L'art de faire pousser des machines

Une machine ou un système peut-il évoluer ?

Peut-on développer un système ayant des propriétés de résilience et de régénération ?

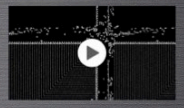
Ces créatures peuvent-elles apprendre et qu'est-ce que l'apprentissage artificiel ?

Une machine peut-elle créer ?

Yves Duthen
yves.duthen@irit.fr

Sommaire

Vie Artificielle

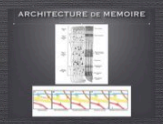


Créatures Artificielles

par assemblage de blocs
Phylogenèse

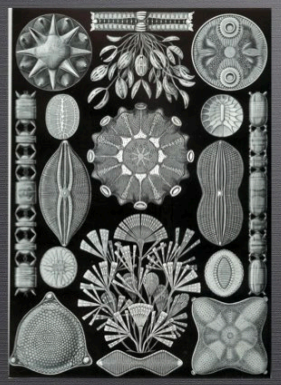
par développement
Ontogenèse

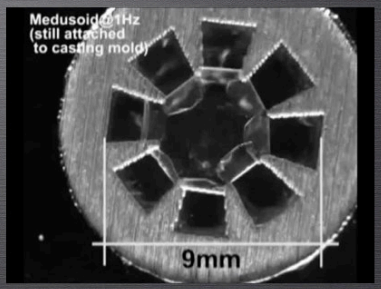
Apprentissage
Epigenèse



des Machines ?...

Design systems that exhibit properties of living organisms

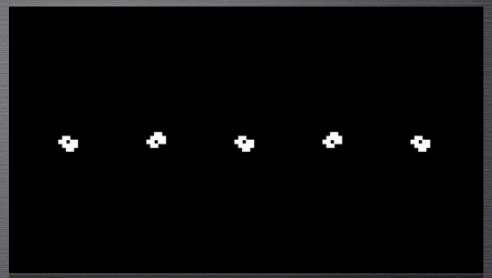




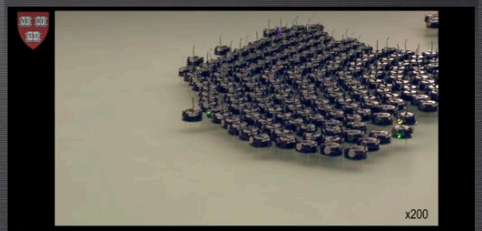
Development, Evolution, Adaptation, Learning, Replication

VIE ARTIFICIELLE

Notion de
Systèmes Complexes

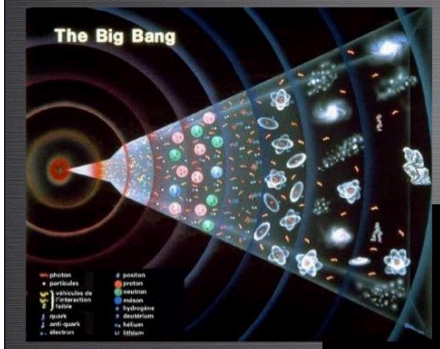


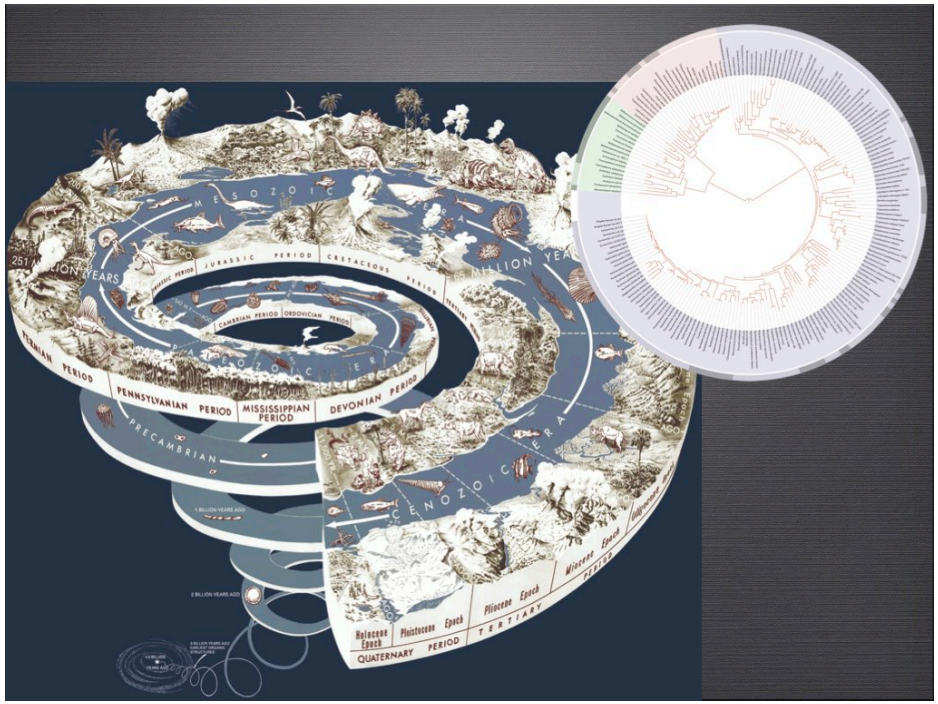
Auto-Organisation
Emergence de propriétés
Autopoïese



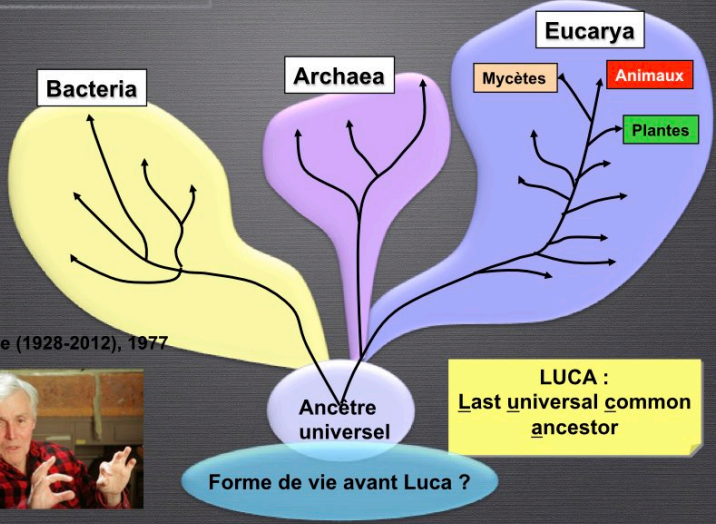
Once inside the shape, robots move until they either are about to exit the shape, or bump the previous robot. When this occurs, they join the shape.

EVOLUTION



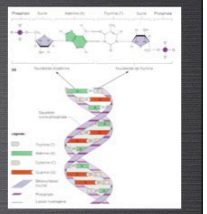


Course of Mathieu Arlat



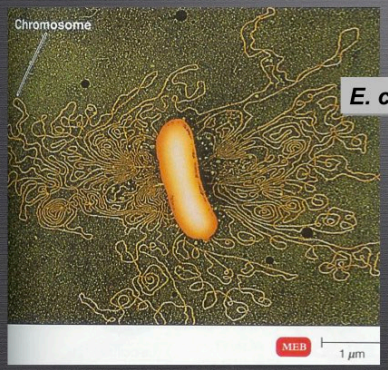
1. Les éléments essentiels

Le nucléoide et le cytoplasme



- 1 chromosome ciruclaire (en général)

➡ Informations génétiques essentielles



E. coli : 4 632 221 pb ~ 4632 kb ~ 4,6 Mb

4288 gènes

1,3 mm (1300 µm) – cellule 2/3 µm ?

