Vision in Human and Machine

Part 8
Models of Perceptual Grouping

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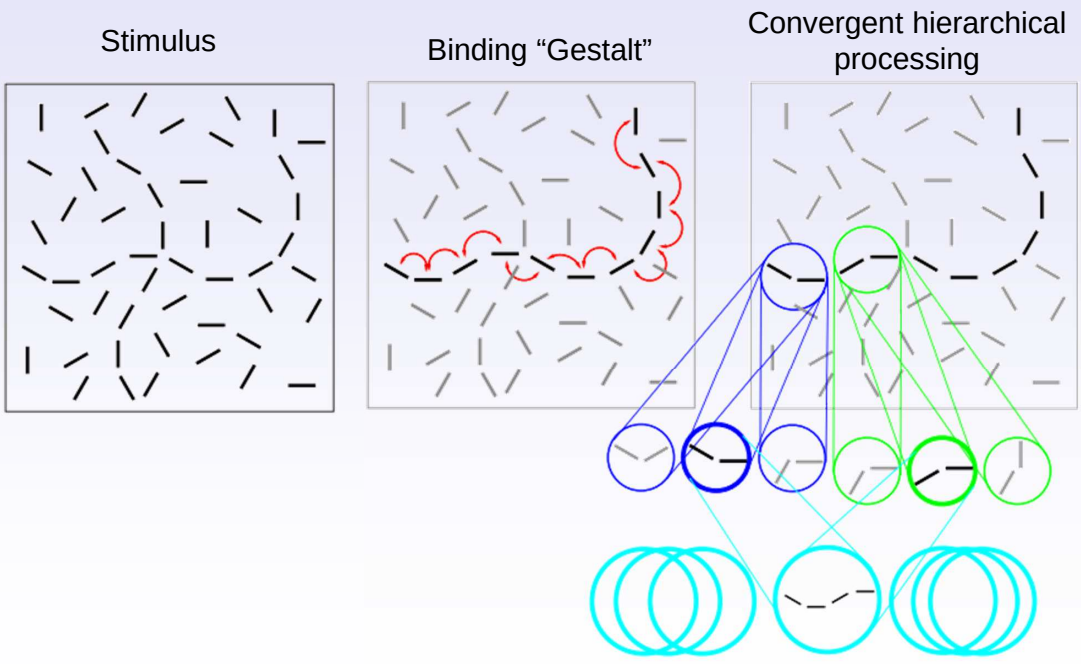
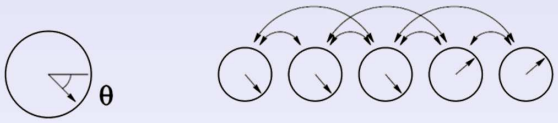


Dynamical modeling approaches

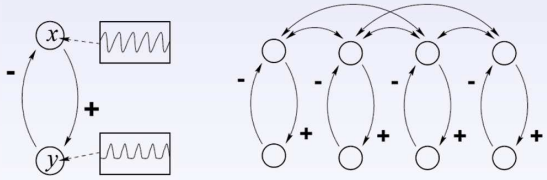
- Phase models

  Baldi & Meir 1990
  Sompolinsky, Golomb, & Kleinfeld 1992
  Zemel, Williams, & Mozer 1993



