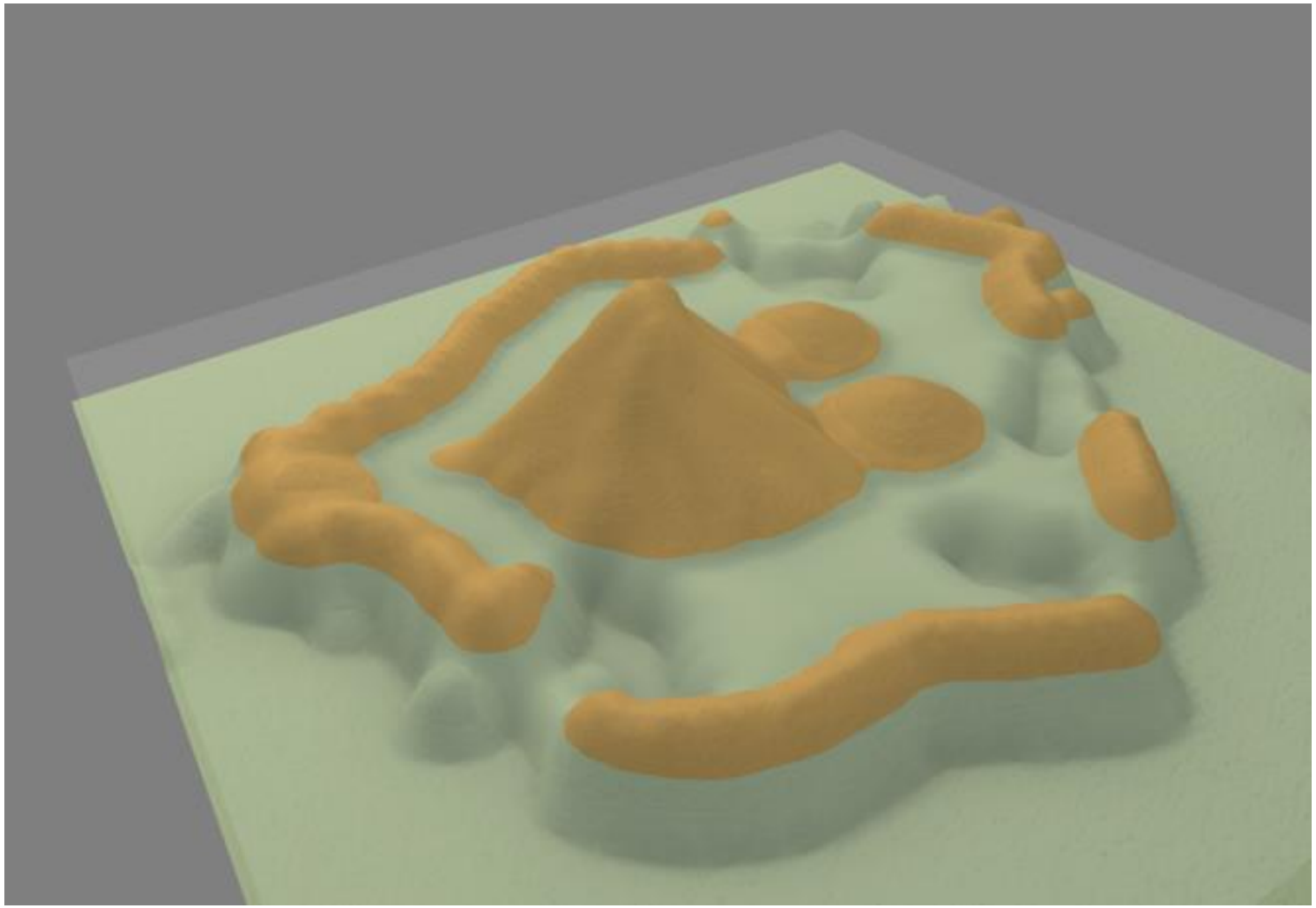
$$f_{beach}(\mathbf{p}) = -dist(\mathbf{p}, island)$$

$$f_{motu}(\mathbf{p}) = (10 - dist(\mathbf{p}, passe)) * (5 - dist(\mathbf{p}, reef)) * sand$$