Repliement ADN par Hu et IHF

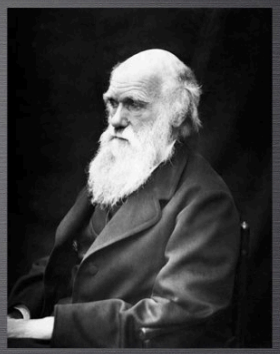
- Tortora, Funke, Case (2003) Introduction à la microbiologie, Edition du renouveau pédagogique ERPI.

Properties of Living organisms:

1 phylogenetic model:
Ability to evolve, to transform genetic material to produce different species.

2 ontogenetic model:
Ability to grow from a single cell by division and differentiation.

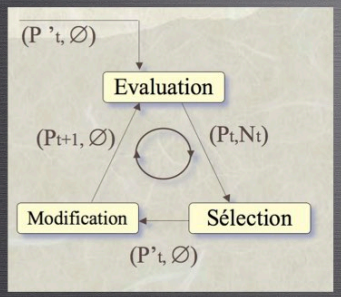
3 epigenetic model:
Ability to learn (nervous system, immune system)



Charles Darwin 1809-1882

... If a machine has these 3 properties, it could be difficult to distinguish it from a living organism. [Daniel Mange - EPFL]

ARTIFICIAL EVOLUTION

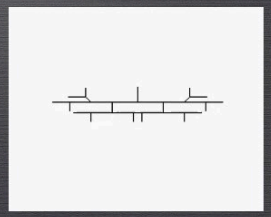


Creation of the initial population

Evaluation of the individuals

Selection of the well adapted (FITNESS)

Modification
- Cross-over
- Mutation...

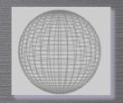


Richard Dawkins
The Blind Watchmaker
The Selfish Gene

MORPHOGENESIS

GENOTYPE ➡ **PHENOTYPE**

$$V(x,y,z) = \sum_{i=1}^{n} b_i * e^{-a_i\left(\frac{(x-x_c)^{fx}}{dx} + \frac{(y-y_c)^{fy}}{dy} + \frac{(z-z_c)^{fz}}{dz}\right)}$$

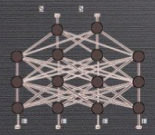


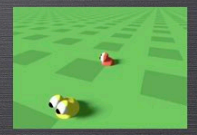
L-System Rules

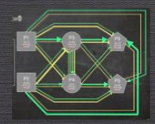
1 A-> C[B]D
2 B-> A
3 C-> C
4 D-> C(E)A
5 E-> D

Root A develops :

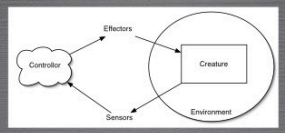
-> C[B]D R 1
-> C[A]C(E)A R 3,2,4
-> C[C[B]D]C(D)C[B]D

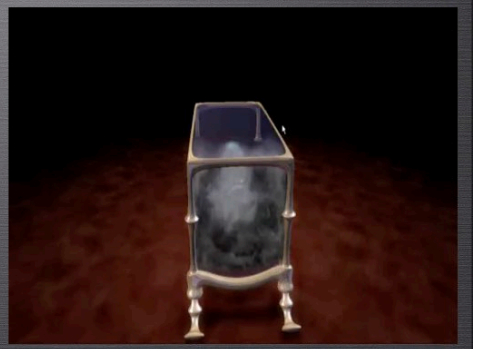






PHYSIC SIMULATOR





NVIDIA

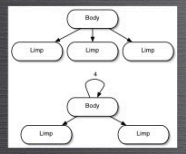
CCP NVIDIA

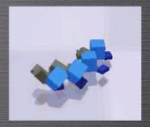
PHYSICALLY SIMULATED CLOTHING
BY CCP (EVE Online)
USING NVIDIA APEX

