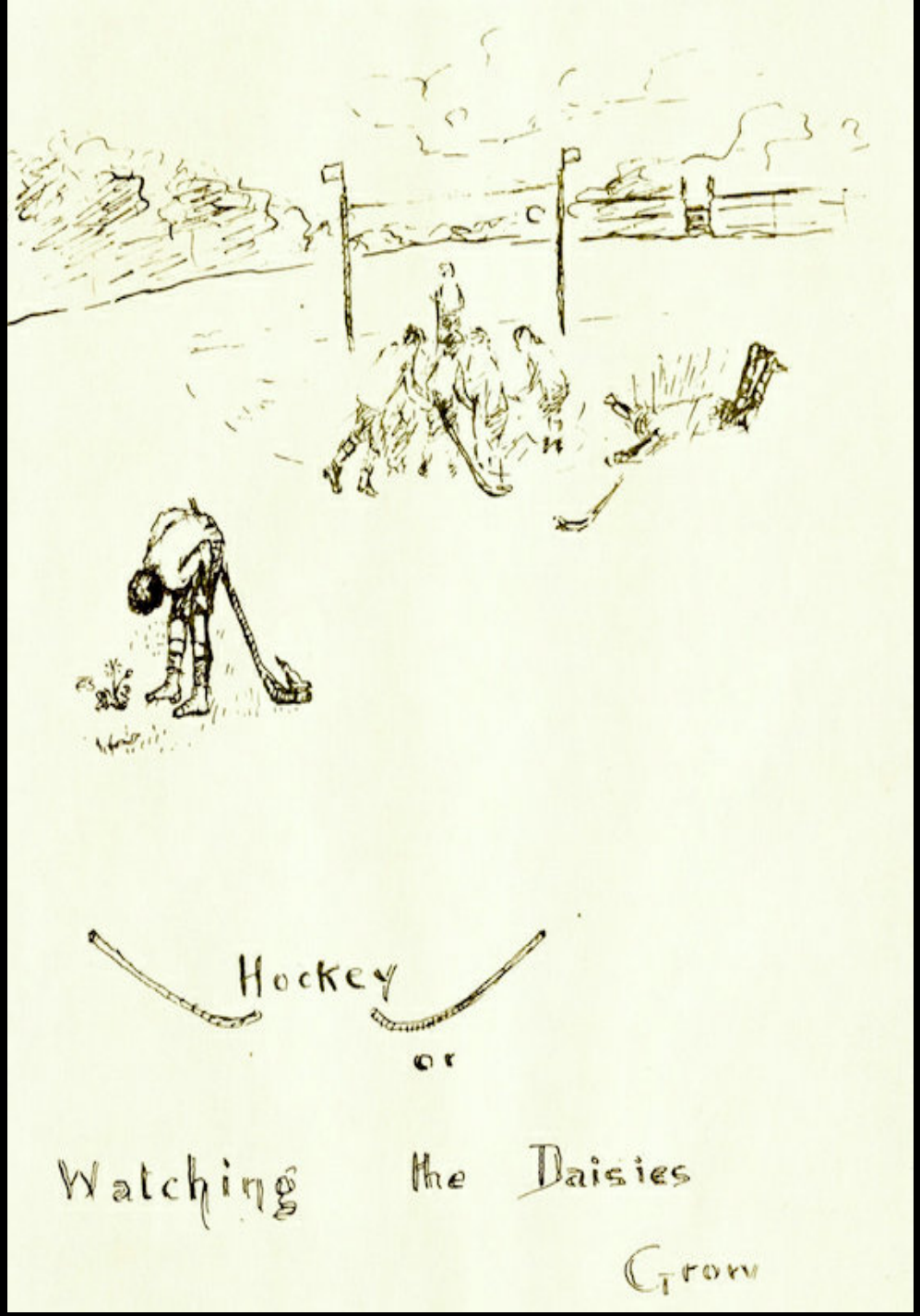
&
Morphogenesis

Source: Google images



Source:
The mathematics of nature at the Alan Turing centenary
S. Barry Cooper and Philip K. Maini

