ANISOTROPIC REACTION-DIFFUSION STEREO ALGORITHM

Atsushi Nomura[1)]Makoto Ichikawa[2)]
Koichi Okada[1)] Hidetoshi Miike[1)]
Tatsunari Sakurai[2)] Yoshiki Mizukami[1)]
[1)]Yamaguchi University, Japan
[2)]Chiba University, Japan

Outline

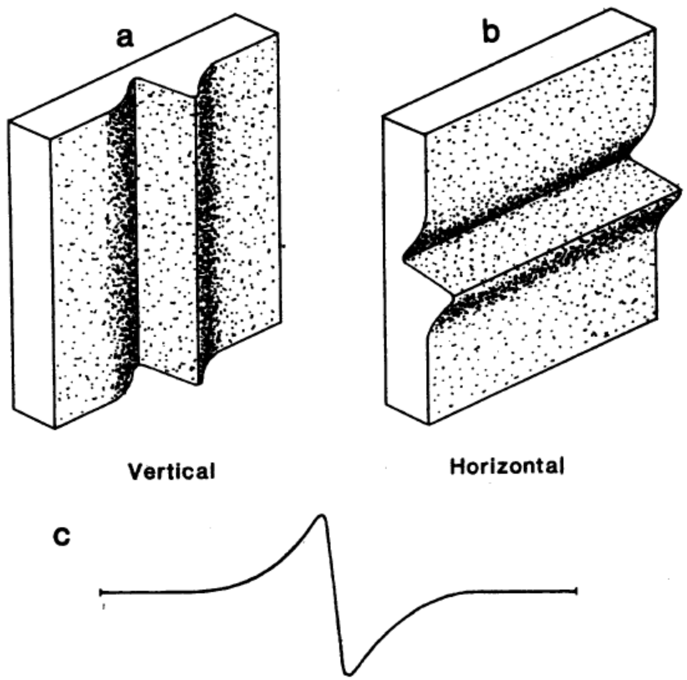
- Motivation
- Previous Stereo Algorithms
- Reaction-Diffusion Stereo Algorithm
- Anisotropic (Nonlinear) Diffusion
- Introducing Anisotropic Diffusion into Reaction-Diffusion Stereo Algorithm
- Experimental Results
- Conclusion

Motivation:

Anisotropy in Human Stereo Depth Perception

- Rogers & Graham, *Science*, 1983
  - Cornsweet profile slanted horizontally or vertically are differently perceived.
- Ichikawa, *Jpn. J. Psychonomic Science*, 1992
  - measured latency for various orientation with RDS.

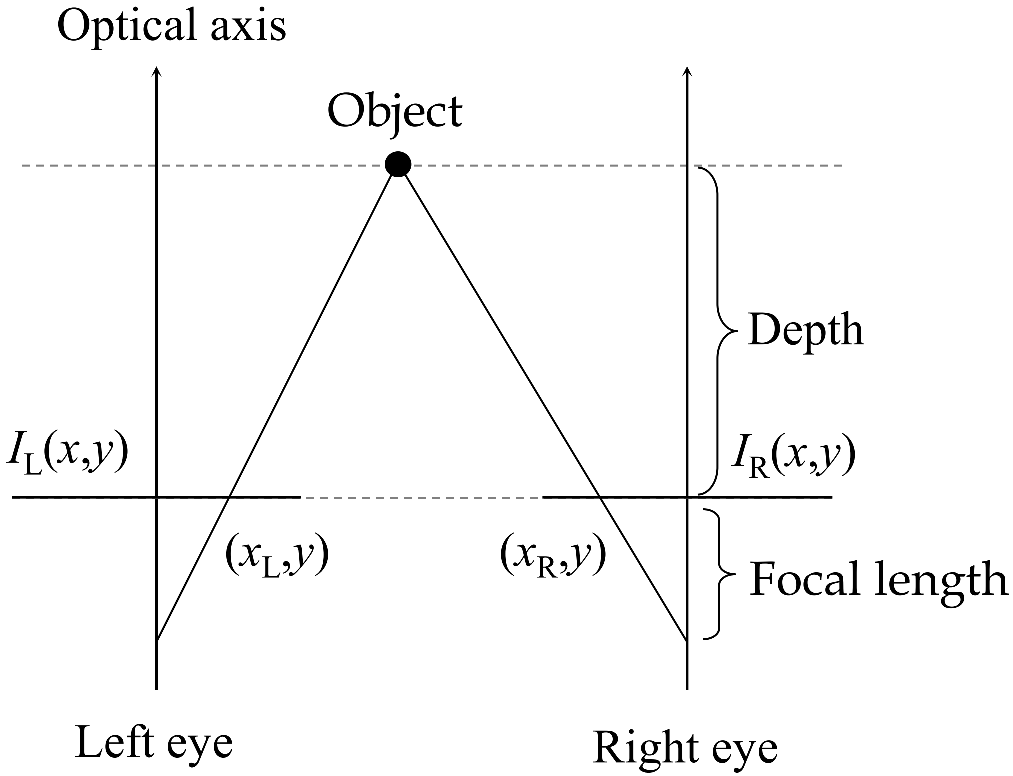
Fig. 1. (a and b) Perspective drawings of the depth surfaces used in the experiments. (c) Approximate shape of the Cornsweet profile, as constructed by adding a positive-going half-cycle sine wave and a negative-going half-cycle sine wave of one-eighth the spatial extent.

