Pattern Formation in Computer Graphics

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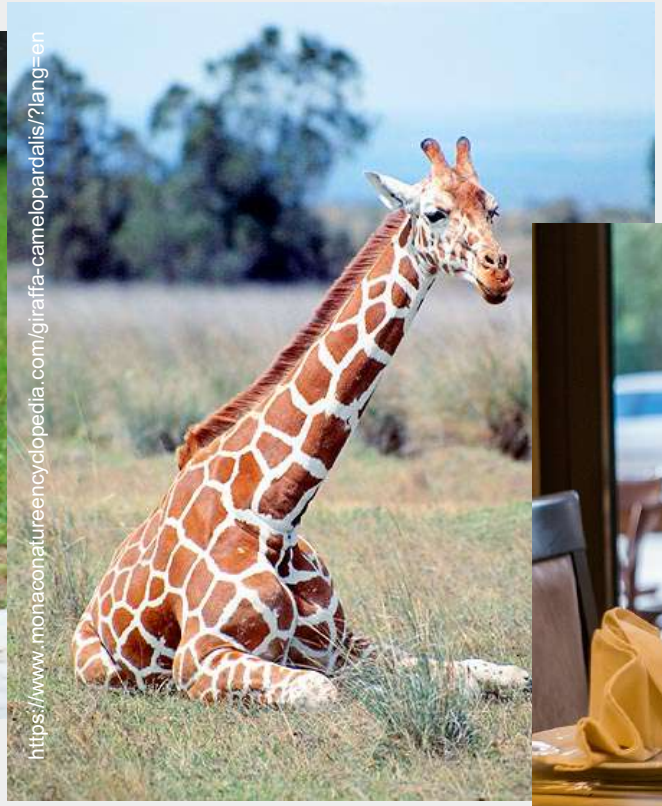
A little bit about our World…