Alan Turing

University of Cambridge
Computer Science
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Title / Author	Cited by	Year
The chemical basis of morphogenesis AM Turing Philosophical Transactions of the Royal Society of London. Series B ...	6003	1952
Computing machinery and intelligence AM Turing Mind 59 (236), 433-460	5443	1950
On computable numbers, with an application to the Entscheidungsproblem (1936) A Turing B. Jack Copeland, 58	5440	2004

Alan Turing

University of Cambridge
Computer Science
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Title	The chemical basis of morphogenesis
Authors	Alan Mathison Turing
Publication date	1952/8/14
Journal name	Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences
Volume	237
Issue	641
Pages	37-72
Publisher	The Royal Society
Description	Abstract It is suggested that a system of chemical substances, called morphogens, reacting together and diffusing through a tissue, is adequate to account for the main phenomena of morphogenesis. Such a system, although it may originally be quite homogeneous, may later develop a pattern or structure due to an instability of the homogeneous equilibrium, which is triggered off by random disturbances. Such reaction-diffusion systems are considered in some detail in the case of an isolated ring of cells, a mathematically convenient, though ...

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The chemical basis of morphogenesis
AM Turing - Philosophical Transactions of the Royal Society of ..., 1952
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The Chemical Basis of Morphogenesis

STOR®

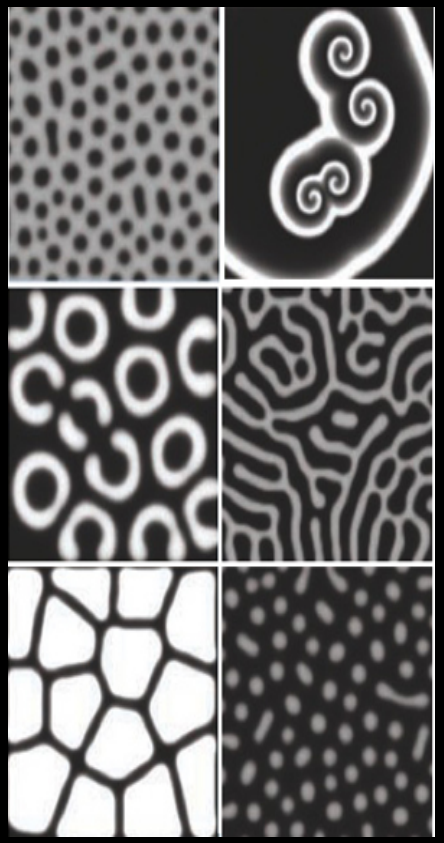
A. M. Turing

Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, Vol. 237, No. 641. (Aug. 14, 1952), pp. 37-72.

- What might cause phenomenon of developmental patterns such as *phyllotaxis.*
- Turing proposed a theory of developmental pattern formation.

Reacting chemicals

diffusion



Morphogens as chemical pre-patterns

It is suggested that a system of chemical substances, called morphogens, reacting together and diffusing through a tissue, is adequate to account for the main phenomena of morphogenesis.

Turing's main hypothesis was that the resulting gradient of chemical concentrations could cue differential cell growth and result in pattern formation.

Diffusion-driven instability

- A system of chemicals which is stable in the absence of diffusion becomes unstable in the presence of diffusion.