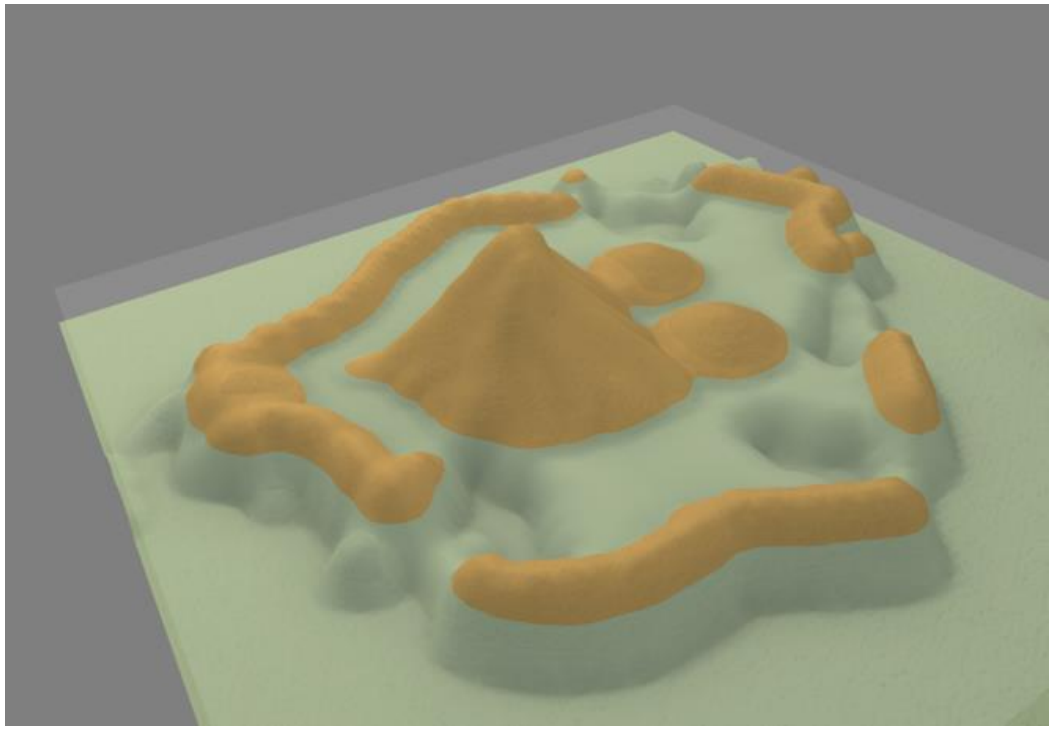
Current state – Changing the environment