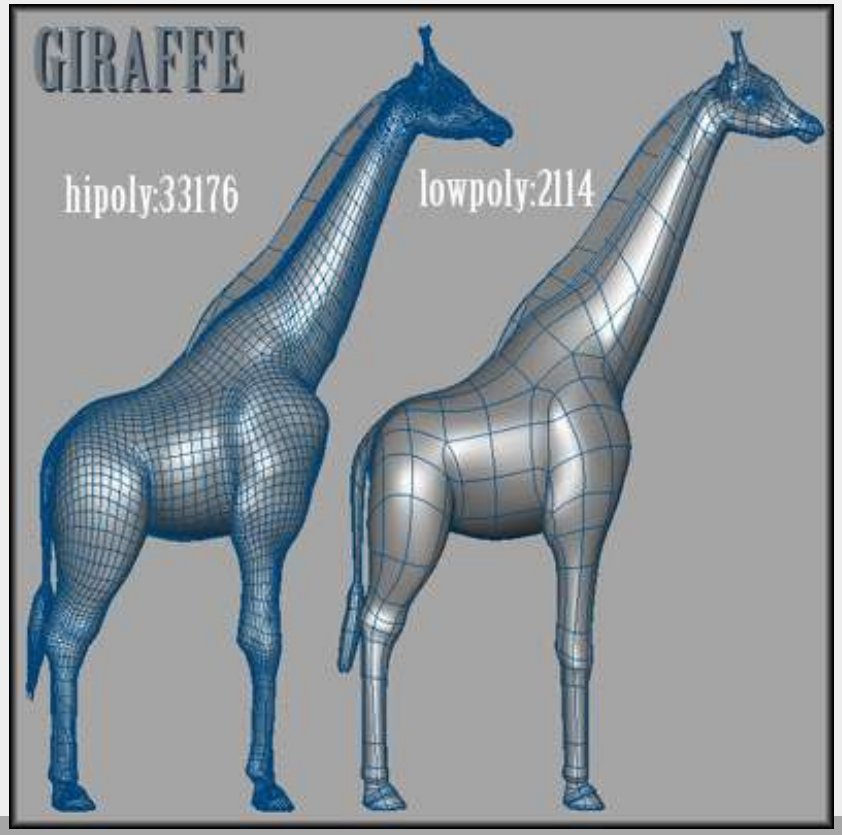
Objects have shape and appearance



https://www.monaconaturereencyclopedia.com/giraffa-camelopardalis/?lang=en

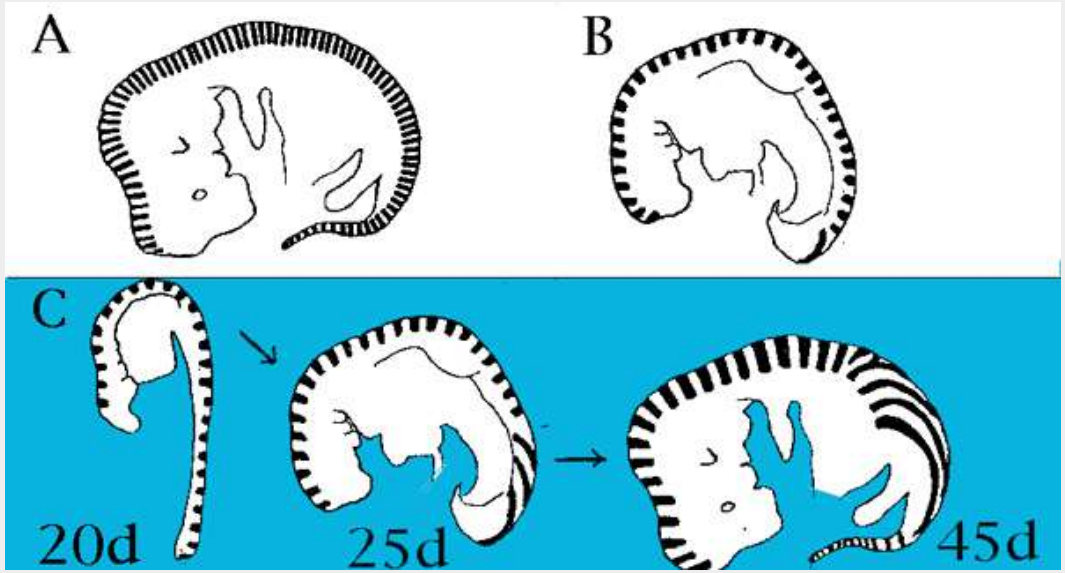
Imagem de Nenad Maric por Pixabay

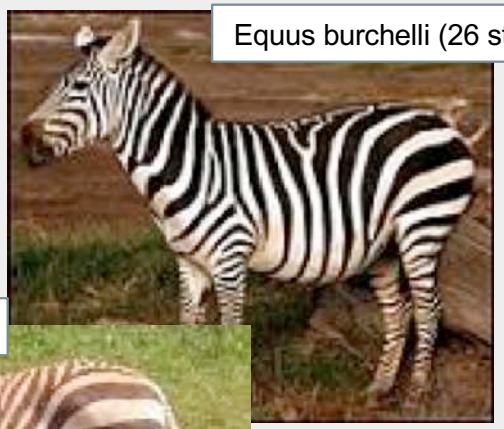
A little bit about our World…in Computer Graphics



Objects have shape and appearance separated…

The Need for Integration





Equus burchelli (26 stripes)

E. Zebra (55 stripes)

E. Grevyi (80 stripes)

A unity underlying the different zebra striping patterns.
B. L. Bard Jonathan. **Journal of Zoology:** 183(4), 1977

Diversity in Animal Kingdom

5000!!

Contrasting coloration in terrestrial mammals. T. Caro. Phil. Trans. R. Soc. B (2009) 364, 537–548