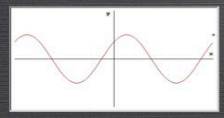
1 PHYLOGENETIC MODELS

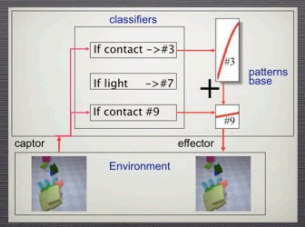
VORTEX

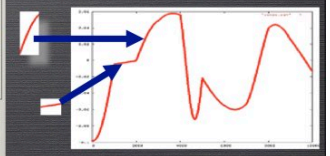
NICOLAS LASSABE

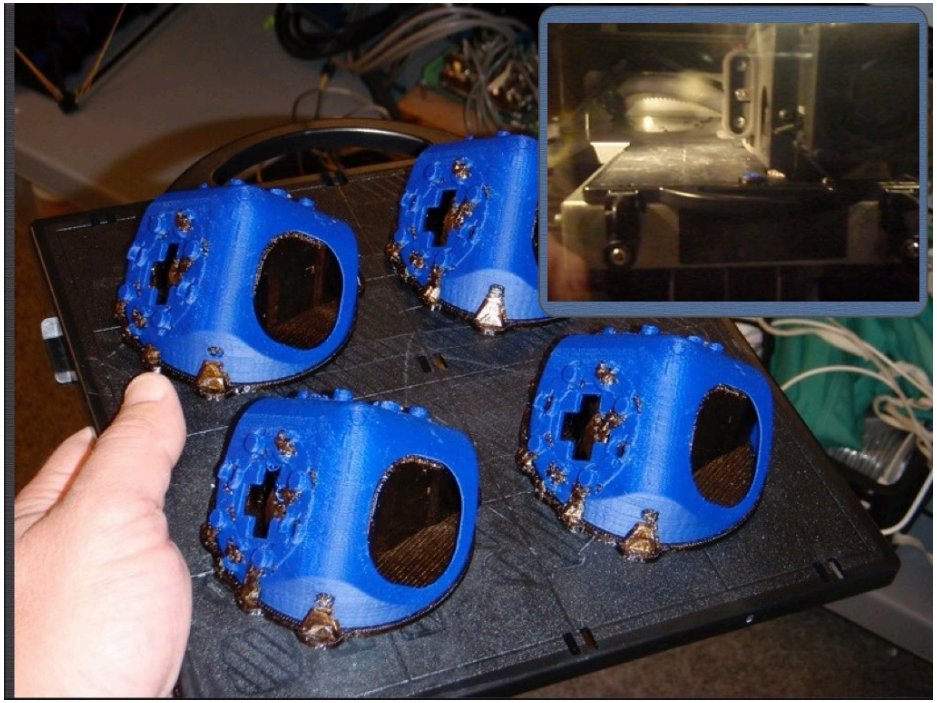




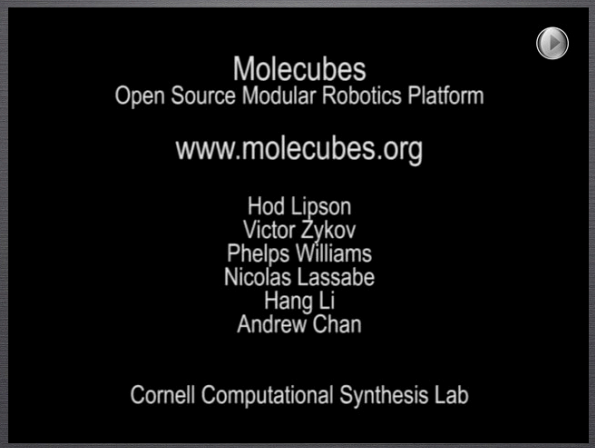






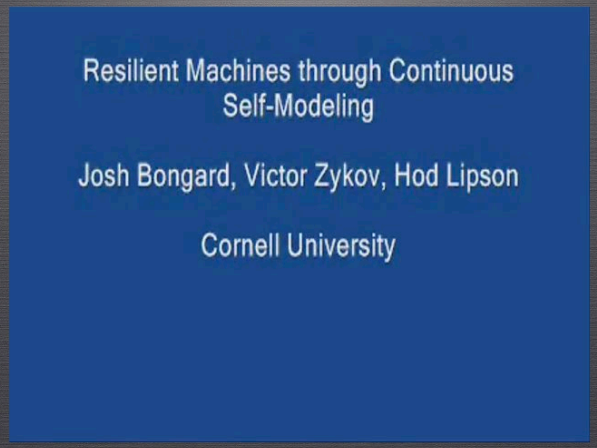


Molecube



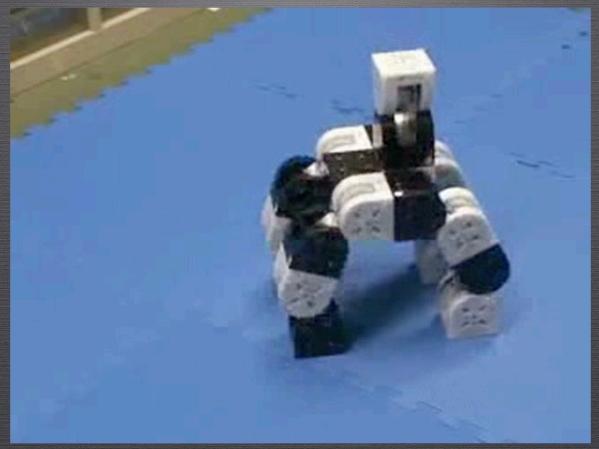
Modular Robots
Roombot, Symbryon : European Projects

"Resilient Machine"

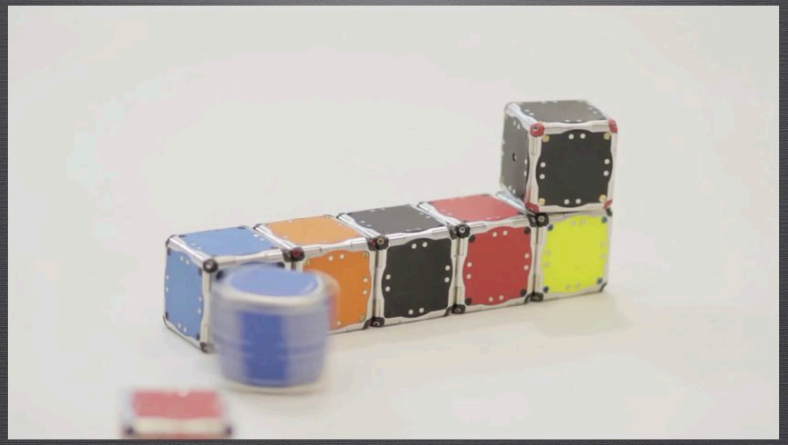


Resilient Machines Through Continuous Self-Modeling (Science Journal 2006)

M TRAN



SELF ASSEMBLY



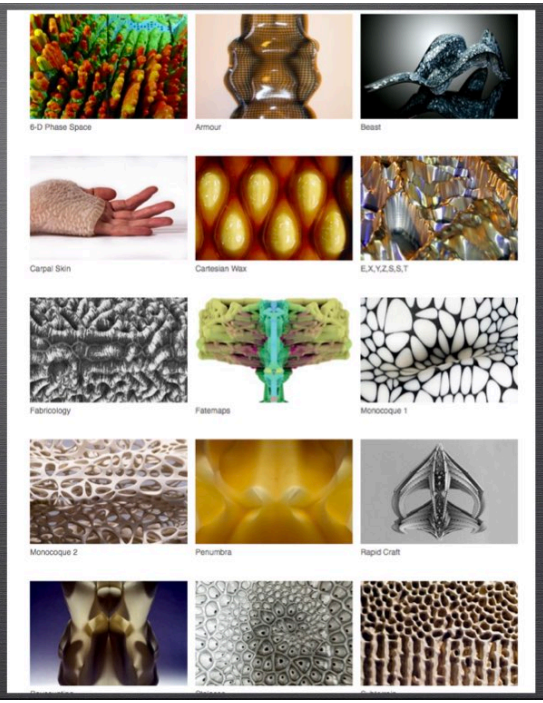
MIT

Festo, Germany

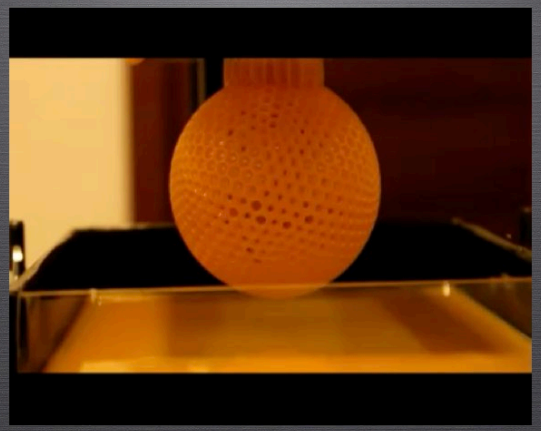
Boston Dynamic

Neri Oxman

MIT medialab



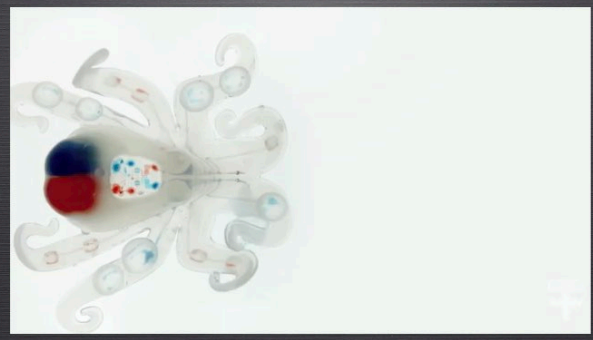
Replication (reproduction)



AIRBUS

OCTOBOT

3D Printing, Molding and Soft Lithography



Jennifer A. Lewis & Robert J. Wood
Harvard (SEAS), WYSS Institute
M. Werner, R. L. Truby. "Nature" 08/2016

Organ Printing

Sean V Murphy & Anthony Atala. Wake Forest University
"Nature Biotechnology"

2 Ontogenetic Models

SELF REPRODUCTION

&

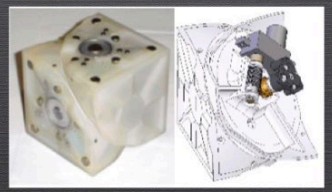
DEVELOPMENT

Artificial Embryogeny : "*methodological approach for reaching the level of complexity seen in natural organisms*"

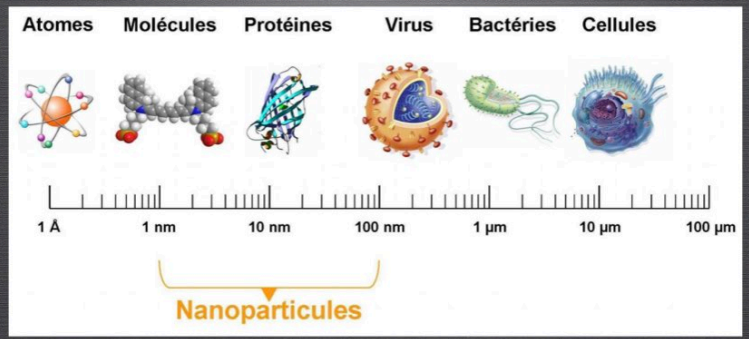
Stanley & Miikklainen 2003

« Design a machine that can design other machines »