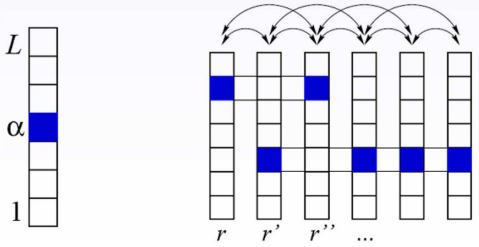
- Coupled oscillator models

  von der Malsburg & Schneider 1986
  Schillen & König 1994
  Wang & Terman 1997

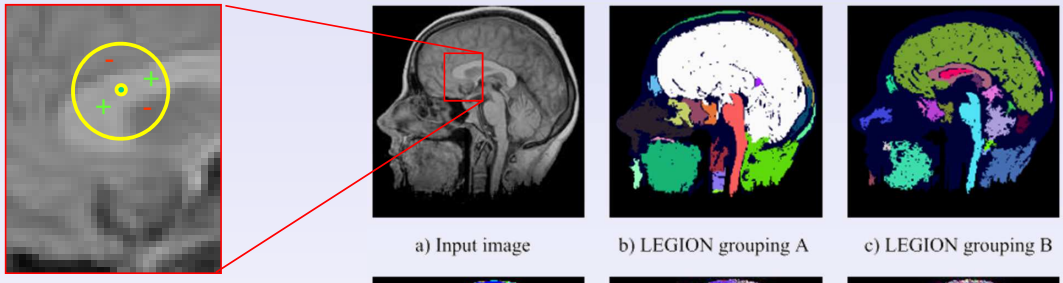


- Assignment/labeling models

  Parent & Zucker 1989
  Opara & Wörgötter 1998
  Wersing, Steil, & Ritter 2000



Example: Greyscale image segmentation



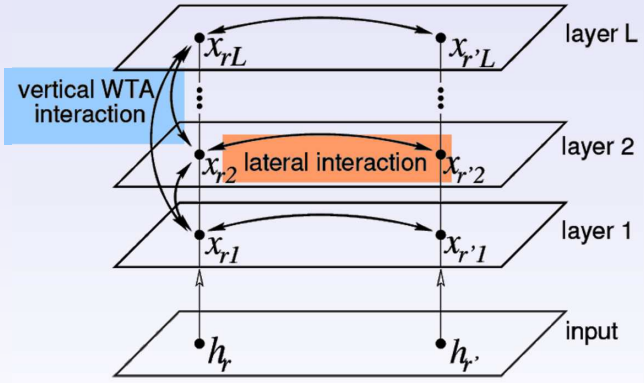
a) Input image | b) LEGION grouping A | c) LEGION grouping B

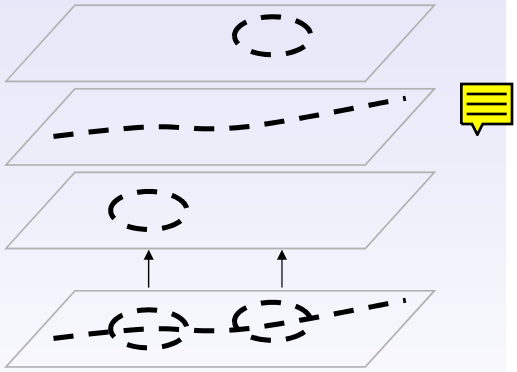
d) ECU T=0.5 | e) ECU T=2.5 | f) ECU T=4.5

g) CLM R=5 | h) CLM R=3 | i) CLM R=1

- Similarity: Pixel distance and intensity difference
- LEGION: Oscillator model (Wang 1997)
- ECU: Energy-based cluster update (spin relaxation model) Opara et al (1998)
- CLM: Competitive Layer Model (Ritter 1990)

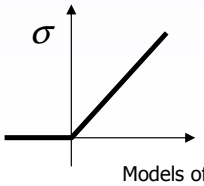
The Competitive Layer Model - CLM



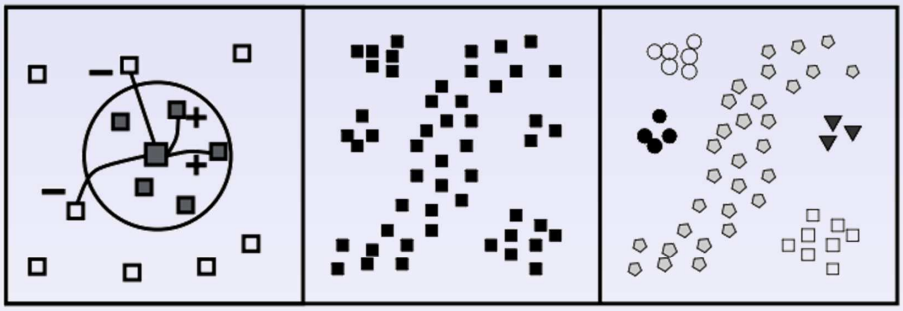


(Ritter 1990)
(Wersing, Steil, & Ritter 2000)

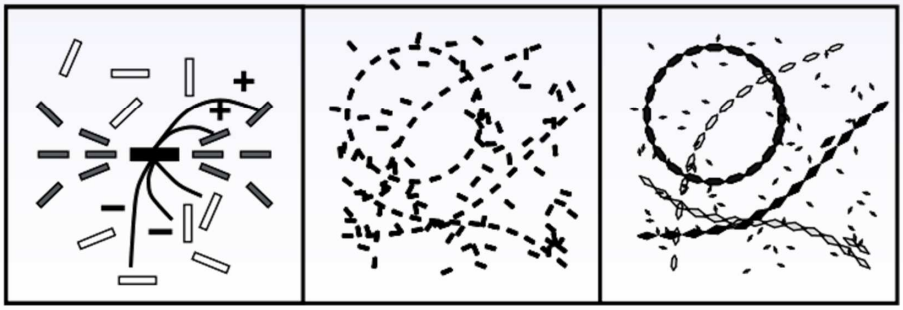
$$\dot{x}_{r\alpha} = -x_{r\alpha} + \sigma\Big(J(h_r - \sum_{\beta} x_{r\beta}) + \sum_{r'} f_{rr'} x_{r'\alpha}\Big),$$