A Brief Timeline

1

1991

3

2003

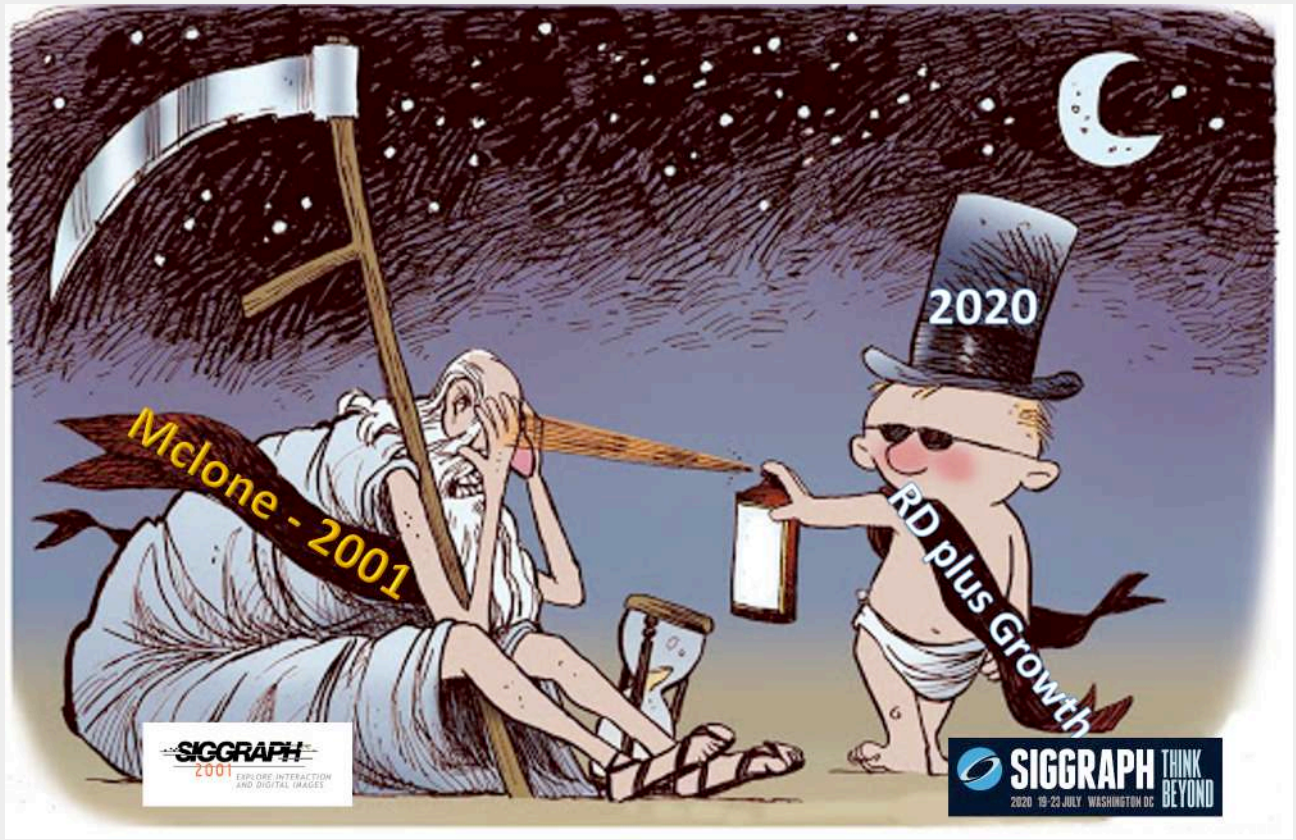
4

2010

2001

2

New Kid on the Block



The leopard never changes its spots: realistic pigmentation pattern formation by coupling tissue growth with reaction-diffusion

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Previous research in pattern formation using reaction-diffusion mostly focused on static domains, either for computational simplicity or mathematical tractability. In this work, we have explored the expressiveness of combining simple mechanisms as a possible explanation for pigmentation pattern formation, where tissue growth plays a crucial role. Our motivation is not only to realistically reproduce natural patterns but also to get insights into the underlying biological processes. Therefore, we present a novel approach to generate realistic animal skin patterns. First, we describe the approximation of tissue growth by a series of discrete matrix expansion operations. Then, we combine it with an adaptation of Turing's non-linear reaction-diffusion model, which enforces upper and lower bounds to the concentrations of the involved chemical reagents. We also propose the addition of a single-reagent continuous autocatalytic reaction, called reinforcement, to provide a mechanism to maintain an already established pattern during growth. By careful adjustment of the parameters and the sequencing of operations, we closely match the appearance of a few real species. In particular, we reproduce in detail the distinctive features of the leopard skin, also providing a hypothesis for the simultaneous productions of the most common melanin types, eumelanin and pheomelanin.

CCS Concepts: • **Computing methodologies** → **Computer graphics**; **Modeling and simulation**.