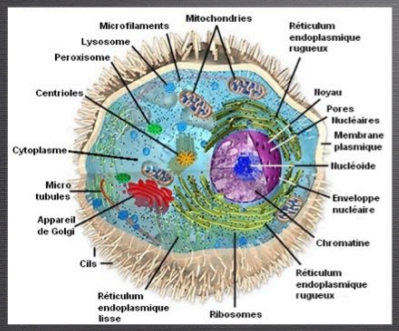
Hod Lipson
Cornell



Échelles du vivant

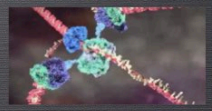


La cellule

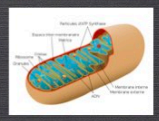


Code ADN

Impr. 3D

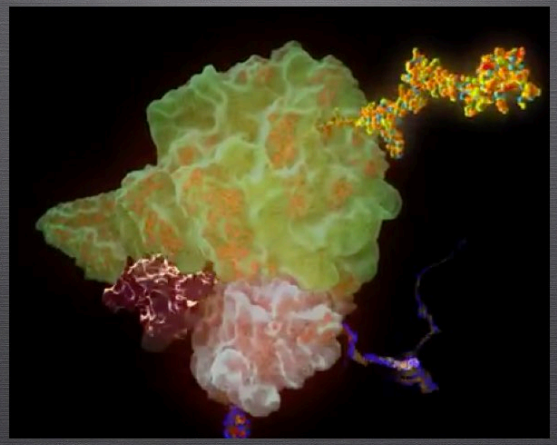


Energie



Images Drew Berry, Ethan Gray

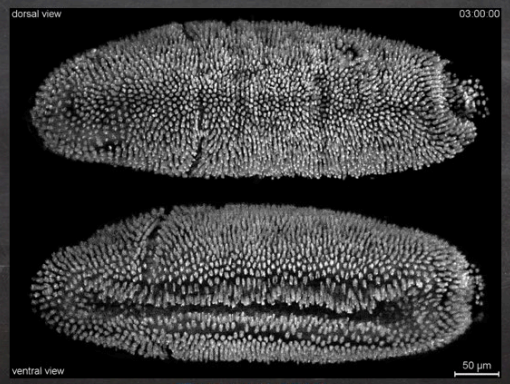
Bio 3D printer : The ribosome



Nobel Prize 2009
Ada E. Yonath Weizman Institute
Thomas A. Steiz, Yale University
Venki Ramakrishman MRC, Cambridge

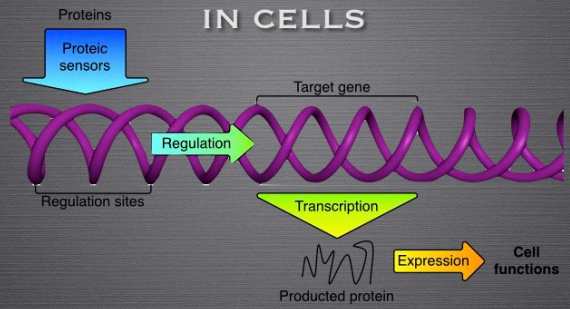
Gene Regulation in Biology

- Gene regulation in developmental biology
  - During the development of an organism, the GRN allows for:
    - the segmentation of the embryo (ex: drosophila)



(Tomer et al. 2012)

Genetic regulatory network in cells

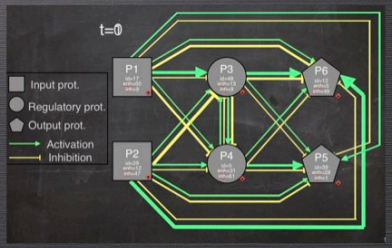


Proteic Sensors

Proteins activate or inhibit regulatory sequence in the DNA

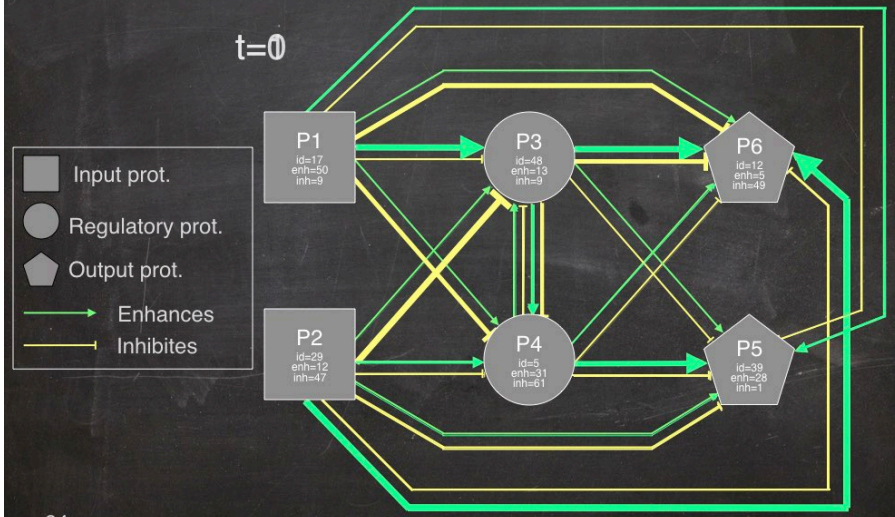
Regulatory sequence activate or not the gene expression

Gene expression determine the function of the cell



Artificial Gene Regulatory Networks

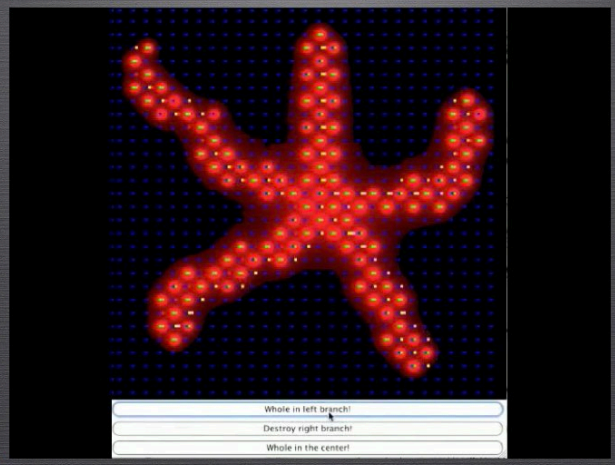
- Computational models: “Object-oriented” models



p=64

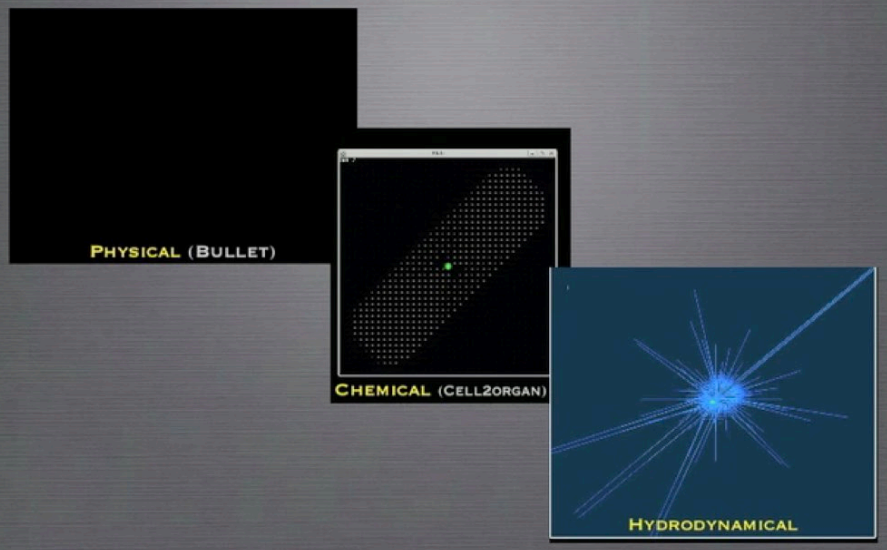
8

From one cell to a morphology and metabolism



VORTEX

3 simulators for growing creatures



VORTEX

Self Organizing Multicellular Artificial Systems

PhD Jean Disset

Mécanique et Chimie des cellules virtuelles

- Système masse-ressort-amortisseur
- Division
- Adhesion
- Collisions

- Morphogènes (molécules diffusées)
- Nutriments
- Energie

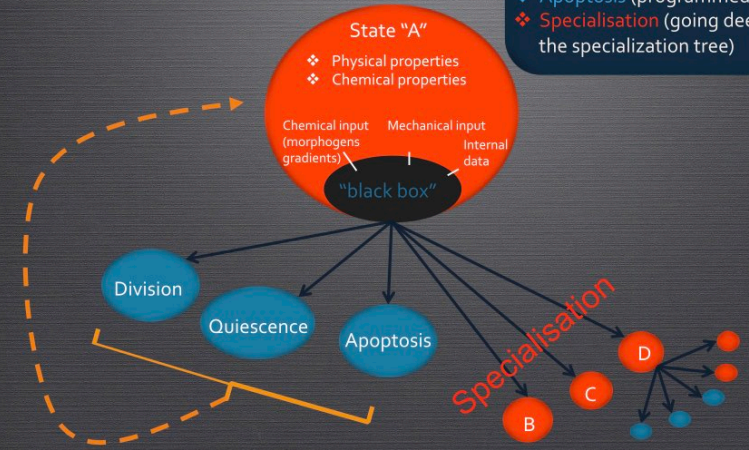
SoMAS

Life and evolution of a cell.