Examples for Gestalt laws



Proximity Interaction Input Grouping



Continuity Interaction Input Grouping

Mathematic formulation

$$\dot{x}_{r\alpha} = -x_{r\alpha} + \sigma\Big(J\big(h_r - \sum_{\beta} x_{r\beta}\big) + \sum_{r'} \mathsf{f}^{\alpha}_{rr'} x_{r'\alpha} + x_{r\alpha}\Big) \quad (1)$$

$$= -x_{r\alpha} + \sigma\Big(-\frac{\partial E}{\partial x_{r\alpha}} + x_{r\alpha}\Big) \quad (2)$$

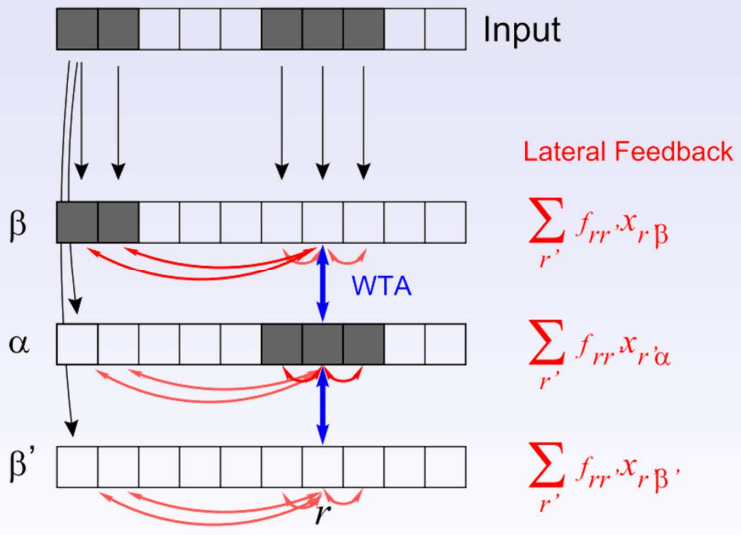
$$\sigma(x) = \max(0, x) \quad (3)$$

$$E = -\frac{J}{2}\sum_{r}\Big(h_r - \sum_{\beta} x_{r\beta}\Big)^2 - \frac{1}{2}\sum_{\alpha}\sum_{rr'} \mathsf{f}^{\alpha}_{rr'} x_{r\alpha} x_{r'\alpha}. \quad (4)$$