Additional Key Words and Phrases: natural phenomena, texturing, pattern formation, reaction-diffusion, Turing model

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1 INTRODUCTION

Growth is an essential mechanism of life and a continuous process since the inception of all living beings. Although much research has been done on cellular biochemistry, the overall mechanisms responsible for growth have been only partially uncovered by now, and are already very complex [Wolpert et al. 2015].

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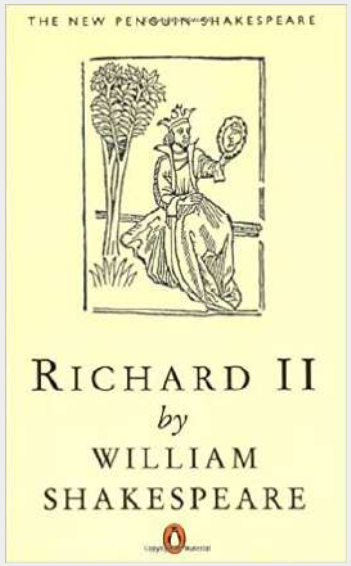
Reaction-diffusion is a well-known model conceived by Turing [1952], being later used in Computer Graphics by the pioneering works of Turk [1991], Witkin and Kass [1991] and Fowler et al. [1992] for simulating natural phenomena. Although interest in reaction-diffusion faded along the years for the graphics community, it continued to play a major role in theoretical models from Mathematical Biology [Maini et al. 2012; Meinhardt 2009; Murray 2003].

We are interested in the general problem of reproducing the appearance of animal skin patterns. Instead of focusing on procedural methods [Hu et al. 2019], exemplar-based techniques [Raad et al. 2018] or indirectly through machine learning [Zhou et al. 2018], we show that a reduced subset of simulated biological mechanisms is enough to generate accurate textures.

Our main contribution is showing that the adequate approximation of tissue growth combined with reaction-diffusion is the key to the emergence of complex yet realistic patterns. By carefully adjusting model parameters and setting up distinct growth phases, we can match skin pigmentation of mammals and other animals. In particular, we have produced *in silico* the characteristic leopard rosettes, depicted in a 3D rendering in Figure 1.

Fig. 1. Synthetic leopard coat: pigmentation generated by our technique and then rendered in 3D by assigning individual fur colors. The skin below the fur layer has a uniform pink color and it is barely visible.

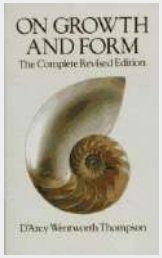
Can the Ethiopian change his skin, or the leopard his spots?
Neither can you do good
who are accustomed to doing evil.
Jeremiah ch. 13, v. 23

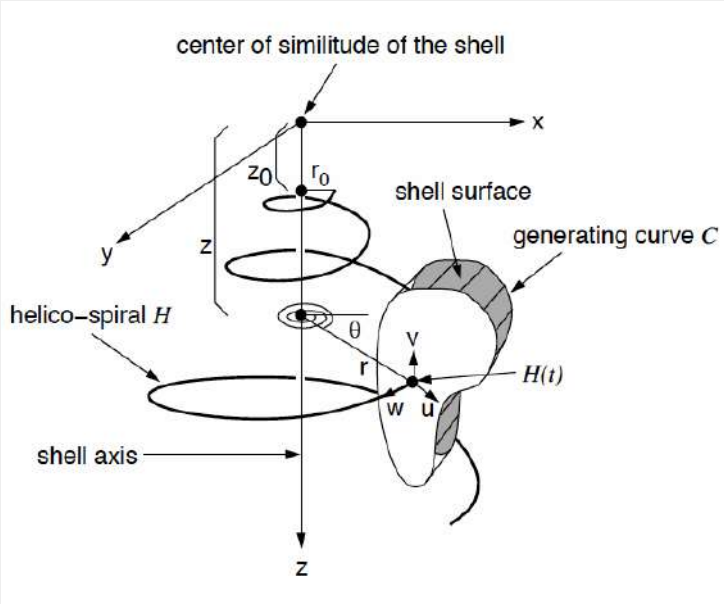


KING RICHARD III
Rage must be withstood:
Give me his gage: lions make leopards tame.

THOMAS MOWBRAY
Yea, but not change his spots:
take but my shame.

