Reaction-Diffusion Systems in Pattern Formation and Pattern Recognition Processes

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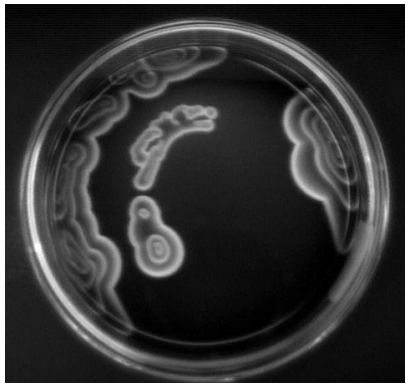
Outline

- Introduction
- Motivation
  - Pattern formation and Pattern recognition
- Our research work
  - reaction-diffusion algorithm of edge detection
- Experimental results
- Conclusion
- Future research work

Introduction:

Pattern Formation Process

- Chemical reaction system
  - Belousov-Zhabotinsky (BZ) reaction
- Biological system
  - Amoeba: Dictyostelium discoideum
- Spiral pattern and target pattern



Laboratory experiment of BZ

Numerical simulation of BZ

Biological signaling Cell density Biological signaling Cell density

Numerical simulation of Dictyostelium discoideum

Introduction:

Stationary Pattern Formation

- Turing scenario in biological systems
  - Turing, *Phil. Trans. Roy. Soc.*, 1952
    - Rapid inhibitory diffusion
  - Gierer & Meinhardt, *Kybernetik*, 1972
    - Realistic models for biological pattern formation
  - Kondo & Asai, *Nature*, 1995
    - Fish skin

Introduction:

Reaction-Diffusion System

- Diffusion equation with a source term:

$$\partial_t u = D_u \nabla^2 u + S$$

S: source term

- Reaction terms describing chemical or biological phenomena
  - chemical reaction, biological signaling
- General form with two variables:

$$\partial_t u = D_u \nabla^2 u + f(u,v)$$

$$\partial_t v = D_v \nabla^2 v + g(u,v)$$

u: activator

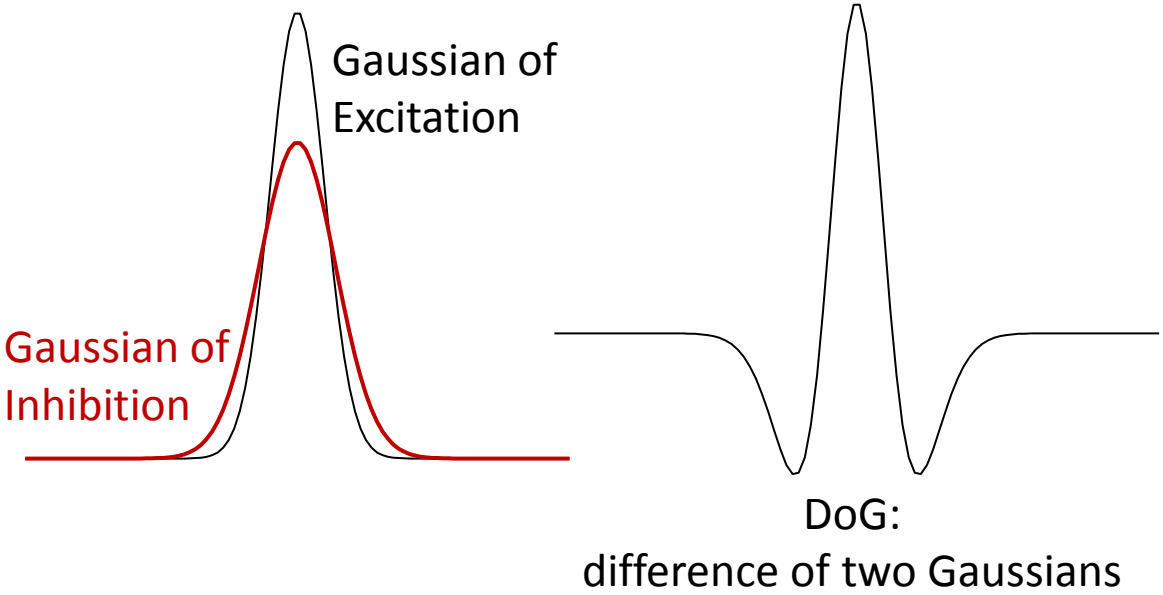
v: inhibitor

f(*u*,*v*), *g*(*u*,*v*): reaction terms

Introduction:

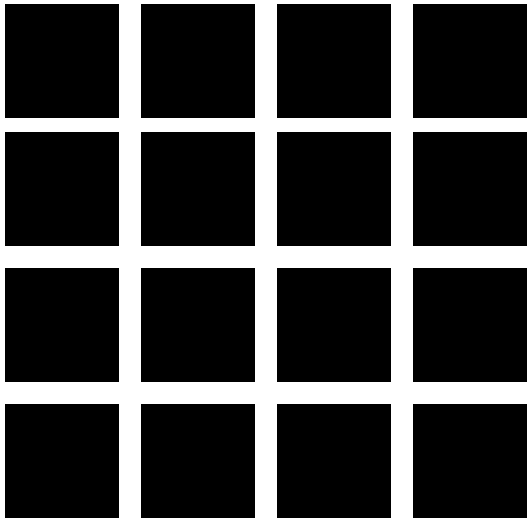
Pattern Recognition Process

- DoG filter
- Mach bands effect
- Long-range inhibition



DoG:
difference of two Gaussians

Mach bands



Is Hermann grid illusion due to long-range inhibition or the Turing scenario?

Motivation:

- Image processing with a reaction-diffusion system
  - Kuhnert et al., *Nature*, 1989
- Pattern formation with reaction-diffusion
  - Model of equations => generating pattern

reaction-diffusion

- Pattern recognition with ...
  - Image pattern => re-cognition

feature extraction:
edges, segments, ...

Question:
Is there any common mechanism?

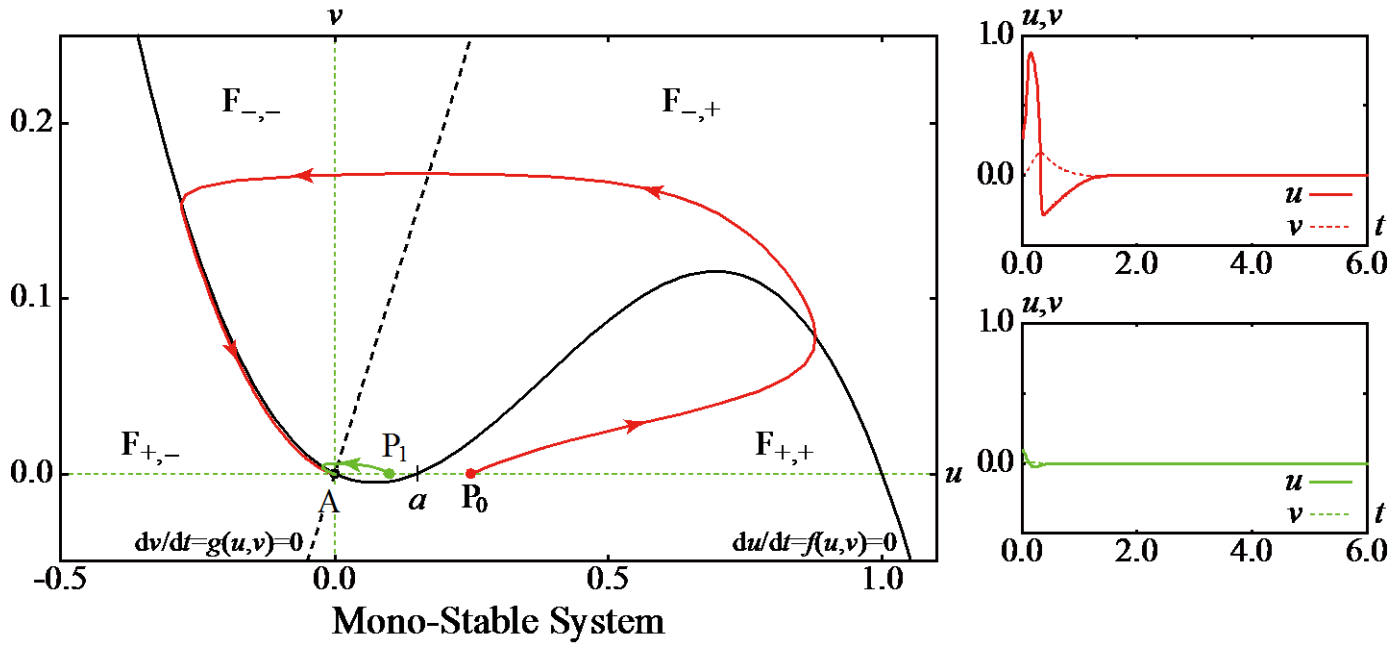
Key word:
Long-range inhibition
Rapid inhibitory diffusion