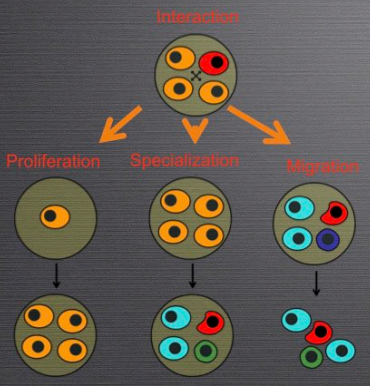
Differentiation and decision system (2/2)

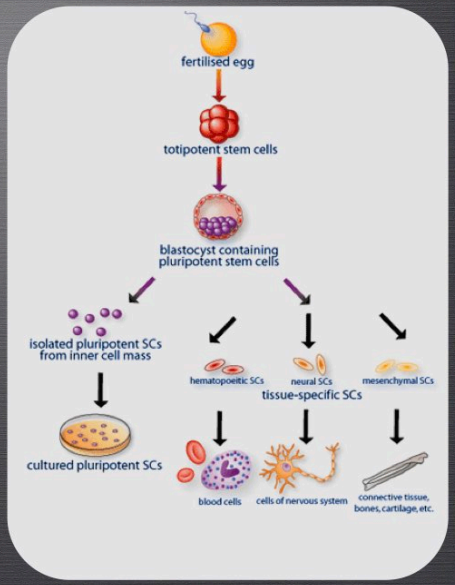
There are 4 possible actions for a cell

- Division (reproduce)
- Quiescence (inactivity)
- Apoptosis (programmed death)
- Specialisation (going deeper into the specialization tree)