Current state



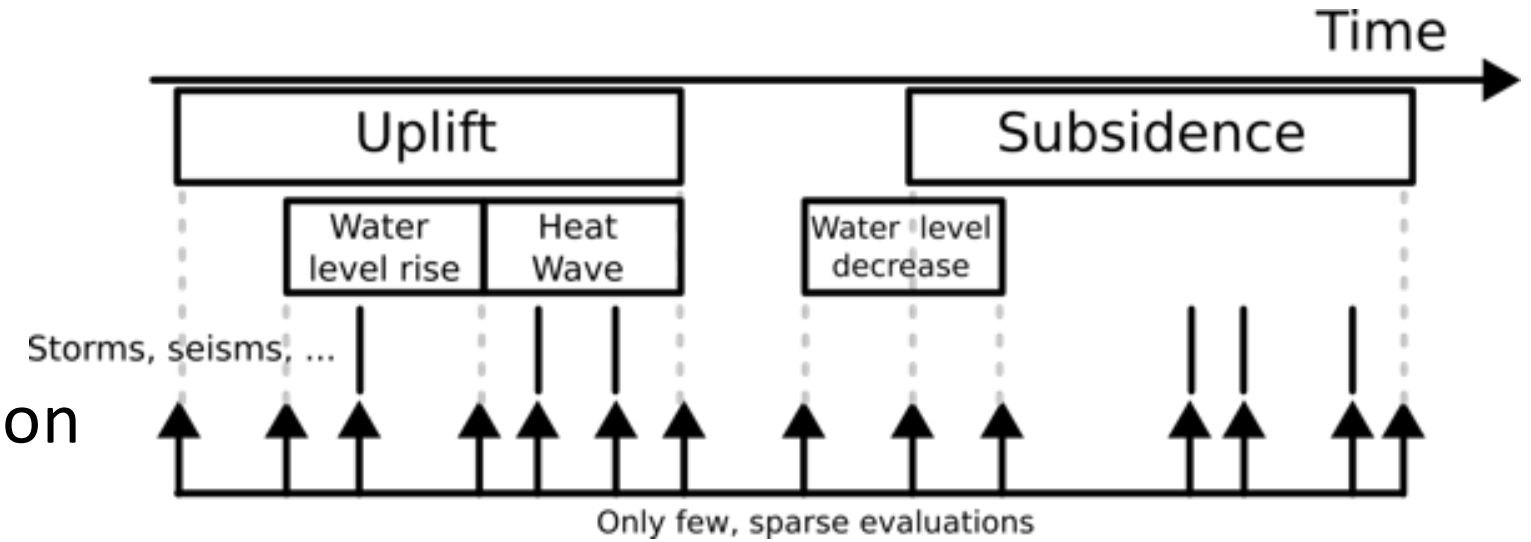
Current state



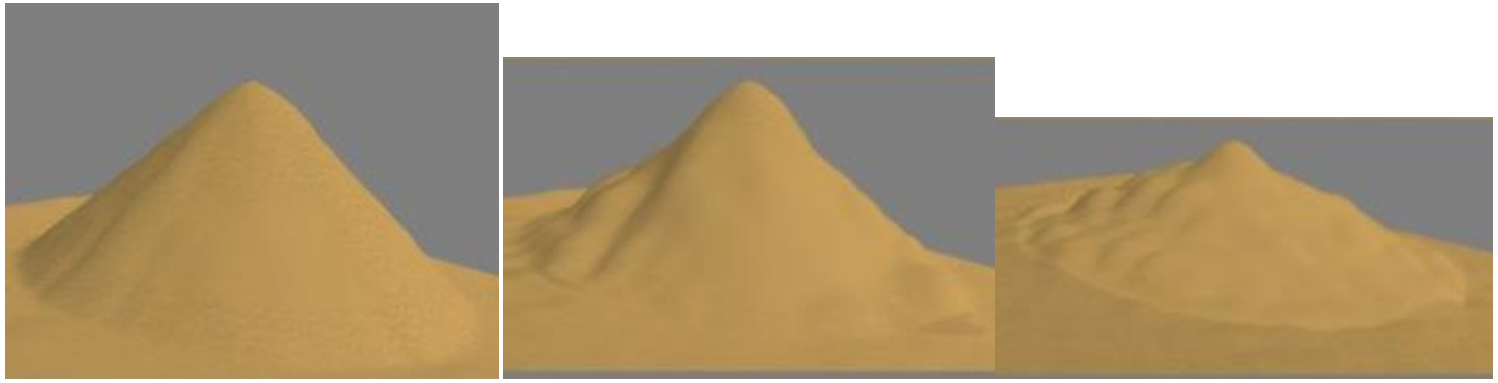
- We can have new elements
  - They change the environment's properties (Water flow and sand deposition)
  - They appear depending on the environment's properties

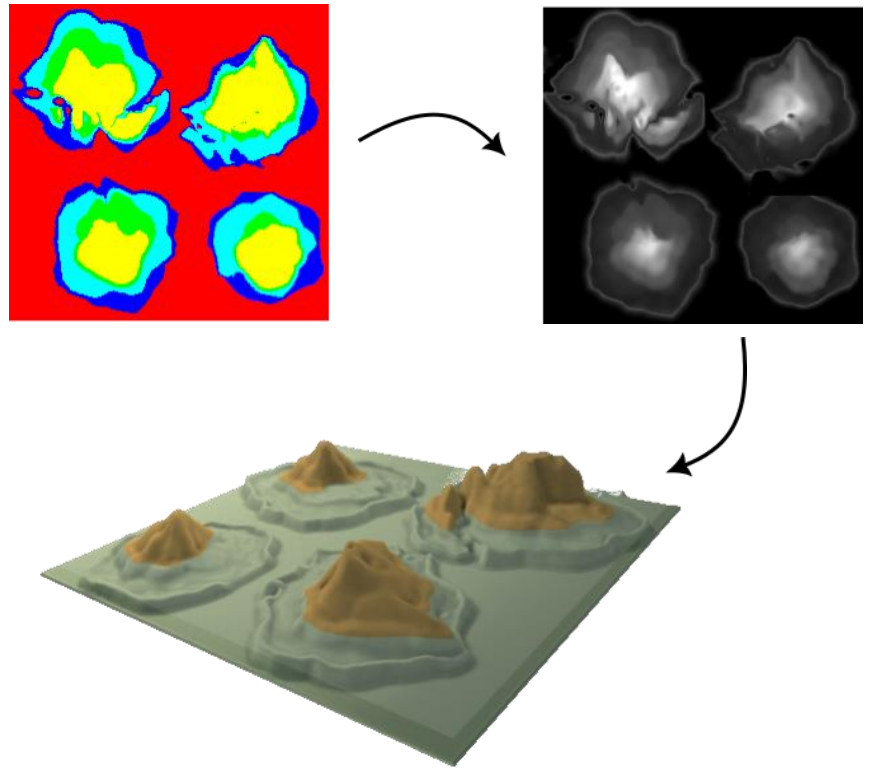
- What we still need:
  - A realistic geometry (use of more advanced implicit surface functions)
  - More robust generation rules
  - More work on the water flow alteration