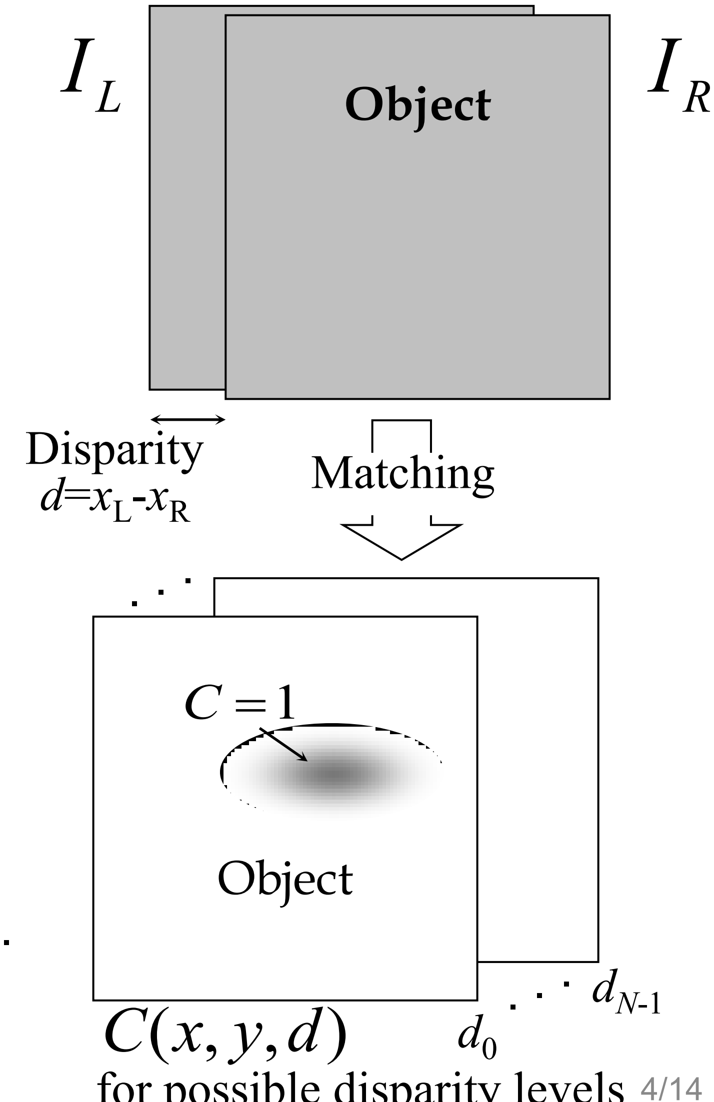


Rogers & Graham:
Anisotropies in the Perception of Three-Dimensional Surfaces
Science, pp.1409-1411, 1983

Fig.1a: The right is perceived nearer than the left.
Fig.1b: Equally perceived.