A Reaction-diffusion Model

$$\frac{\partial u}{\partial t} = \gamma f(u,v) + D_u \nabla^2 u,$$

$$\frac{\partial v}{\partial t} = \gamma g(u,v) + D_v \nabla^2 v,$$

$$\frac{\partial f}{\partial u} + \frac{\partial g}{\partial v} < 0;$$

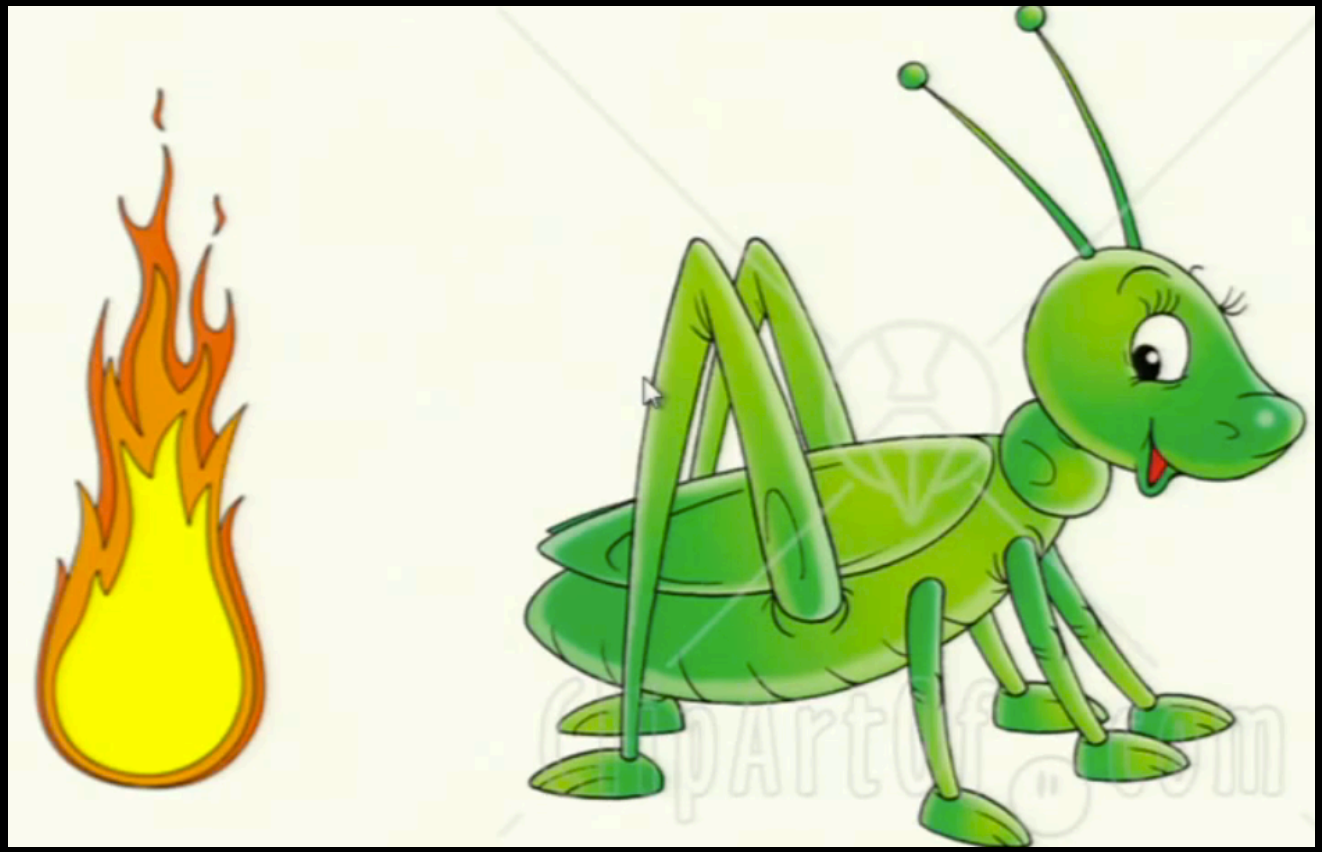
$$\frac{\partial f}{\partial u}\frac{\partial g}{\partial v} - \frac{\partial f}{\partial v}\frac{\partial g}{\partial u} > 0;$$

$$D_u\frac{\partial g}{\partial v} + D_v\frac{\partial f}{\partial u} > 0;$$

$$D_u\frac{\partial g}{\partial v} + D_v\frac{\partial f}{\partial u} > \sqrt{D_u D_v}\left(\frac{\partial f}{\partial u}\frac{\partial g}{\partial v} - \frac{\partial f}{\partial v}\frac{\partial g}{\partial u}\right)$$