Future works



- An event-driven generation
- A parametric erosion representation





- Object's geometry from real data

Conclusion

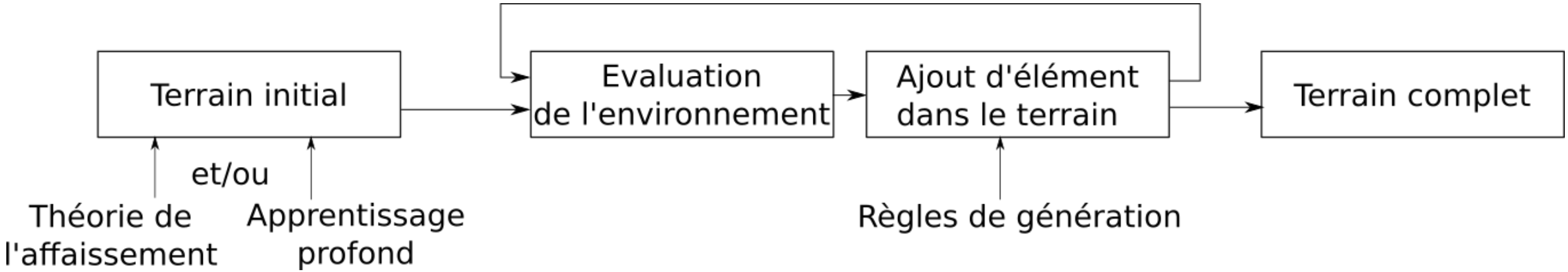
- A sparse semantic representation of landscape's elements
  - Applying phenomenology
  - Injecting expert's knowledge
  - Without physical simulation

- The overall objectives being
  - Generating underwater scenes
  - With models that have explicability
  - A representation that can be modified more easily by a user
  - Improving the link between field experts and computer scientists

The end!

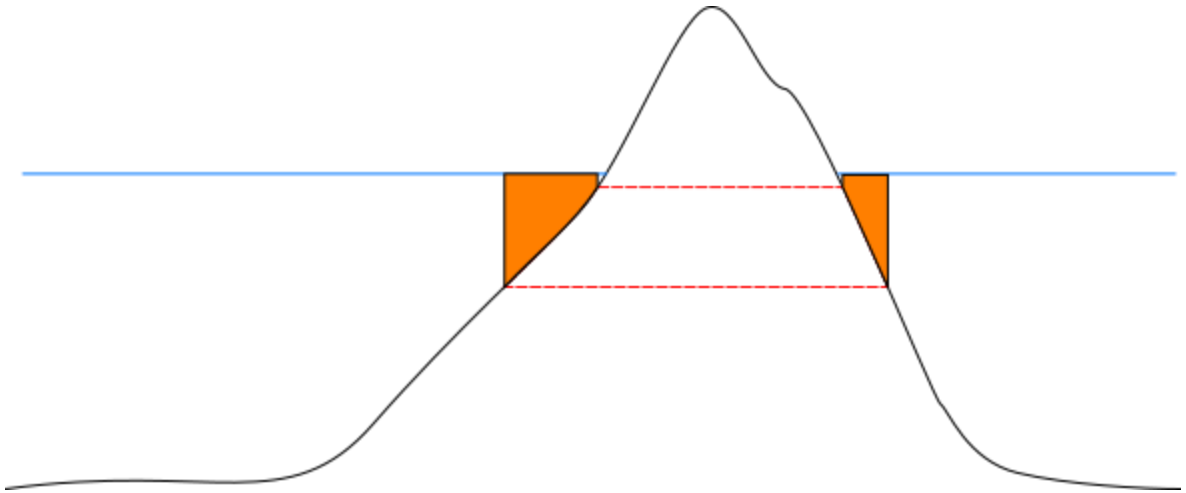
Des questions?