Introduction: Stereo Vision System





I_L, I_R: left and right image brightness distributions.
d: disparity
$C(x,y,d)$: similarity between $I_L(x,y)$ and $I_R(x-d,y)$.
N: number of possible disparity levels.

Previous Stereo Algorithms in Computer Vision

- Cooperative Algorithm
  - Marr & Poggio, *Proc. Roy. Soc. Lond.*, 1979
    - continuity & uniqueness constraints, bio-inspired algorithm
  - Zitnick & Kanade, *IEEE-PAMI*, 2000
    - modern cooperative algorithm + occlusion detection
- Belief-Propagation Algorithm
  - Sun et al., *IEEE-PAMI*, 2003
  - Yang et al., *IEEE-PAMI*, 2009
- Graph-Cuts Algorithm
  - Kolmogorov & Zabih, *IEEE-PAMI*, 2004
  - Deng et al., *IEEE-PAMI*, 2007

Diffusion Equation & PDE Approach in Image Processing & Computer Vision Research

- Diffusion equation = Gaussian filter
  - Koenderink, *Biol. Cybern.*, 1984
- Anisotropic (nonlinear) diffusion
  - Perona & Malik, *IEEE-PAMI*, 1990
  - Black et al., *IEEE-IP*, 1998

Isotropic diffusion equation:

$$\partial_t u = D\nabla^2 u + s$$

D: diffusion coefficient, *s*: source

=> uniform distribution

Anisotropic diffusion equation: (nonlinear)

$$\partial_t u = \nabla \cdot [D(x,y)\nabla u] + s$$

D(x,y): anisotropic diffusion coefficient

diffusion depends on a position (x,y)

Reaction-Diffusion Algorithm

- Kuhnert et al., *Nature*, 1989
  - chemical reaction-diffusion system + image processing
- Adamatzky et al., *Reaction-Diffusion Computers*, 2005
  - proposed novel computer architecture.
- FitzHugh-Nagumo reaction-diffusion equations

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

$$\partial_t v = \underbrace{D_v \nabla^2 v}_{\text{Diffusion Terms}} + \underbrace{u - bv}_{\text{Reaction Functions}}$$