- CLM dynamics performs gradient descent in a quadratic energy function

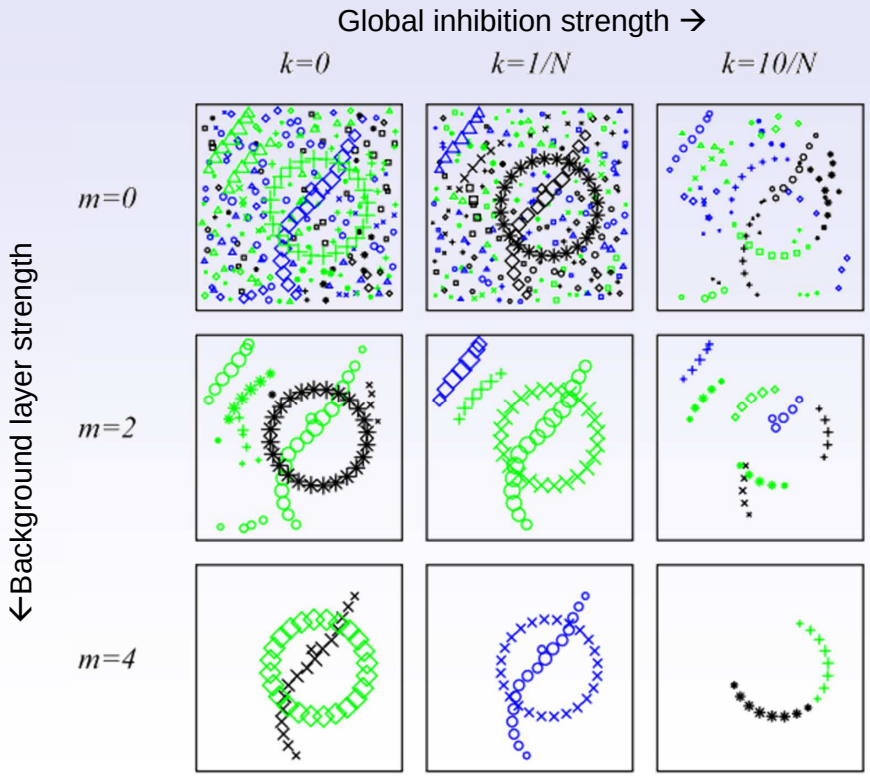
Assignment property of the CLM

- Gradient descent dynamics
- Local minima satisfy consistency equation

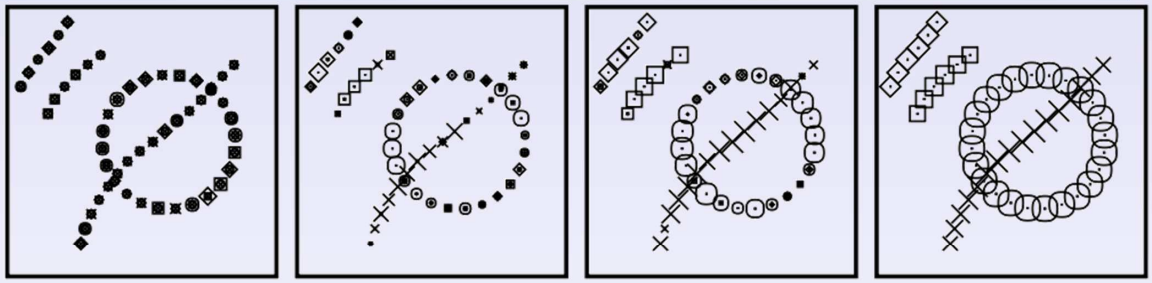


$$\sum_{r'} f_{rr'} x_{r'\alpha} > \sum_{r'} f_{rr'} x_{r'\beta} \quad \text{for all} \quad r, \beta \neq \alpha(r)$$

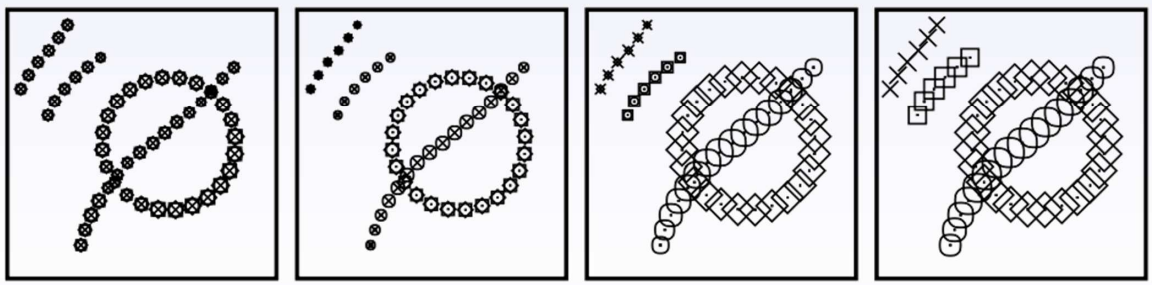
Deterministic Annealing



Deterministic Annealing



a) Activity dynamics without annealing



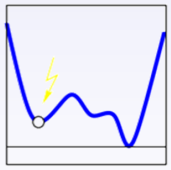
b) Activity dynamics with self-inhibitory annealing

Deterministic Annealing

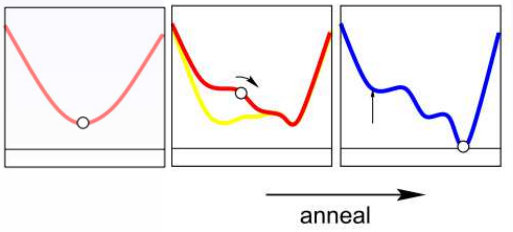
$$E = -\frac{J}{2}\sum_r \left(h_r - \sum_\beta x_{r\beta}\right)^2 - \frac{1}{2}\sum_\alpha \sum_{rr'} \mathsf{f}^\alpha_{rr'} x_{r\alpha} x_{r'\alpha}. \quad (4)$$

$$E = -\frac{J}{2}\sum_r \left(h_r - \sum_\beta x_{r\beta}\right)^2 - \frac{1}{2}\sum_\alpha \sum_{rr'} \mathsf{f}^\alpha_{rr'} x_{r\alpha} x_{r'\alpha} + T\sum_r x^2_{r\alpha}. \quad (5)$$

Without annealing:
Suboptimal local minimum



Deterministic annealing:
Slowly allow more structure
For optimization



CLM simulation algorithm

1. Initialize all $x_{r\alpha}$ with small random values around

$$x_{r\alpha}(t=0) \in [h_r/L - \epsilon, h_r/L + \epsilon].$$

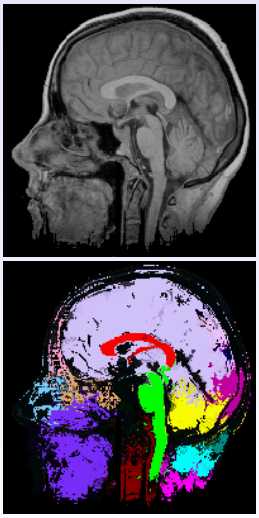
   Initialize T with $T = T_c$.