Seashells – Fully Integrated Model





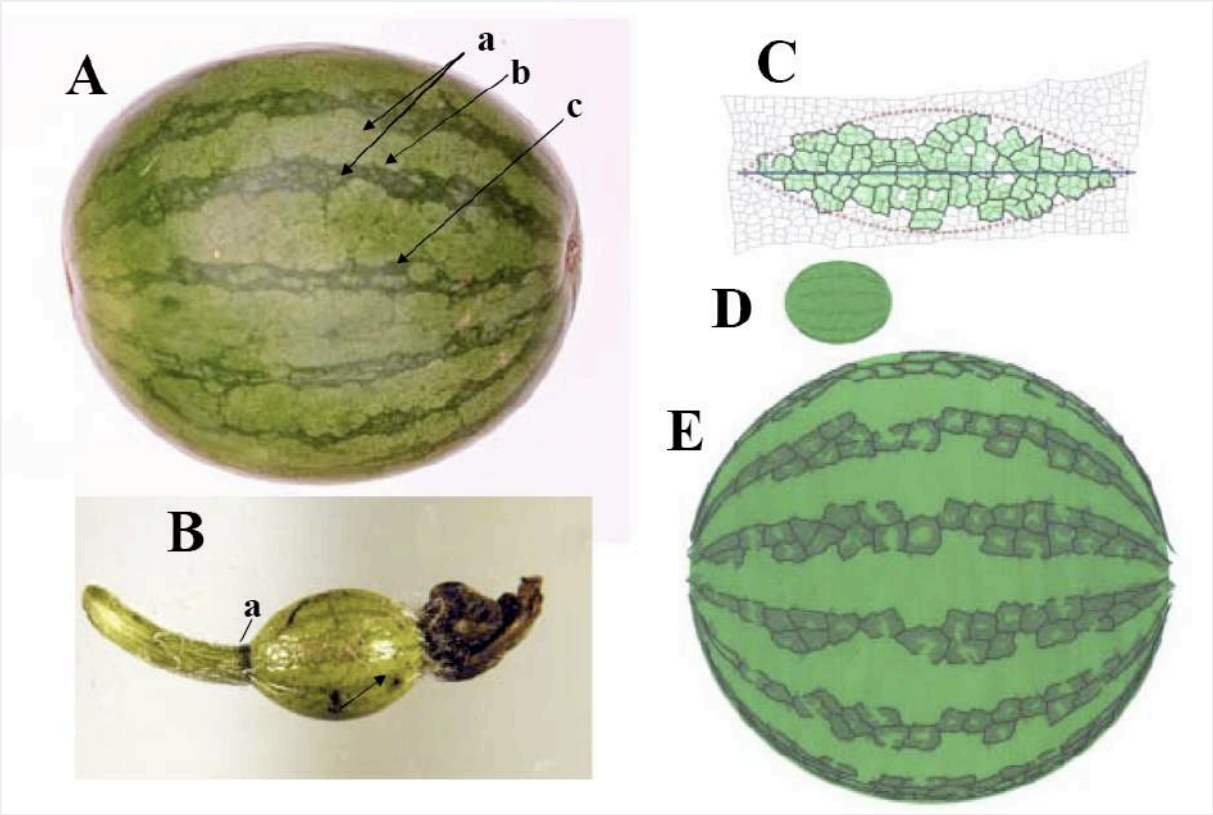
Modeling Seashells
Deborah R. Fowler, Hans Meinhardt, Przemyslaw Prusinkiewicz
Proceedings of SIGGRAPH 92

What about other domains?

http://www.africanbudgetsafaris.com/images/tours/three-rondawels.jpg

Fortaleza Canyon – RS

What about the Plant Kingdom?



Robert W. Korn. ***Watermelon stripes. A case for the clonal mosaic model in plants***. Journal of Theoretical Biology *(2007)*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thelope.com

A unifying theory?

Hanwoo Cow

Biology of epidermal and hair pigmentation in cattle: a mini-review.
Seo K, Mohanty TR, Choi T, Hwang I. Vet Dermatol. 2007;18(6):392-400


http://en.wikipedia.org/wiki/Loricariidae

To Wrap it Up

The Bad News is that we still have a long way to go!

The Good News is that we still have a long way to go!

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Obrigado!

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