Constants:
$0<\varepsilon<<1$
a, b

Diffusion Terms   Reaction Functions

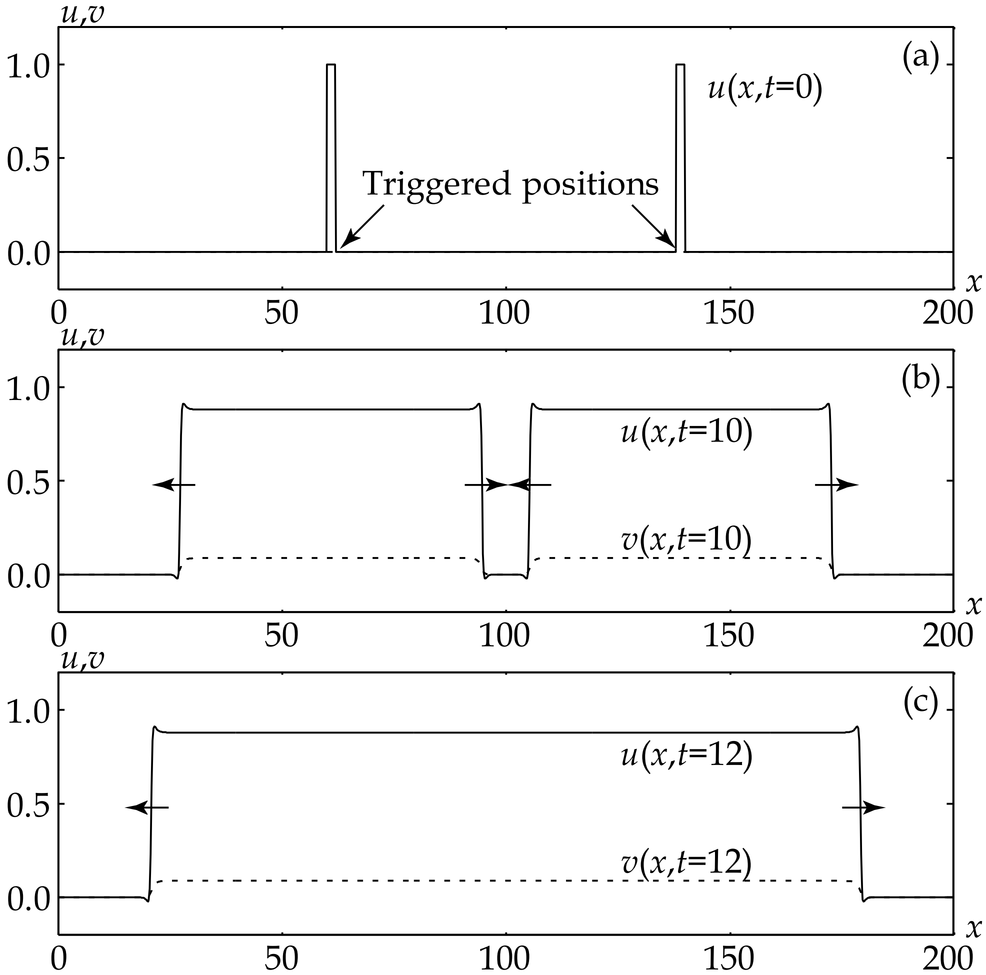
u: activator, v: inhibitor

$\partial_t = \partial / \partial t, \nabla^2$: Laplacian Operator

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

Numerical Computation of Reaction-Diffusion Model

- FitzHugh-Nagumo equations: bi-stable system



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

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

Parameter settings:
D_u=1.0, D_v=3.0
a=0.05, b=10.0, ε=1/100

Reaction-Diffusion Stereo Algorithm

- Nomura et al., *Mach. Vis. Appl.* (2009)

Reaction-Diffusion Systems

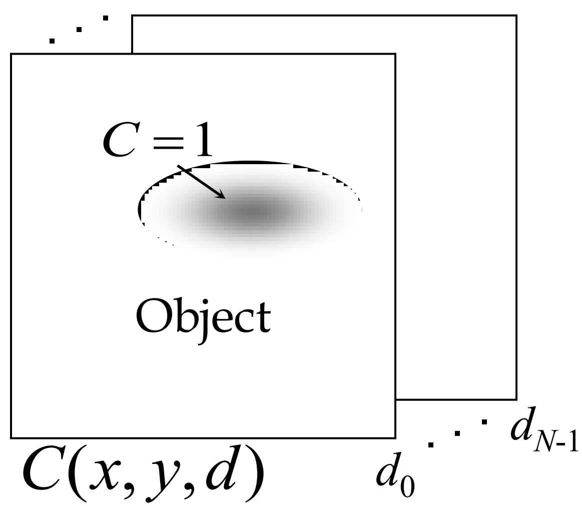
$$\begin{cases} \partial_t u_n(x,y,t) = D_u \nabla^2 u_n + f(u_n, v_n, u_{\max}) + \mu C(x,y,d_n) \\ \partial_t v_n(x,y,t) = D_v \nabla^2 v_n + g(u_n, v_n) \end{cases}$$

Reaction Functions

$$\begin{cases} f(u_n, v_n, u_{\max}) = \dfrac{1}{\varepsilon}\left[u_n(u_n - a(u_{\max}))(1-u_n) - v_n\right] \\ g(u_n, v_n) = u_n - b v_n \end{cases}$$

Disparity Map

$$\left\{ M(x,y,t) = \underset{n\in\{0,1,\cdots,N-1\}}{\operatorname{argmax}} \; u_n(x,y,t) \right.$$



μ: constant, N: total number of possible disparity levels
C: similarity measure, d_n: disparity level