2. Do $N \cdot L$ times: Choose (r, α) randomly and update $x_{r\alpha} = \max(0, \xi)$, where

$$\xi = \frac{Jh_r - \sum_{\beta\neq\alpha} Jx_{r\beta} + \sum_{r'\neq r} \mathsf{f}^\alpha_{rr'} x_{r'\alpha}}{J - \mathsf{f}^\alpha_{rr} + T}.$$

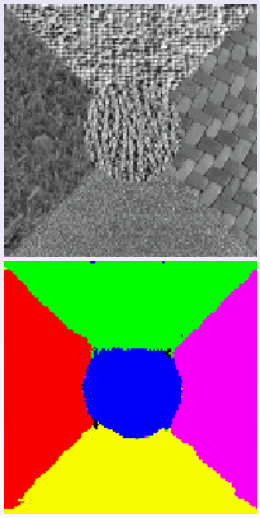
3. Decrease T by $T := \eta T$, with $0 < \eta < 1$. Go to step 2 until convergence.

Applications of the CLM

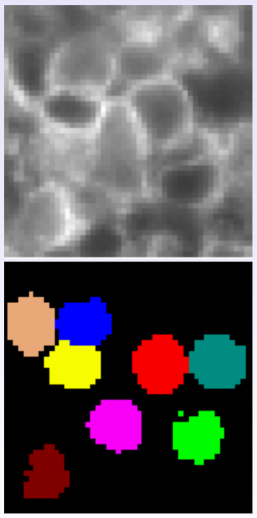


(Wersing, 2000)

(Wersing, Steil, & Ritter. Neural Computation 2000)

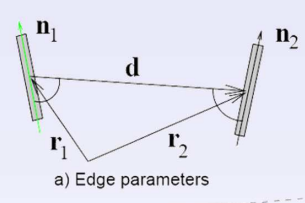


(Ontrup, Wersing & Ritter. Cognitive Processing 2004)

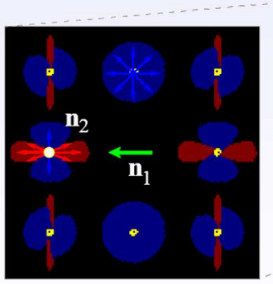


(Nattkemper, Wersing, Schubert, & Ritter. Neurocomputing 2002)

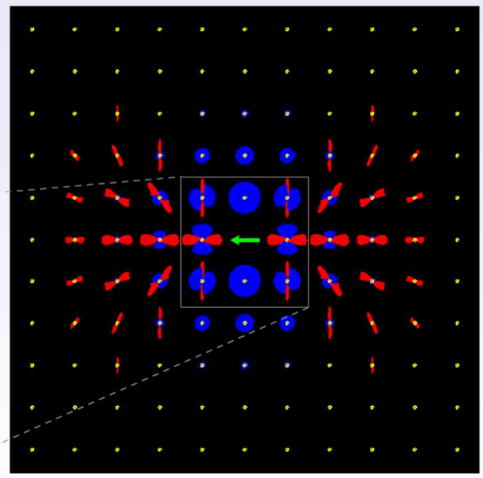
Design of lateral interactions



a) Edge parameters



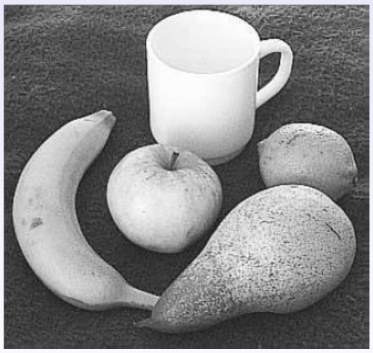
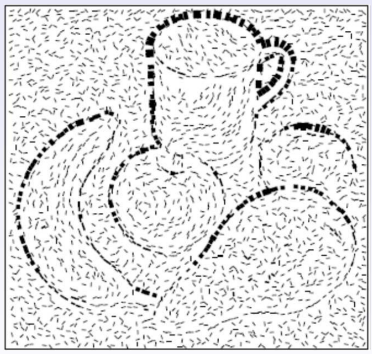
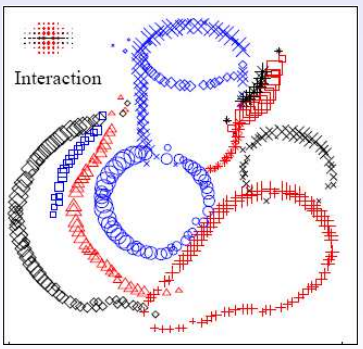
b) Plotting scheme