A stability analysis of the steady states of the kinetics shows that to generate spatial patterns in u and v, it is necessary, among other things, that the inhibitor have a higher diffusion rate than the activator, that is $D_v > D_u$;

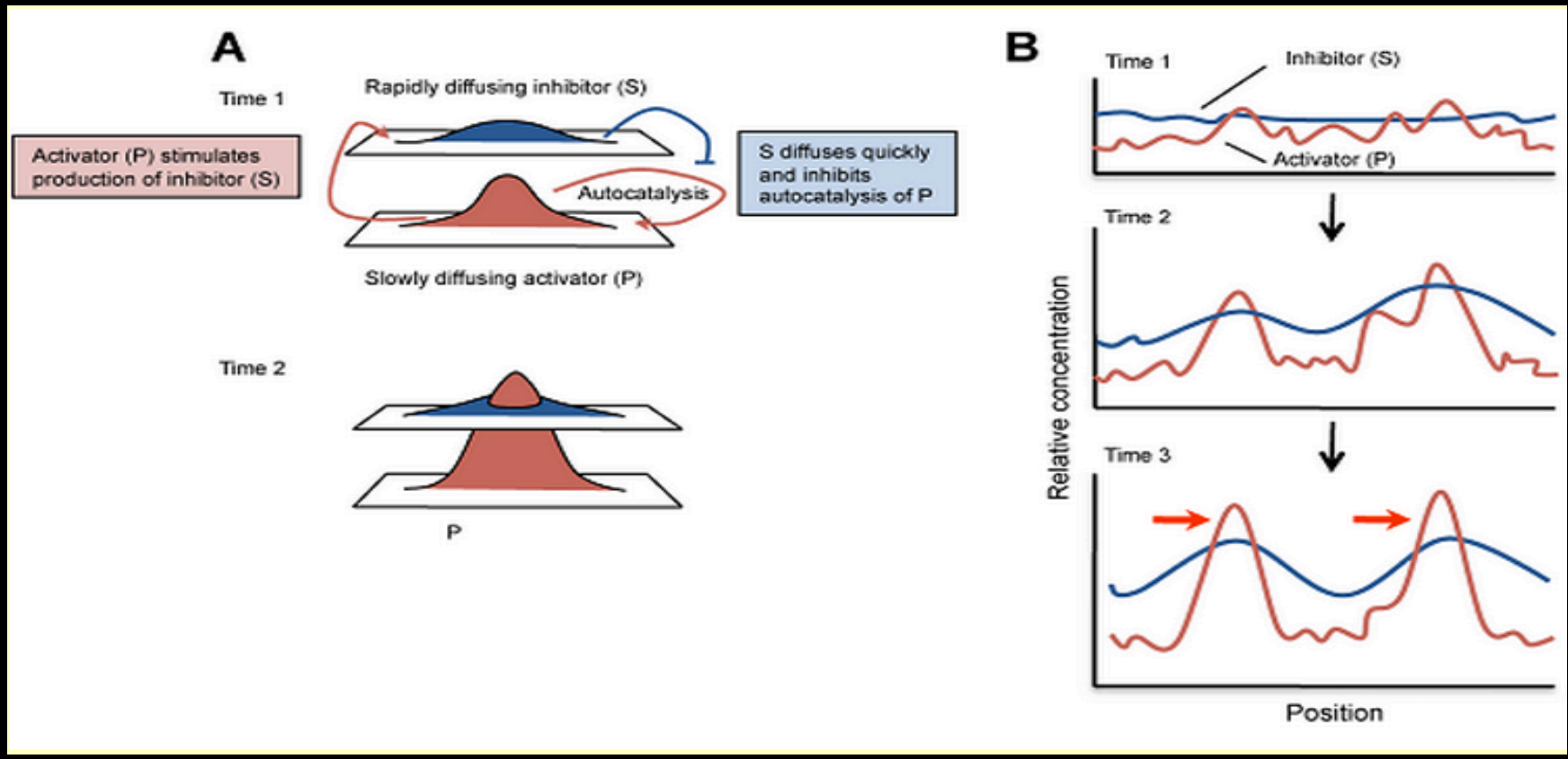
J.D. Murray's Fire and Grasshopper metaphor