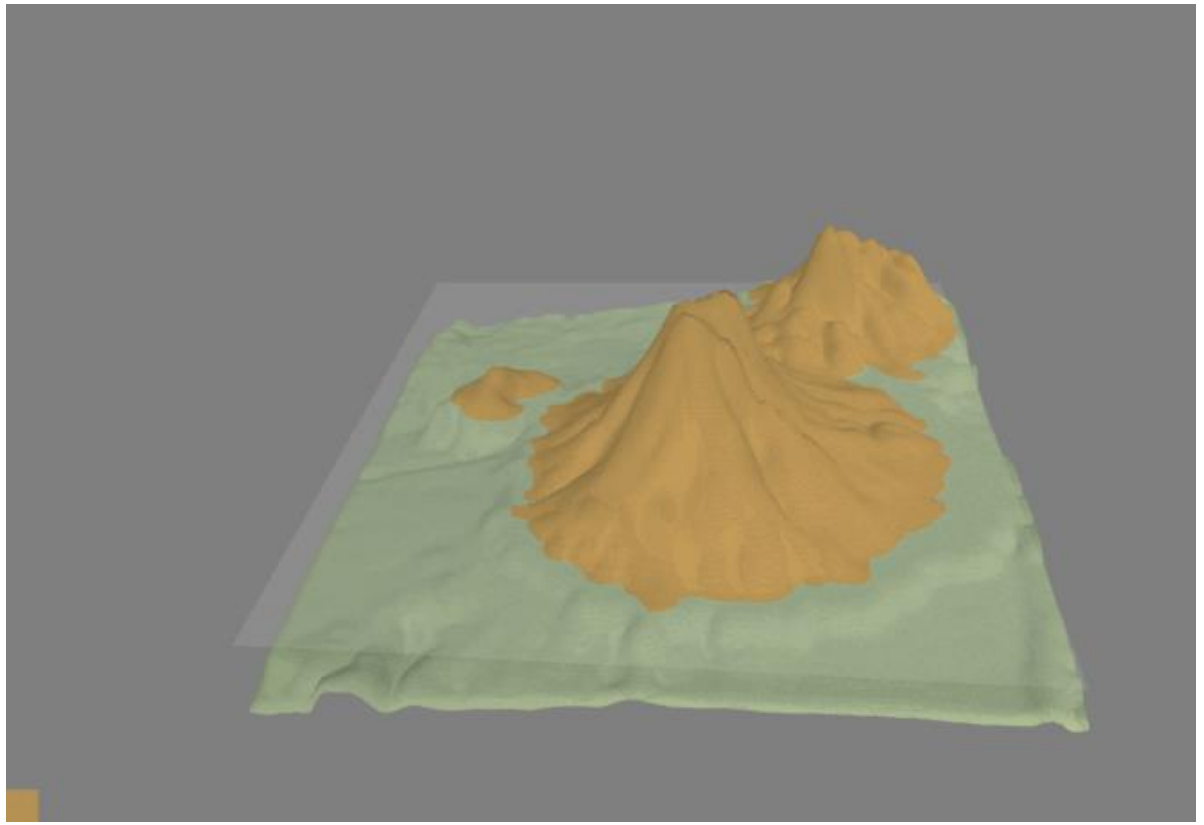
Pipeline


Terrain initial
Evaluation
de l'environnement
Ajout d'élément
dans le terrain
Terrain complet
et/ou
Théorie de
l'affaissement
Apprentissage
profond
Règles de génération

Coral barrier formation

- The Subsidence Theory (Darwin)