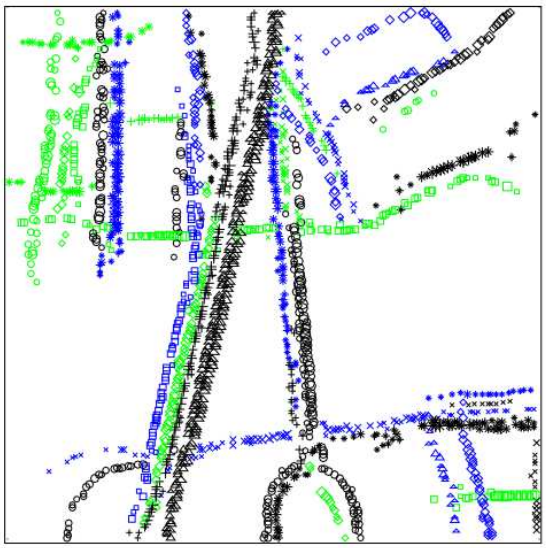
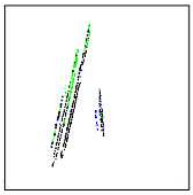
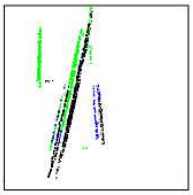
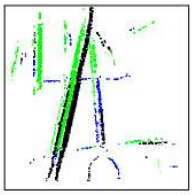
c) Continuity interaction field

CLM Dynamics

- The dynamics can be characterized by linear eigenmodes
- Symmetry breaking dynamics performs the grouping operation
- Good grouping quality requires deterministic annealing

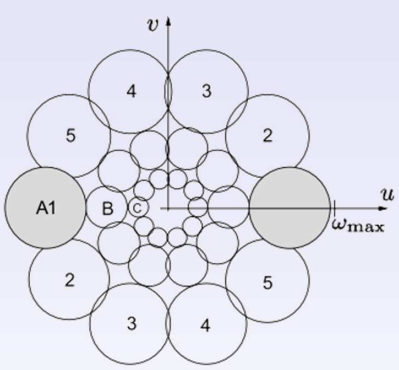




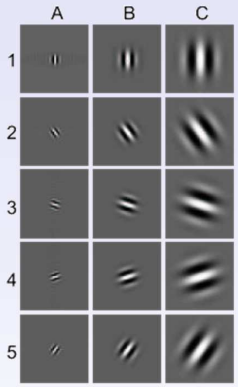
Emergence of groups with annealing

Texture Segmentation (Ontrup 1998)

- Vector of local Gabor responses
- Feature vector consists of mean and variance of vector on the image
- Perform a PCA in this space→Use proximity in the feature space

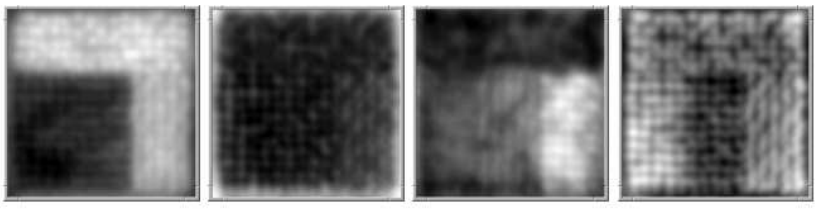




$$d_{\text{text}}(r,r') = \sqrt[n]{\sum_{i=1}^{4}\left(\frac{|p_r^i - p_{r'}^i|}{\sqrt{\sigma(p^i)}}\right)^n},$$

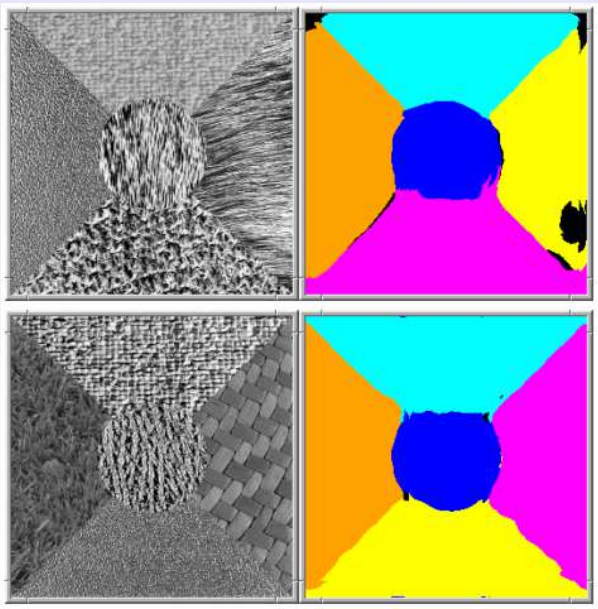
$$f_{rr'} = e^{-\frac{d^2_{\text{text}}(r,r')}{R^2_{\text{sim}}}} + c\,e^{-\frac{|\mathbf{x}_r - \mathbf{x}_{r'}|^2}{R^2_{\text{prox}}}} - k$$