Source Philip Maini's talk on youtube:
http://www.youtube.com/watch?v=pN8tVldm6QY

Basic principles behind patterning

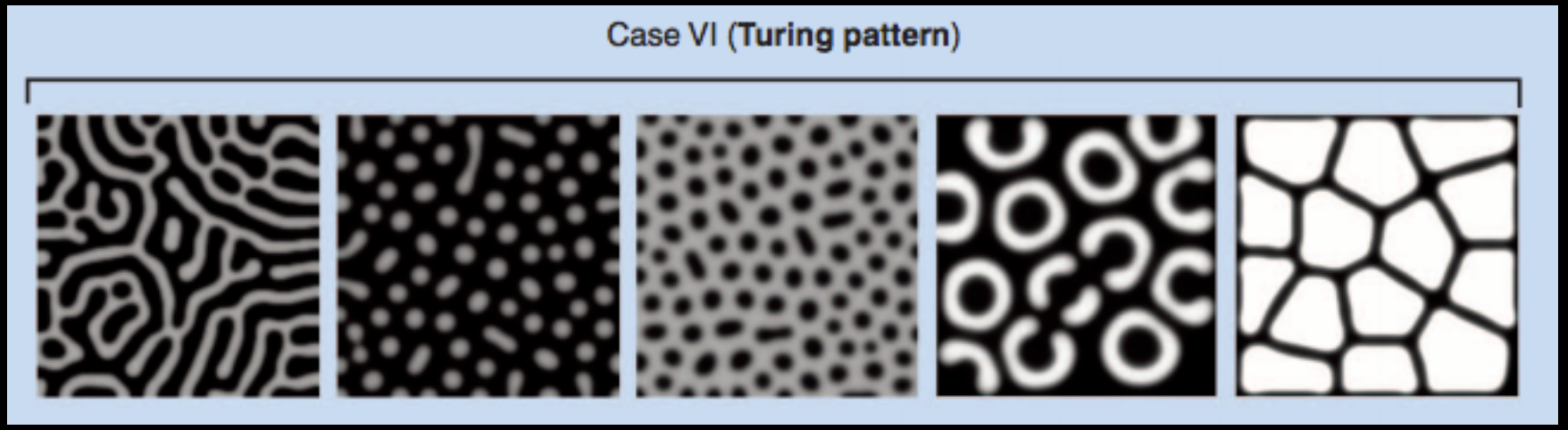
- Short-range activation gives long-range inhibition



Source: https://sitn.hms.harvard.edu/sitnflash_wp/2012/07/morphogenesis/

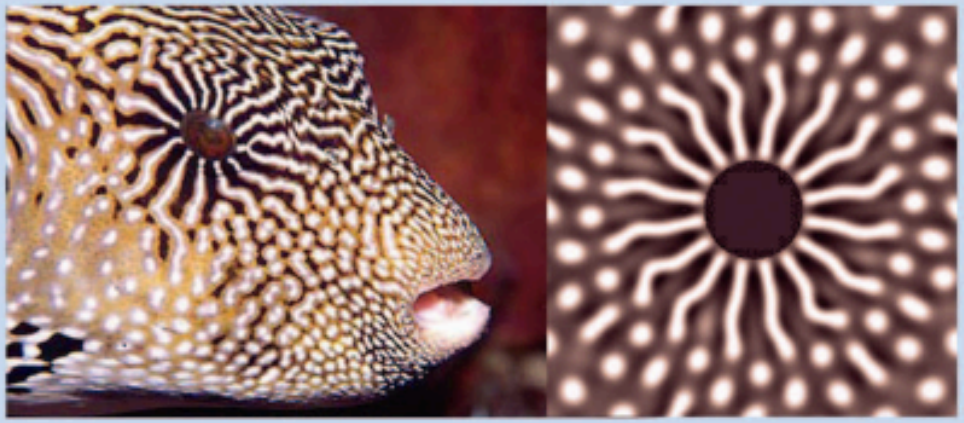
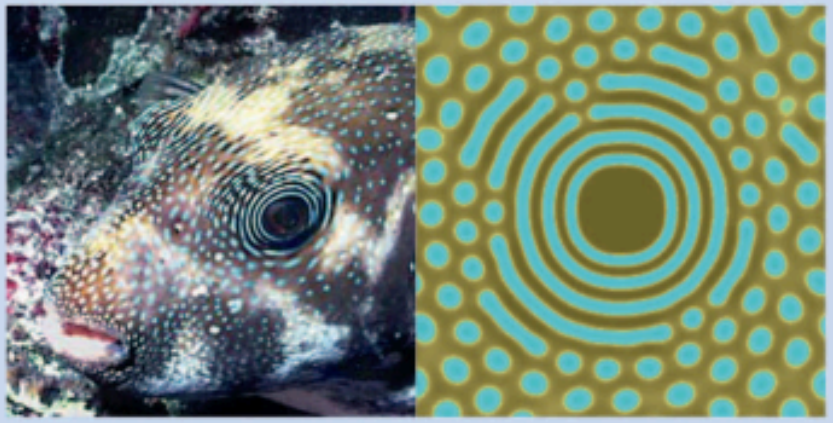
Predictions from Turing's Model