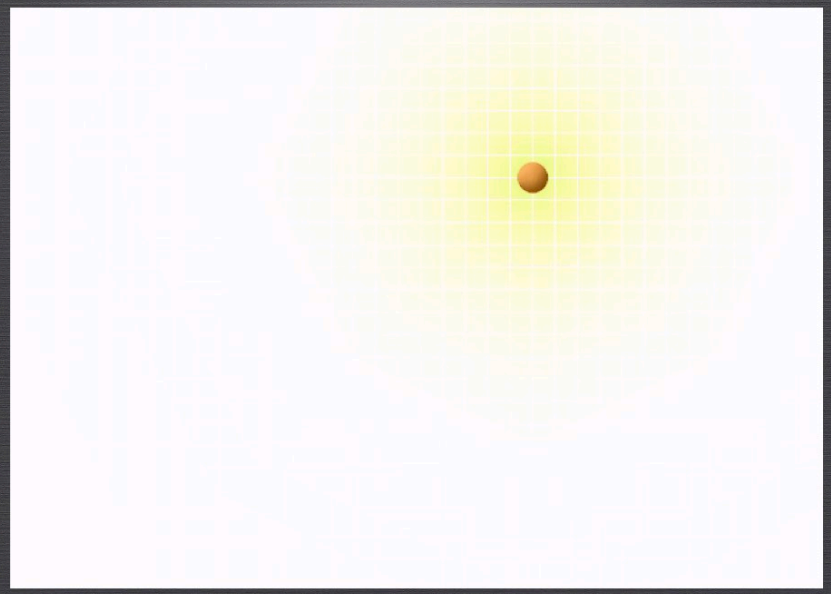


SoMAS

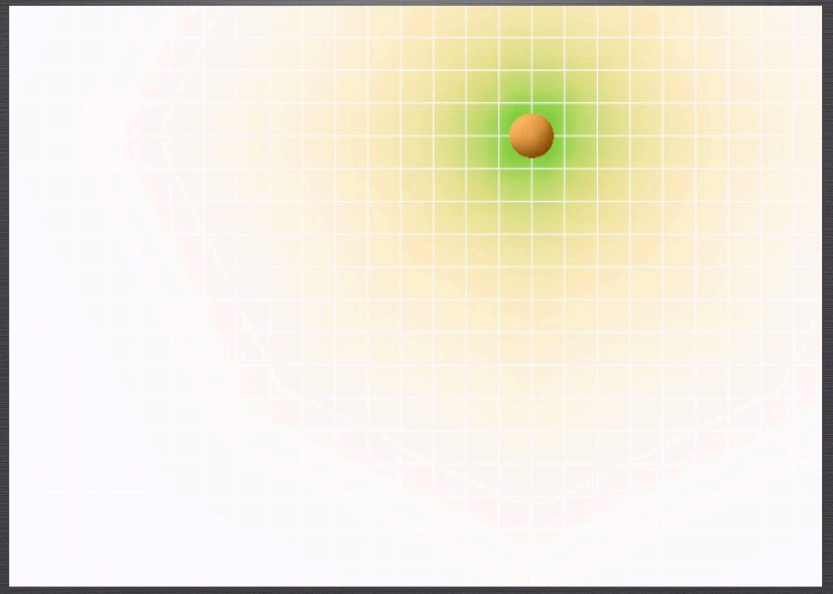


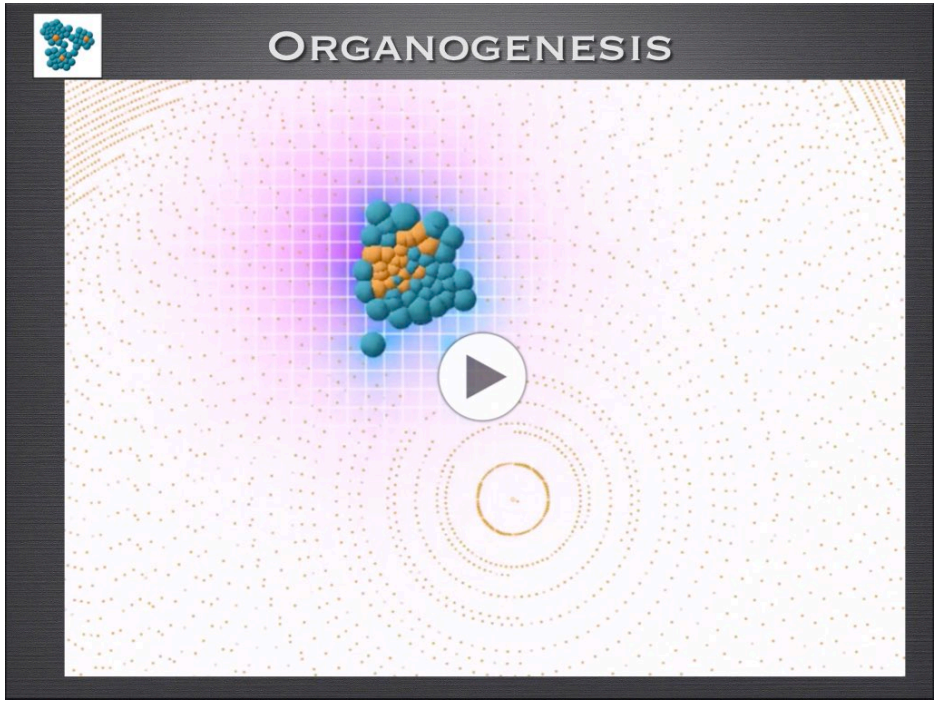


Organogenesis

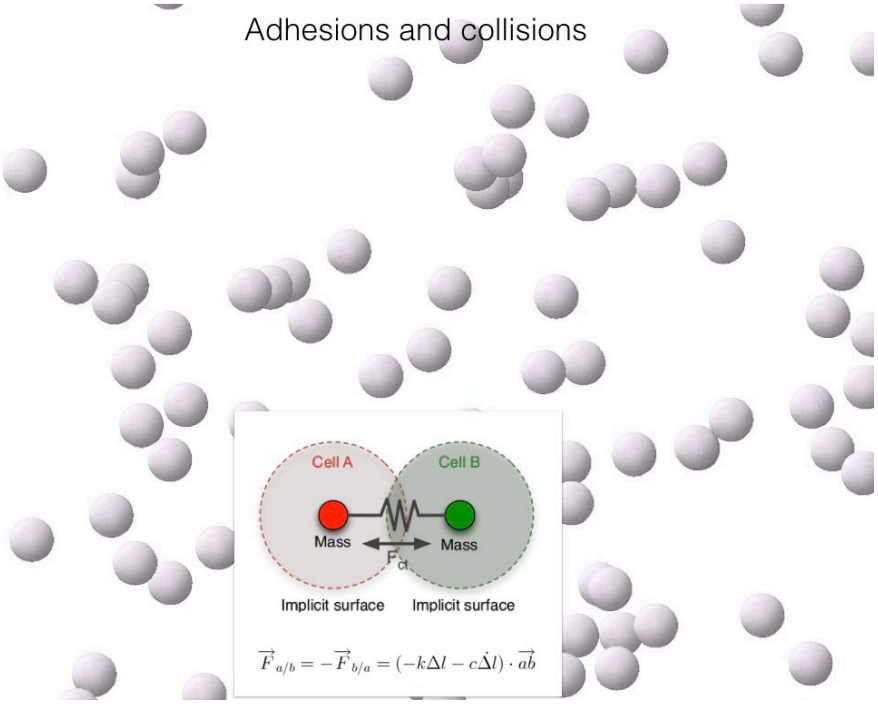


Organogenesis



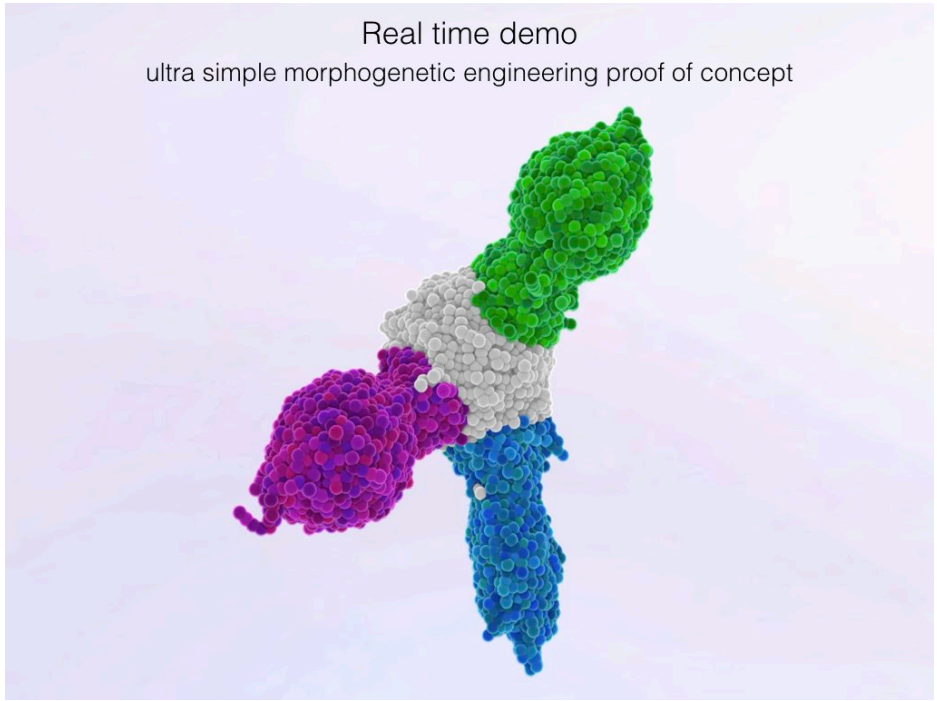


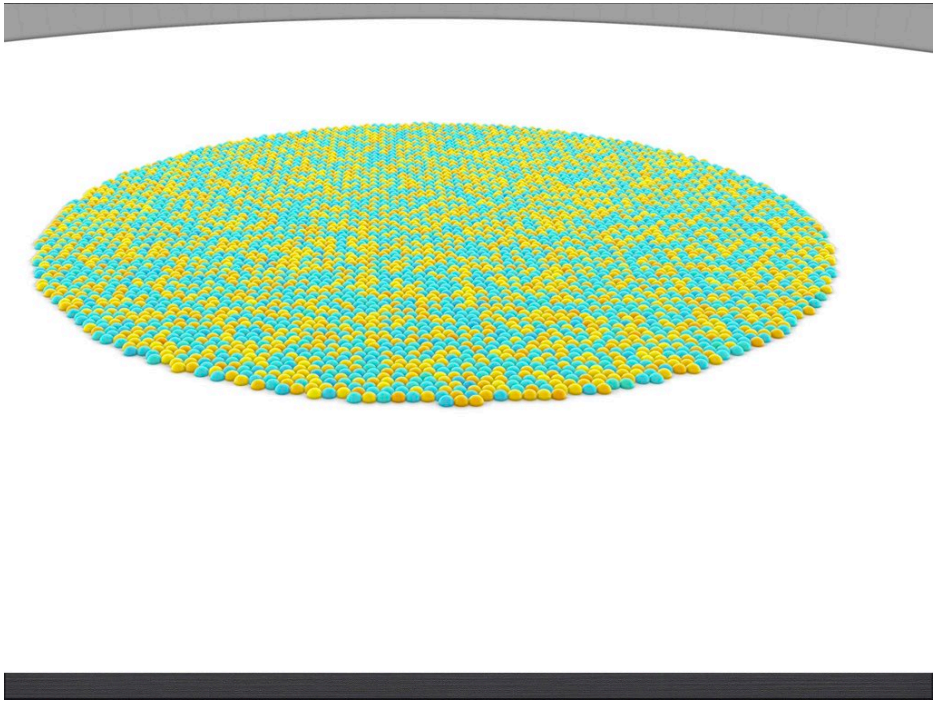
Adhesions and collisions



Real time demo

ultra simple morphogenetic engineering proof of concept





Performances

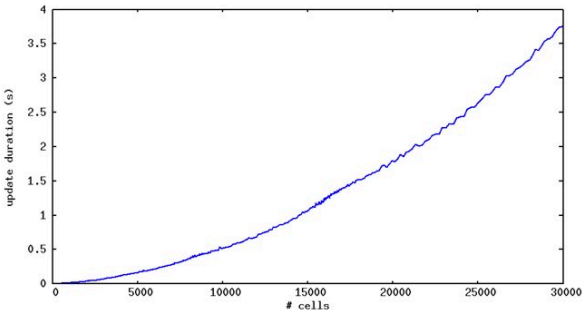
VORTEX

Self Organizing Multicellular Structures:

Application to cancer simulation

J. Disset, S. Cussat-Blanc, Y. Duthen

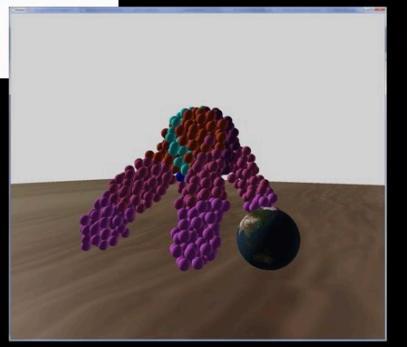
IRIT



e gave evolution four materials:

- **Muscle:** contract then expand
- **Tissue:** soft support
- **Muscle2:** expand then contract
- **Bone:** hard support

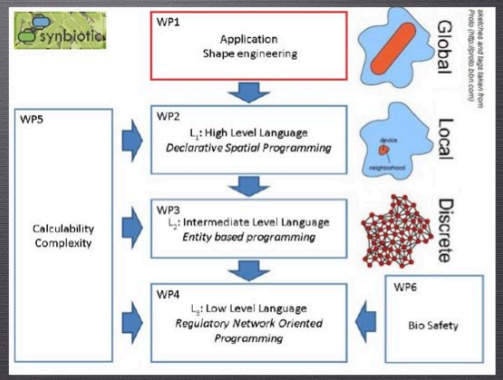
Corruci, Cheney, Lipson 2016



Doursat, Sanchez 2014

MORPHOGENETIC SYNTHETIC BIOLOGY

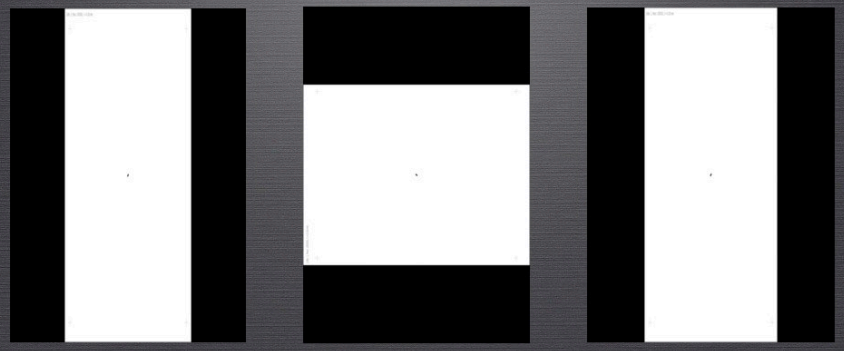
Biologie + Ingénierie pour concevoir et synthétiser des nouveaux systèmes et fonction biologique



Susan Stepney et al. (2012) GroCyPhy Project: Gardening cyber-physical systems.

Jonathan Pascalie 2016

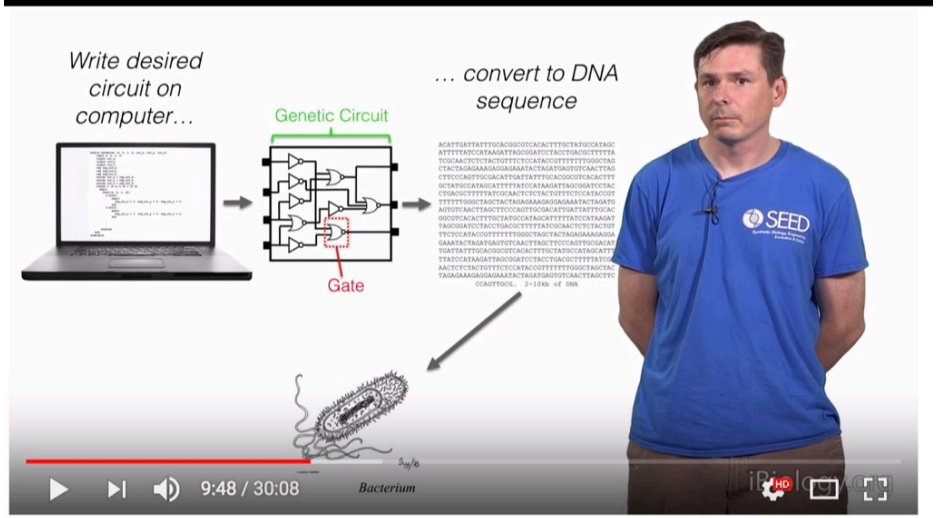
Signal + oscillateur interne => différentiation



3-armed starfish

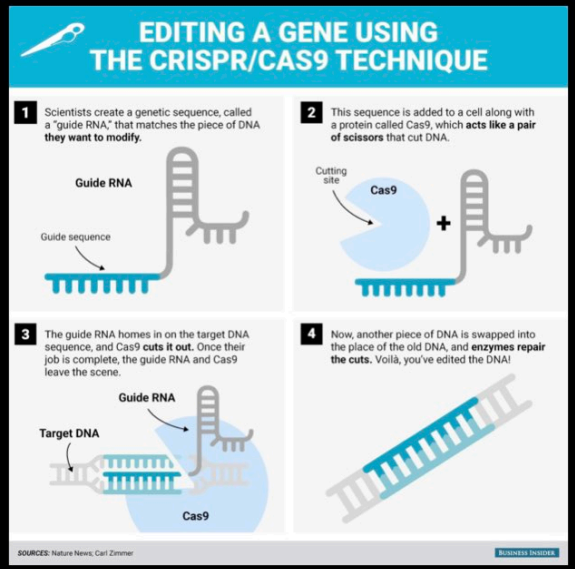
4-armed starfish

5-armed starfish



Synthetic Biology: Programming Living Bacteria - Christopher Voigt

MIT



Emmanuelle Charpentier / Jennifer Doudna (Berkeley)

3 Epigenetic Models

Epigenetic : ***developmental psychology*** *describe psychological development as the result of an ongoing, bi-directional interchange between heredity and the environment.*

Artificial Intelligence

SYMBOLIC (cognitive)
11 mai 1997 Deep Blue / Gary Kasparov

CONNEXIONNIST (constructivist)
Mars 2016 AlphaGo / Lee Seedol

- **Deep Learning Yann Le Cun**
- Deep reinforcement Learning, HTM-CLA
- HyperNEAT
- GAN

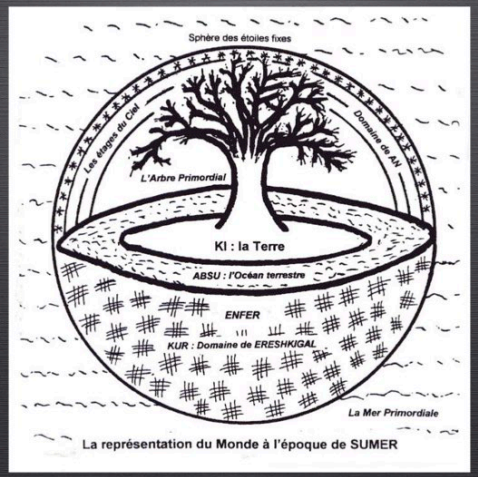
Impact Entreprise

Environnement, Santé, Transport, Commerce, Systèmes Sociaux et Culturel

Algorithmes maitres du monde ?

Google (rachat de Deep Mind)
IBM Watson
Facebook IA
Microsoft (Cortana, Bing, Azure ML)
Apple Siri, emotient Inc, proces
Baidu, EZDL deep Learning
Amazon, Alexa,
Uber AI, neuro-évolution, developmental learning
…

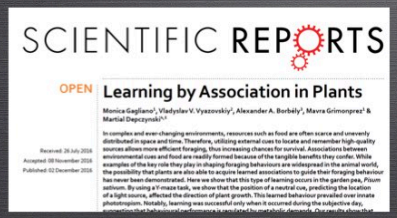
Représentation du Monde



(3500-2000 avant J.-C.)

Apprentissage

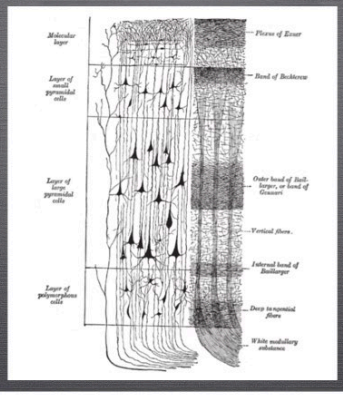
Animaux : neurones, système immunitaire
Plantes : ?