Our research work:

Reaction Terms of FitzHugh-Nagumo

- FitzHugh-Nagumo model
  - FitzHugh, *Biophysical J.*, 1961; Nagumo et al., *Proc. IRE*, 1962

$$\frac{du}{dt} = \frac{1}{\varepsilon}\left[u(u-a)(1-u)-v\right], \quad \frac{dv}{dt} = u - bv$$



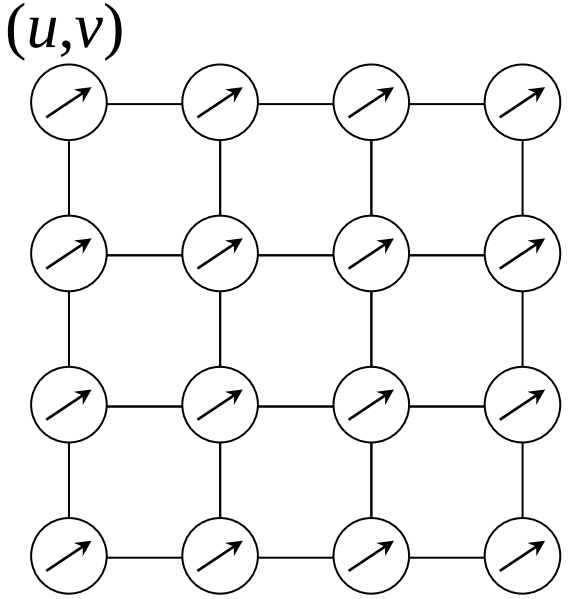
Our research work:

Edge Detection for Binary Image

- Discretely spaced system of reaction-diffusion
  - Kurata et al., *Phys. Rev. E*, 2009

$$\partial_t u = D_u \nabla^2 u + \frac{1}{\varepsilon}\left[u(u-a)(1-u) - v\right]$$

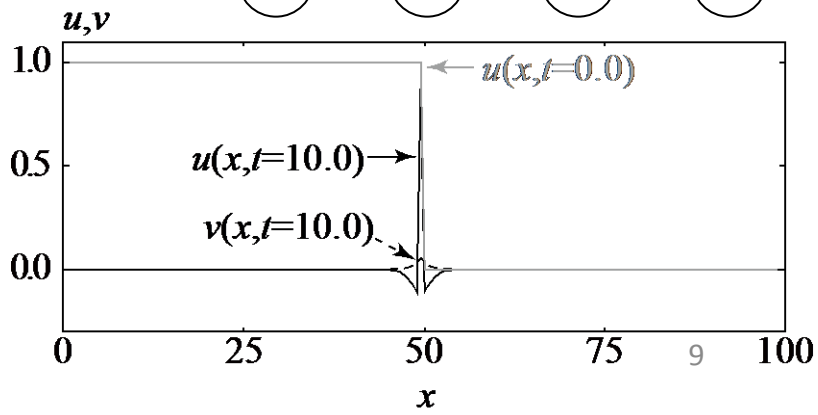
$$\partial_t v = D_v \nabla^2 v + u - bv$$



$D_u << D_v$: strong inhibition

a : Constant (threshold level)

b, ε : constants



Our research work:

Edge Detection for Gray Level Image

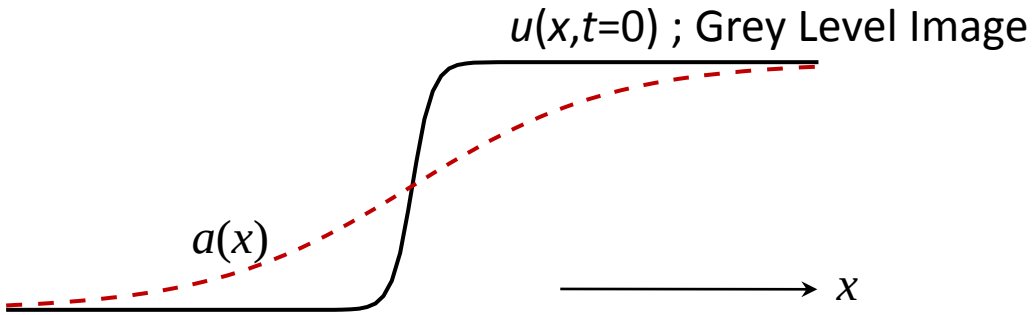
- Reaction-diffusion equations

$$\partial_t u = D_u \nabla^2 u + \frac{1}{\varepsilon}\left[u(u-a)(1-u) - v\right]$$