Setting parameters

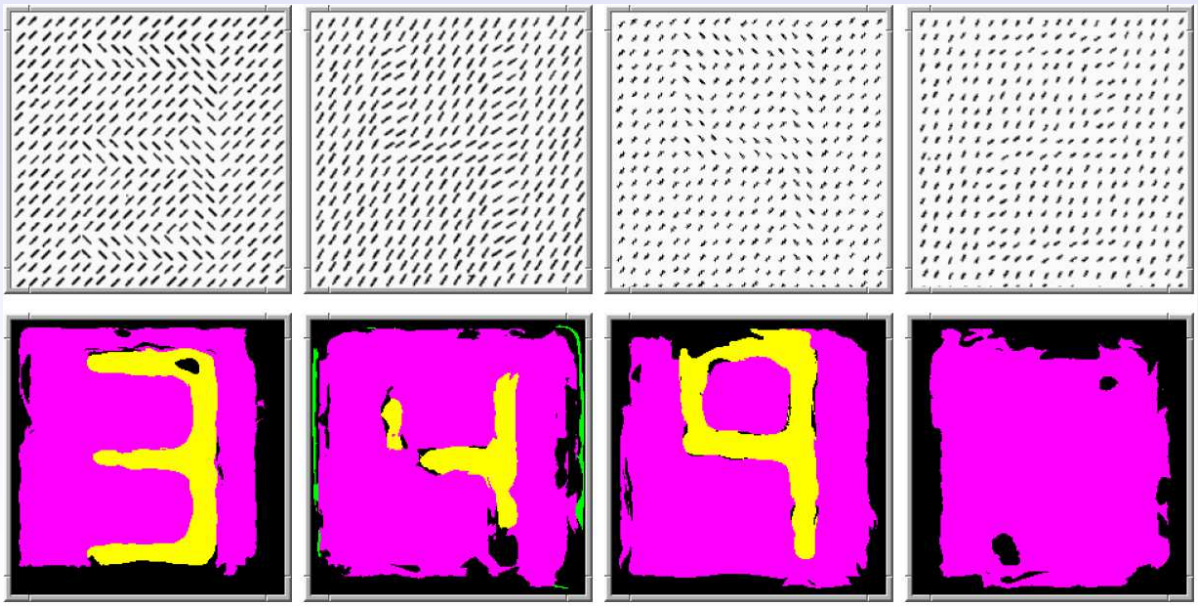


(a) 1st (b) 2nd (c) 3rd (d) 4th

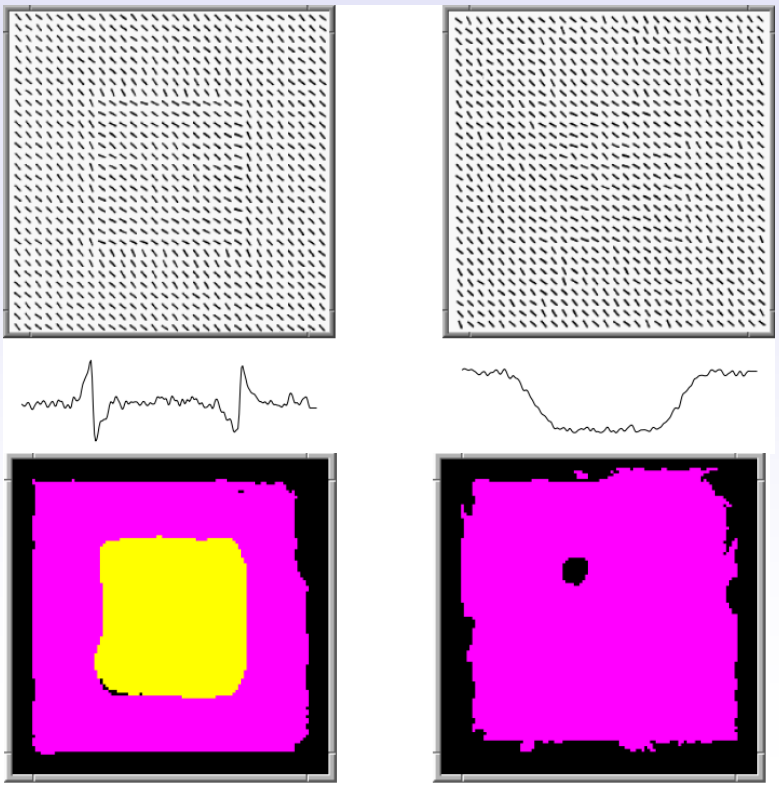
Grouping results



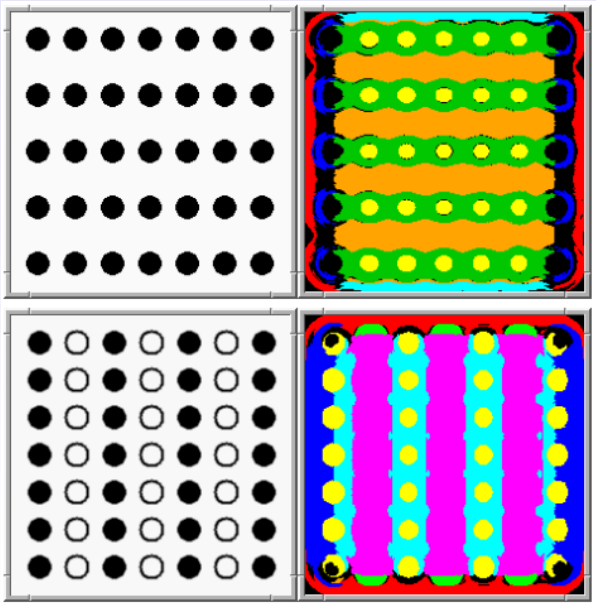