Proposed Reaction-Diffusion Stereo Algorithm

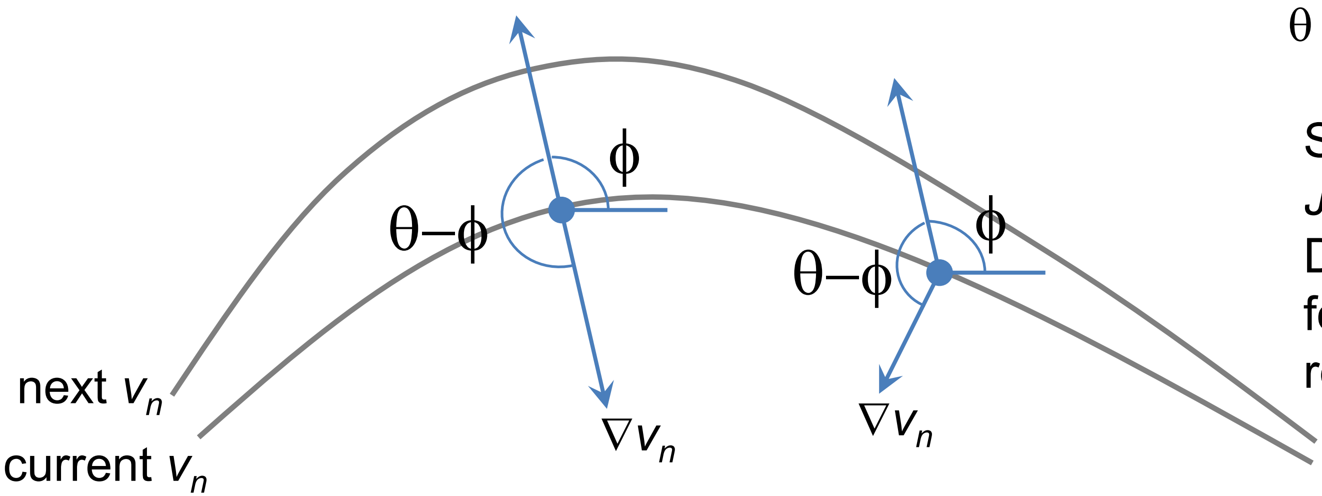
Reaction-Diffusion Systems

$$\begin{cases} \partial_t u_n = D_u \nabla^2 u_n + f(u_n, v_n, u_{\max}) + \mu C(x, y, d_n) \\ \partial_t v_n = D_v \nabla \cdot \left[A(\theta) \nabla v_n \right] + g(u_n, v_n) \end{cases}$$

Anisotropy

$$\begin{cases} A(\theta) = 1 / \sqrt{1 - \delta \cos(2\theta - 2\phi)} \\ \theta = \tan^{-1}\left(\partial_y v_n / \partial_x v_n \right) \end{cases}$$

$0 \le \delta < 1$: strength of anisotropy
ϕ : specific orientation
θ : gradient direction of v_n



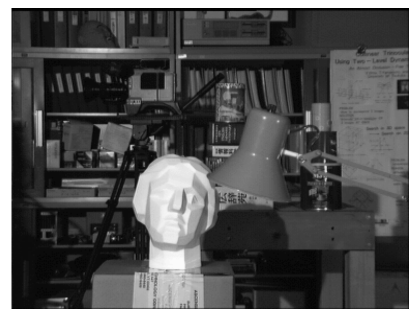
Shoji et al.
J. theor. Biol., 2002
Directionality of stripe formed by anisotropic reaction-diffusion models

Experiments with Middlebury Data Set

- Middlebury stereo vision page provides
  - stereo image pairs,
  - ground-truth data of disparity maps,
  - definition of areas (occlusion & depth discontinuity),
  - URL   http://vision.middlebury.edu/stereo/
- Example of stereo image pairs

CONES 450X375 pixels
60 disparity levels
(N=60)

TEDDY 450X375 pixels
60 disparity levels
(N=60)



TSUKUBA
384X288 pixels
15 disparity levels
(N=15)

VENUS 434X383 pixels
30 disparity levels
(N=30)

Bad-Match-Percentage Error Scores for Several Versions of Reaction-Diffusion Stereo Algorithm (RDSA)