- For Turing patterns to occur, the spatial domain should have a minimum size
- Complexity of the Turing patterns is dependent on the domain size.
- Geometry of the spatial domain plays a big role



Source: *Reaction-Diffusion Model as a Framework for Understanding Biological Pattern Formation* Shigeru Kondo and Takashi Miura
Science 329, 1616 (2010);



From: *Reaction-Diffusion Model as a Framework for Understanding Biological Pattern Formation* Shigeru Kondo and Takashi Miura
Science 329, 1616 (2010);

How the Leopard got its spots?

Source: Google images

$$\frac{\partial u}{\partial t} = \gamma f(u,v) + D_u \nabla^2 u,$$

$$\frac{\partial v}{\partial t} = \gamma g(u,v) + D_v \nabla^2 v,$$

$$f(u,v) = a - u - h(u,v),$$

$$g(u,v) = \alpha(b - v) - h(u,v),$$

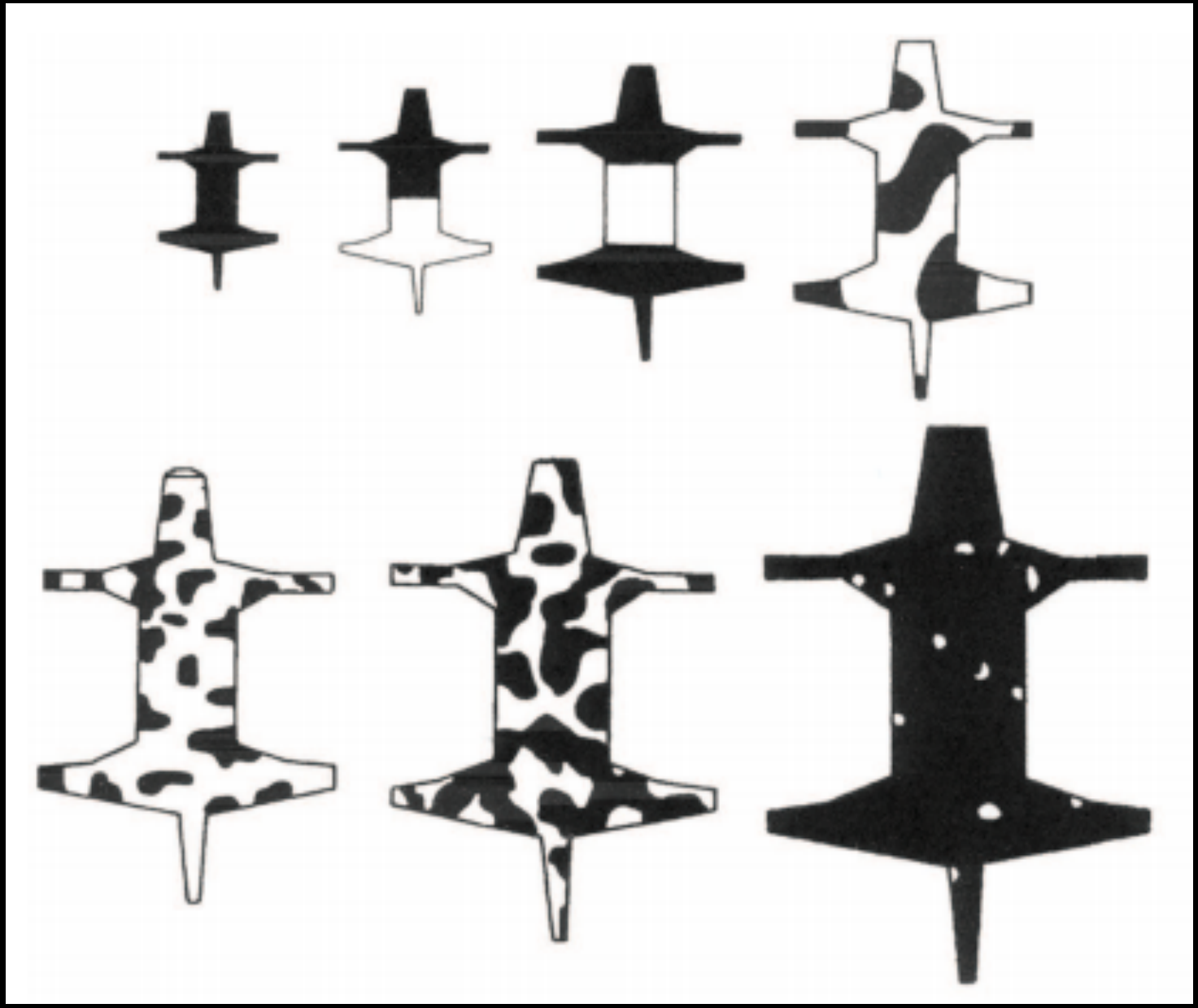
$$h(u,v) = \frac{\rho u v}{1 + u + K u^2},$$

Source: J. D. Murray's article, http://www.ams.org/notices/201206/rtx120600785p.pdf

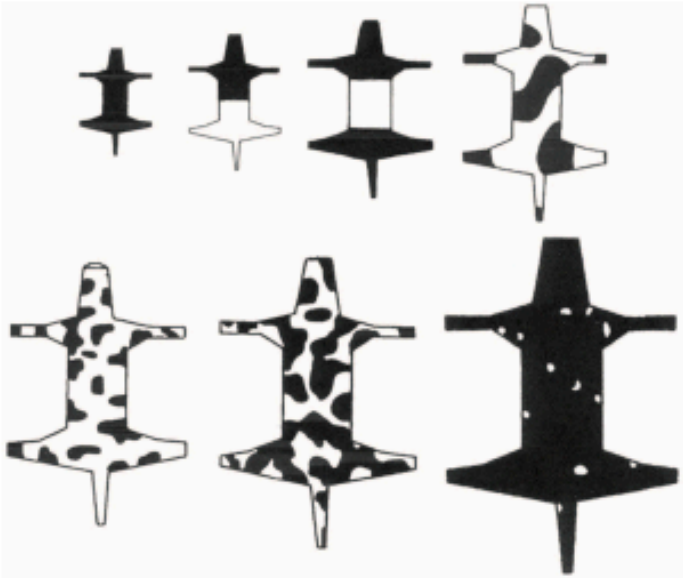
Spotted animals can have striped tails but not the other way round

“All Models are wrong… but some are useful” – George Box

Source Philip Maini’s talk on youtube:
http://www.youtube.com/watch?v=pN8tVldm6QY



Source: J. D. Murray's article, http://www.ams.org/notices/201206/rtx120600785p.pdf



(a)

(b)

(c)

(d)