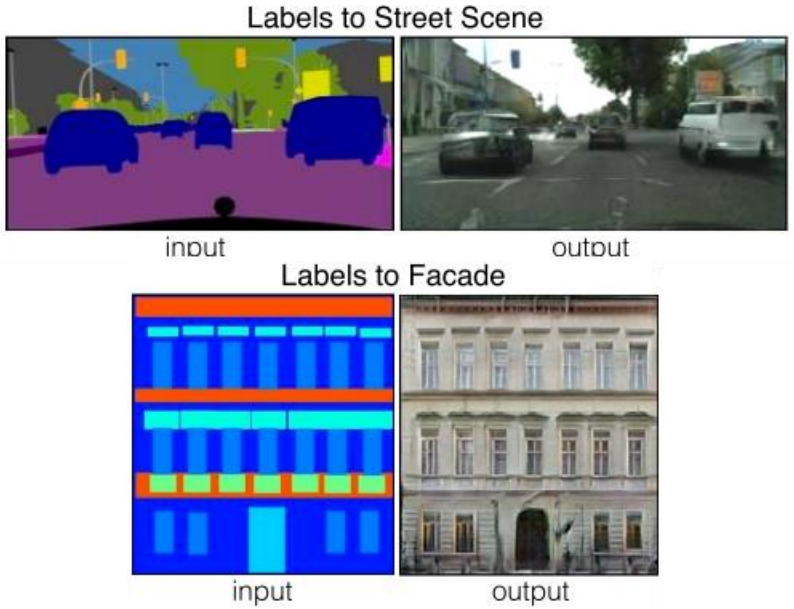


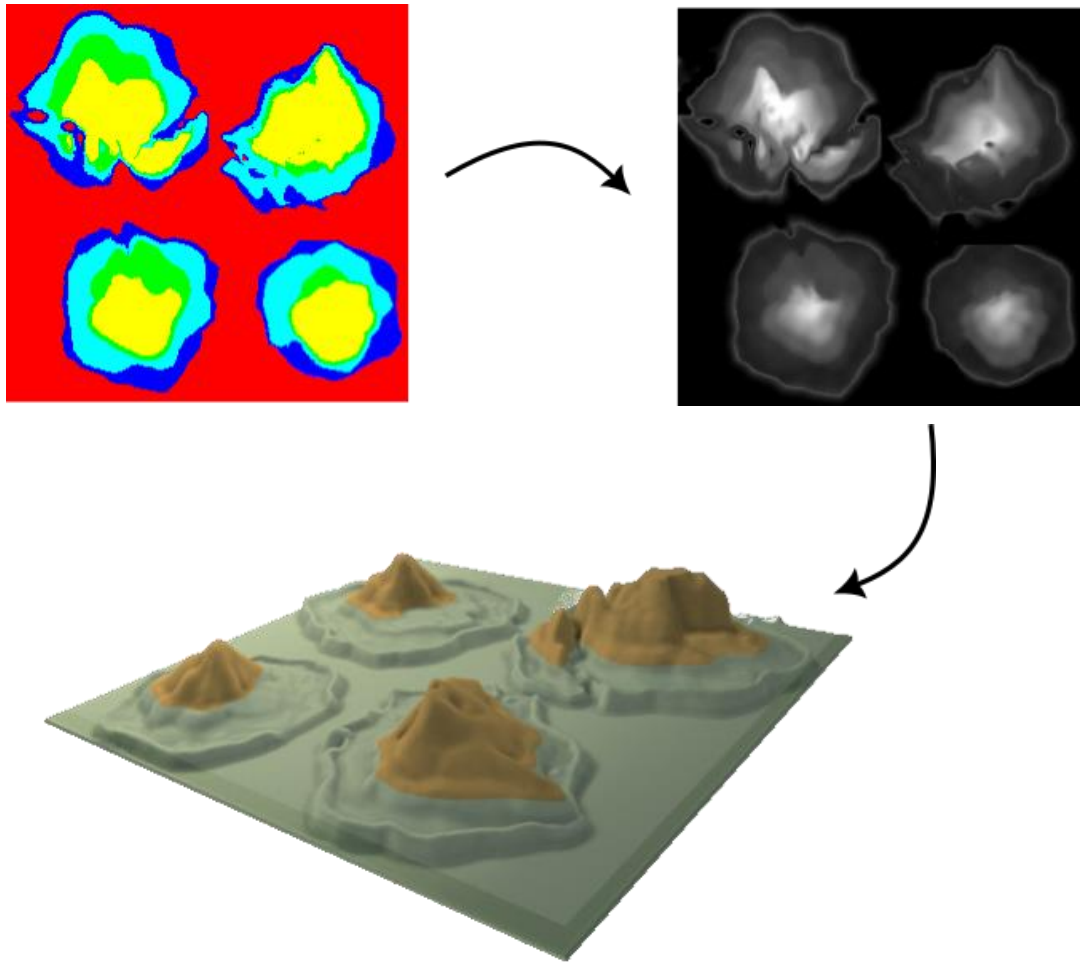


Darwin, Charles (1842), *The Structure and Distribution of Coral Reefs.* *Being the first part of the geology of the voyage of the Beagle, under the command of Capt. Fitzroy, R.N. during the years 1832 to 1836*