$$\partial_t v = D_v \nabla^2 v + u - bv$$

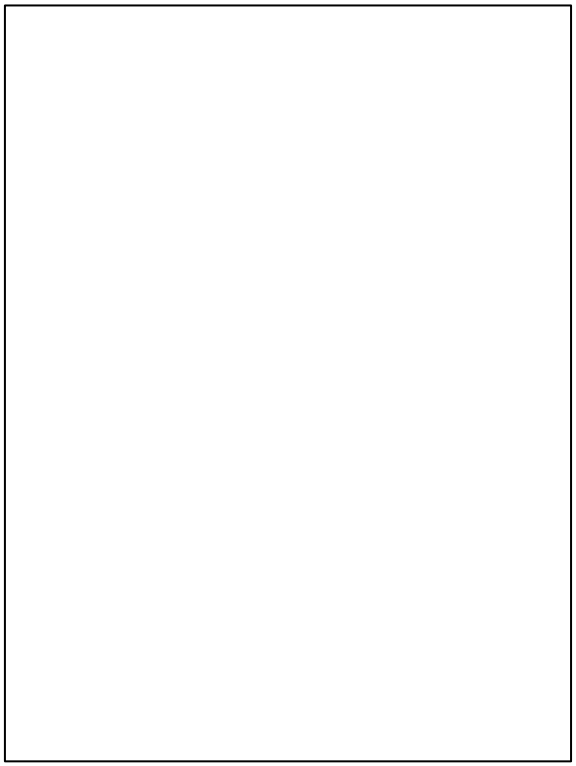
$D_u << D_v$: Strong inhibition

$a(x)$: blurred image

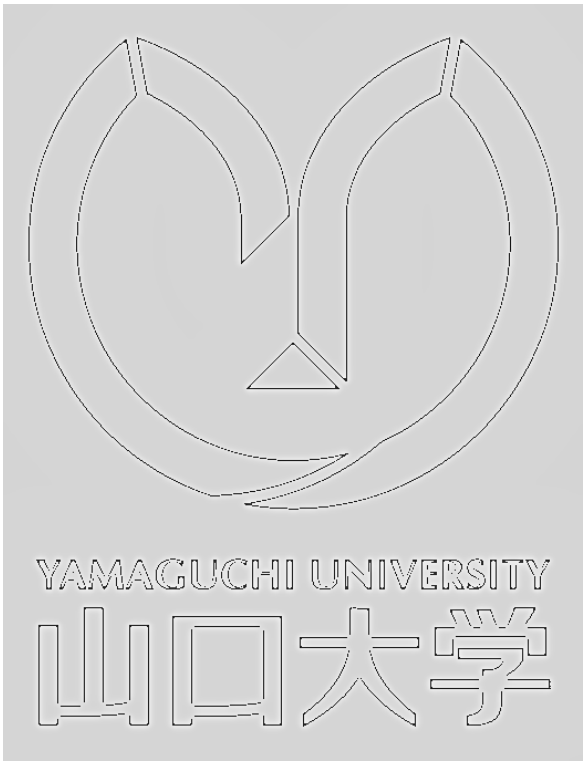


Experimental Results:
for Binary Image

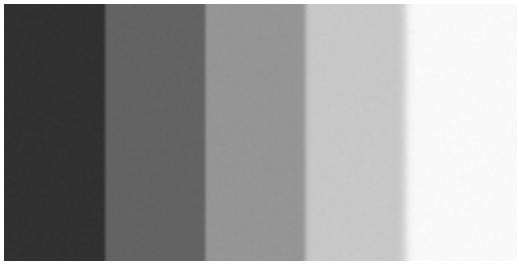
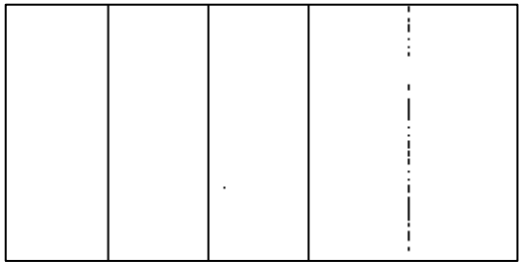
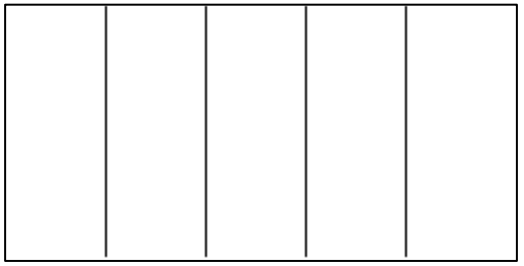
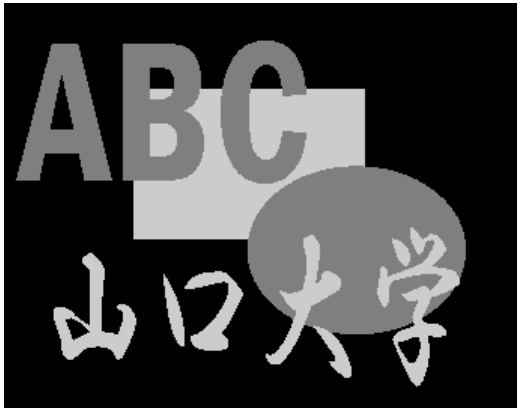
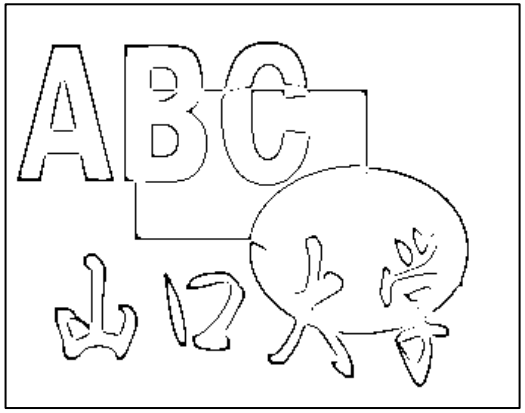
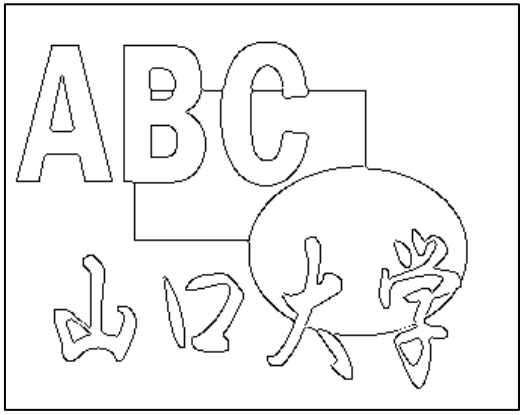
Original binary image
(Initial condition of u)



Edge distribution detected with
the FitzHugh-Nagumo reaction-diffusion system.
$u(x,y,t)$