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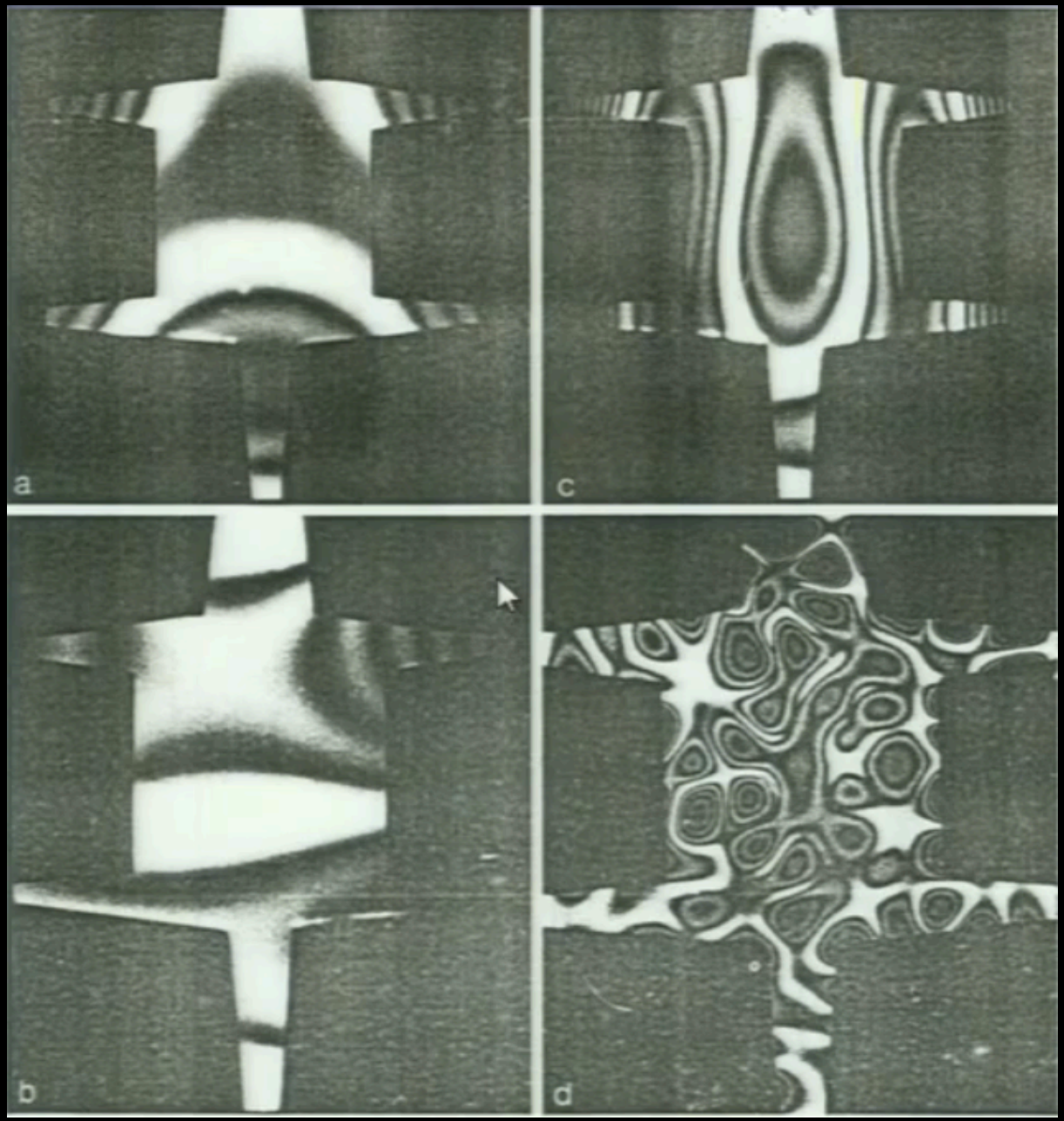

Source Philip Maini's talk on youtube:
http://www.youtube.com/watch?v=pN8tVldm6QY

Conclusions

- Turing's paper on morphogenesis revolutionized biology
- Still remains a seminal work in several areas
- Inspired an enormous amount of mathematics.