Using cGAN

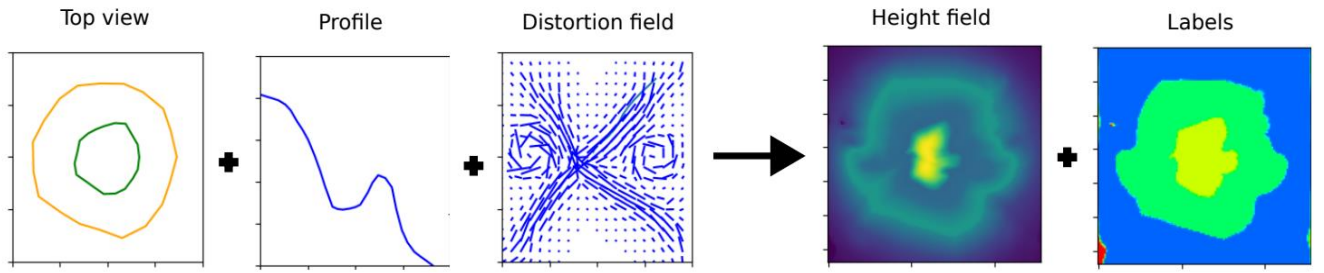
- Model pix2pix



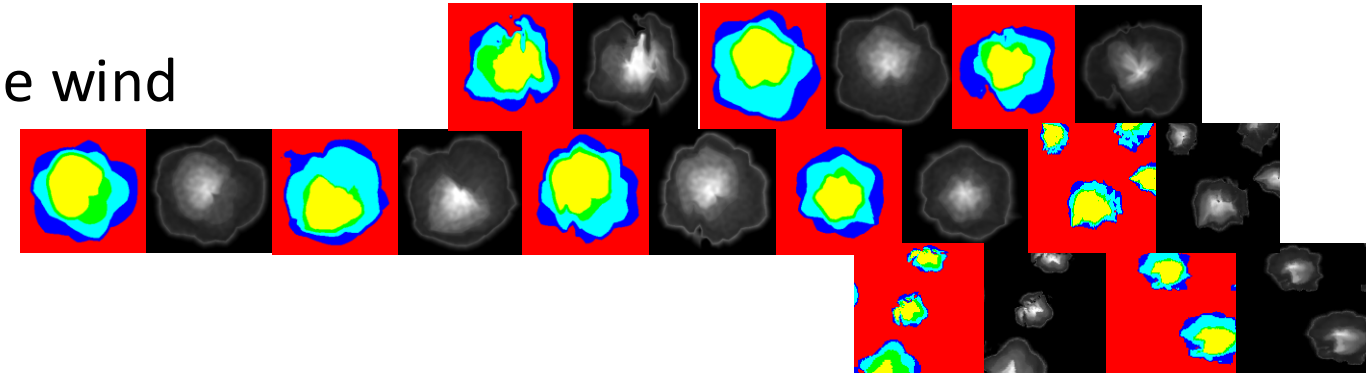


Isola et al. (2017). *Image-to-Image Translation with Conditional Adversarial Networks*. IEEE Conference on Computer Vision and Pattern Recognition

Using cGAN



- Lack of labeled data -> Creation of synthetic dataset
- What we know :
  - Islands are globally circular
  - Deformations are caused by the wind
  - The reef surrounds the island
  - We know the profile



Pelletier, D. M. A. G. M. (2019). *Problèmes et méthodes de l'étude géomorphologique des récifs coralliens*.
Purkis, S. J. (2018). Remote sensing tropical coral reefs: The view from above. *Annual Review of Marine Science*.
Goldberg, W. M. (2016). *Atolls of the world: Revisiting the original checklist*. Atoll Research Bulletin
Terry, J. P., & Goff, J. (2013). *One hundred and thirty years since Darwin : ' Reshaping ' the theory of atoll formation*.