Experimental Results:
for Grey Level Image

	Original image	RD algorithm	Canny edge detector
Example 1			
Example 2			

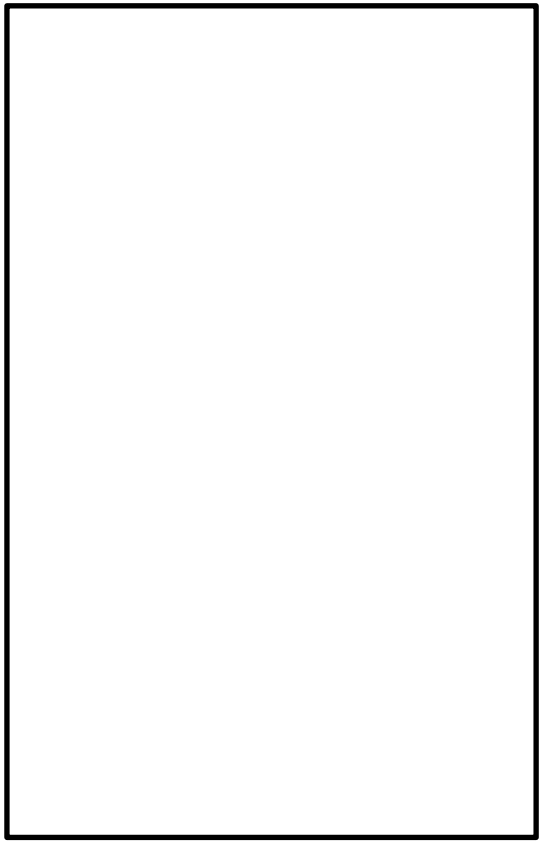
Conclusion

- Pattern formation - Pattern recognition
  - Long-range inhibition
  - Rapid inhibitory diffusion
- Reaction-diffusion algorithm of edge detection with rapid inhibitory diffusion
- Future research work
  - Edge strength evaluation
  - Other visual functions such as stereo, motion, ...

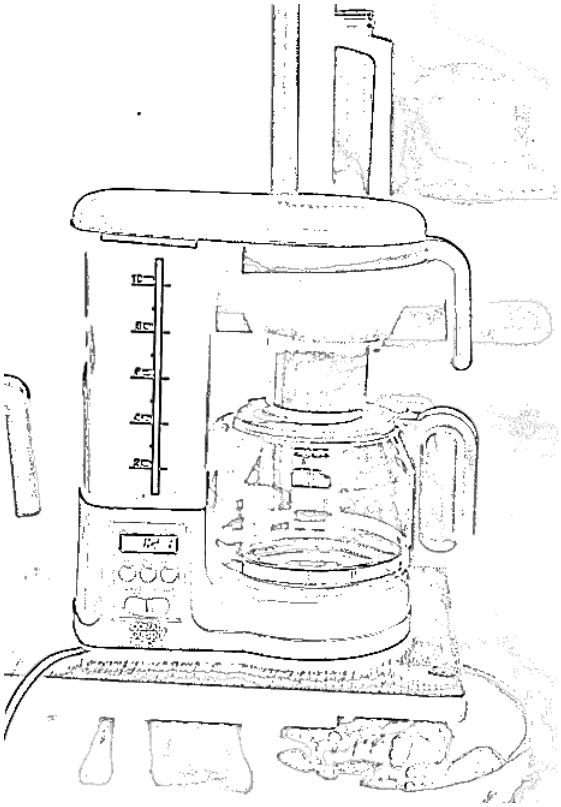
Further research work:

Edge Strength Evaluation

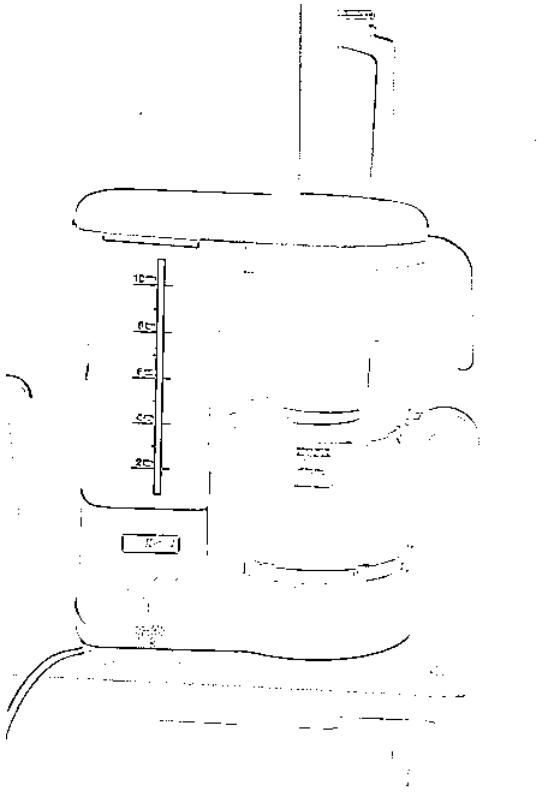
Original image



Detected edges



Extracted strong edges



http://marathon.csee.usf.edu/edge/edgecompare_main.html