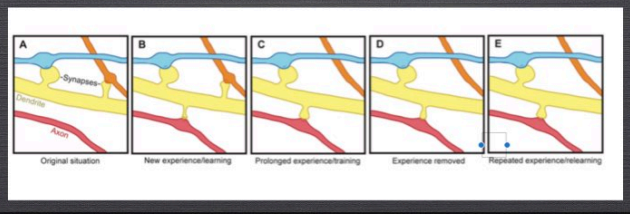

SCIENTIFIC REPORTS

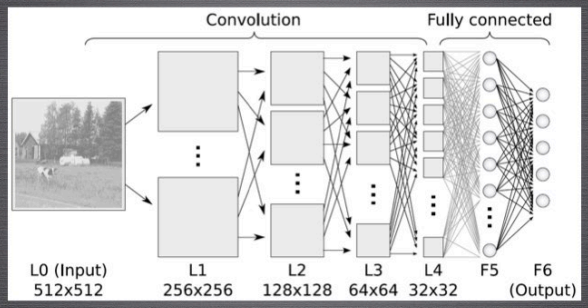
OPEN

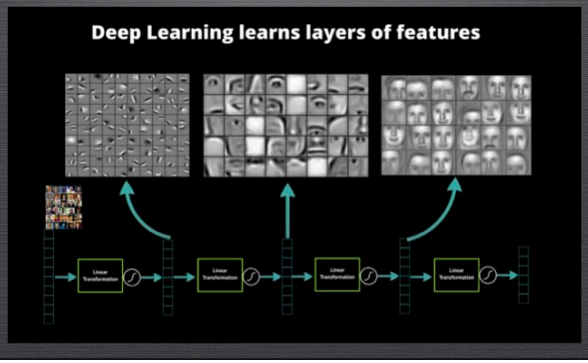
Learning by Association in Plants

Memory Architecture









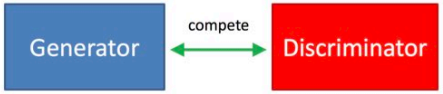
DEEP DREAM

GENERATIVE ADVERSARIAL NETWORK

https://openai.com/blog/generative-models/

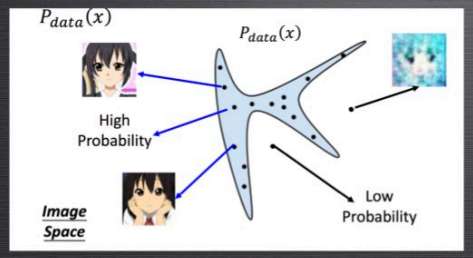
Two networks:

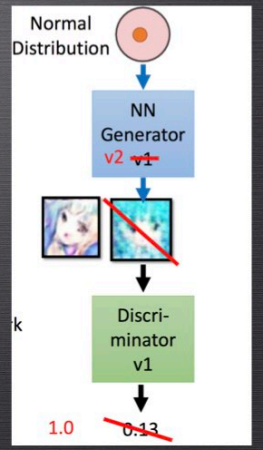
- Generator *G*: creates (fake) samples that the discriminator cannot distinguish
- Discriminator *D*: determine whether samples are fake or real



Les programmes peuvent-ils créer ?
ou peuvent-ils imaginer ?

PRINCIPLE





TEXTE vers IMAGE

Zhang et al 2016

Texte vers Image

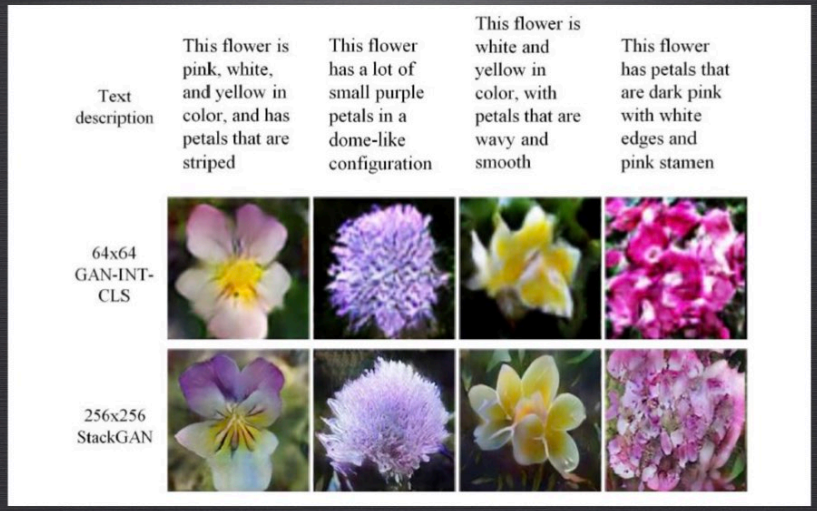
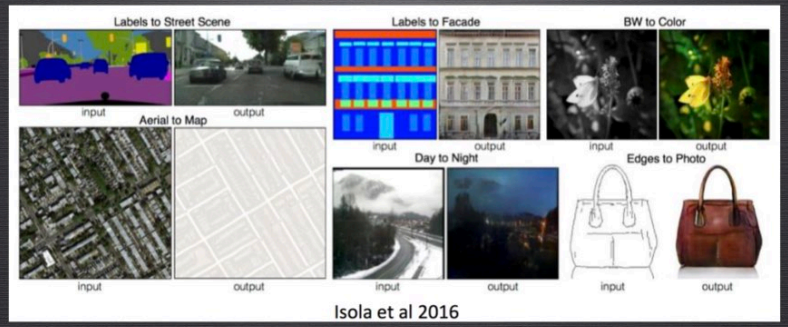


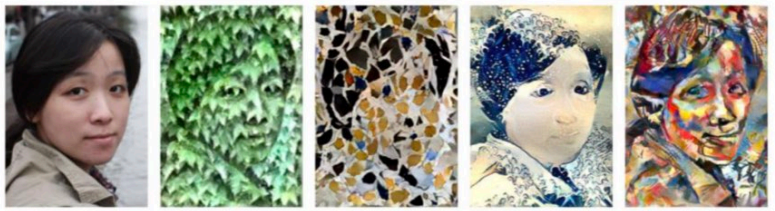
Image vers Image



Isola et al 2016

Textures

- Synthesize textures for input images

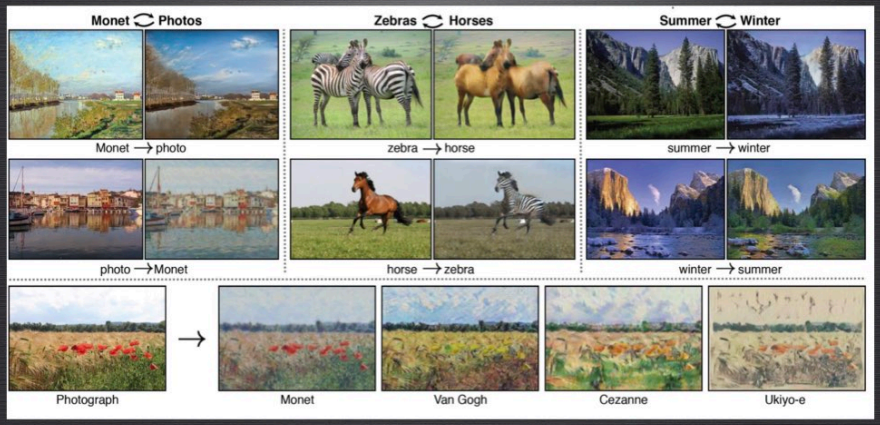


Li and Wand 2016

Textures

Li and Wand 2016

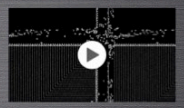
Cycle GAN



Synthèse de visage Mike Tyca
Générativité et humanité

Résumé

Vie Artificielle

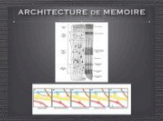


Créatures Artificielles

par assemblage de blocs
Phylogenèse

par développement
Ontogenèse

Apprentissage
Epigenèse



René Doursat