	Algorithm	RDSA-Iso	RDSA-AnisoH	RDSA-AnisoV	RDSA-Var
	Parameters	D_v=3.0, δ=0.0 -	D_v=2.0,δ=0.9 ϕ=0	D_v=2.0,δ=0.9 $\phi=\pi/2$	D_v=2.0, variable δ,ϕ
TSUKUBA	nonocc.	6.77 (4)	6.31 (2)	6.31 (2)	6.00 (1)
	all	8.53 (4)	8.11(3)	8.10(2)	7.83 (1)
	disc.	18.68 (1)	20.44(4)	20.25(2)	20.28 (3)
VENUS	nonocc.	2.76 (4)	2.01(2)	2.42(3)	1.93(1)
	all	4.15 (4)	3.47(2)	3.86(3)	3.30(1)
	disc.	21.18 (4)	18.86(1)	19.71(3)	19.00(2)
TEDDY	nonocc.	14.26 (4)	13.45(1)	13.86(2)	14.10(3)
	all	20.18 (4)	19.46(1)	19.84(2)	20.15(3)
	disc.	29.19 (2)	29.23(3)	29.05(1)	29.43(4)
CONES	nonocc.	5.03 (1)	5.18(2)	5.58(4)	5.18(2)
	all	13.40 (2)	13.64(3)	13.75(4)	13.30(1)
	disc.	14.05 (1)	14.27(2)	15.66(4)	14.38(3)
	Average Rank	**2.92**	**2.17**	**2.67**	**2.08**

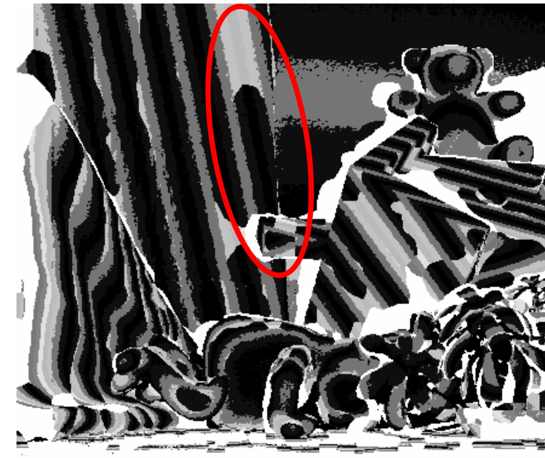
nonocc.: non-occlusion area, all: all area, disc.: depth discontinuity area, threshold=1.0 pixel

Demonstration with TEDDY Data Set

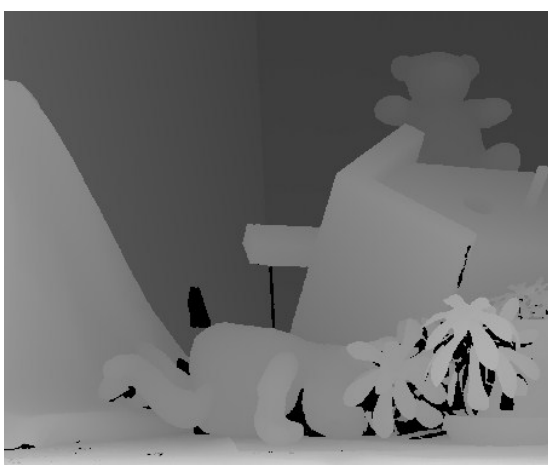
Left image

δ=0.5,ϕ=0.0

δ=0.9,ϕ=0.0



Error distributions



Ground truth disparity map

Obtained disparity maps

Conclusion

- Motivated by anisotropy in human stereo depth perception.
- We proposed to introduce anisotropic diffusion into the reaction-diffusion stereo algorithm.
- We confirmed effect of the anisotropy on performance for Middlebury stereo data set.

Acknowledgments:
The present study was supported in part by the Grant-in-Aid for Scientific Research (C) (No. 20500206) from the Japan Society for the Promotion of Science, and Sasagawa Grants for Science Fellows (SGSF) from the Japan Science Society (No. F11-313)

Thank you for your attention!