Grouping results – Orientation Contrast



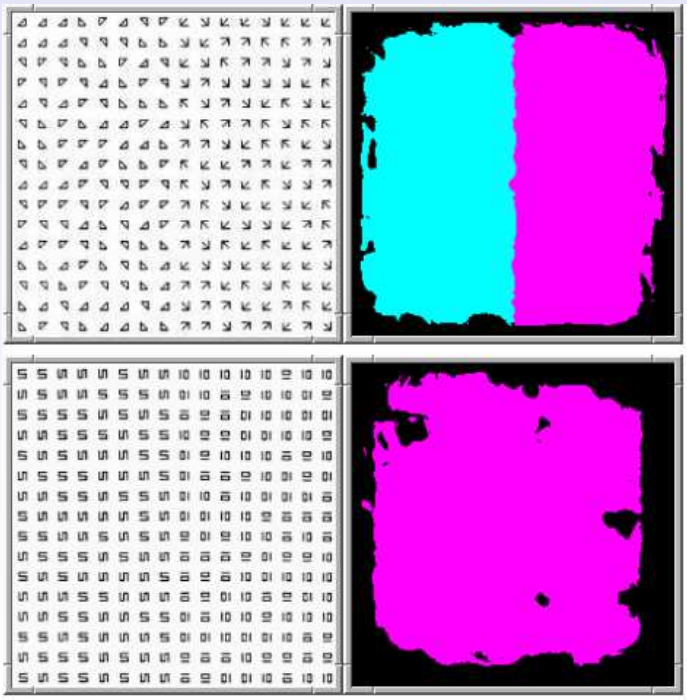
Grouping results – Craig/Cornsweet Illusion



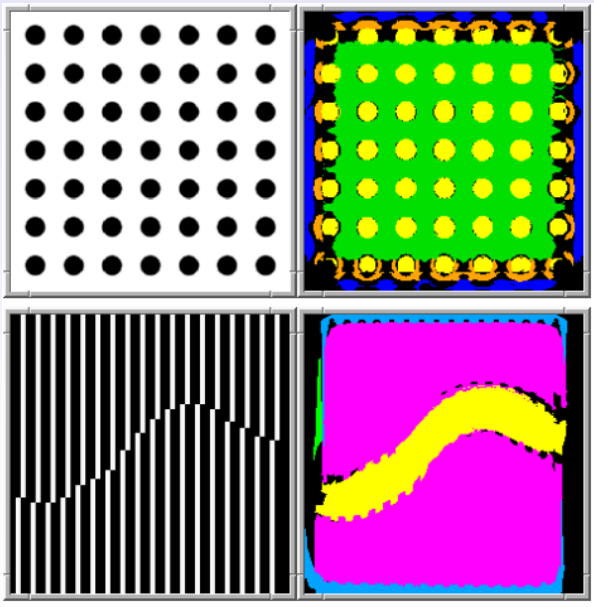
Grouping results



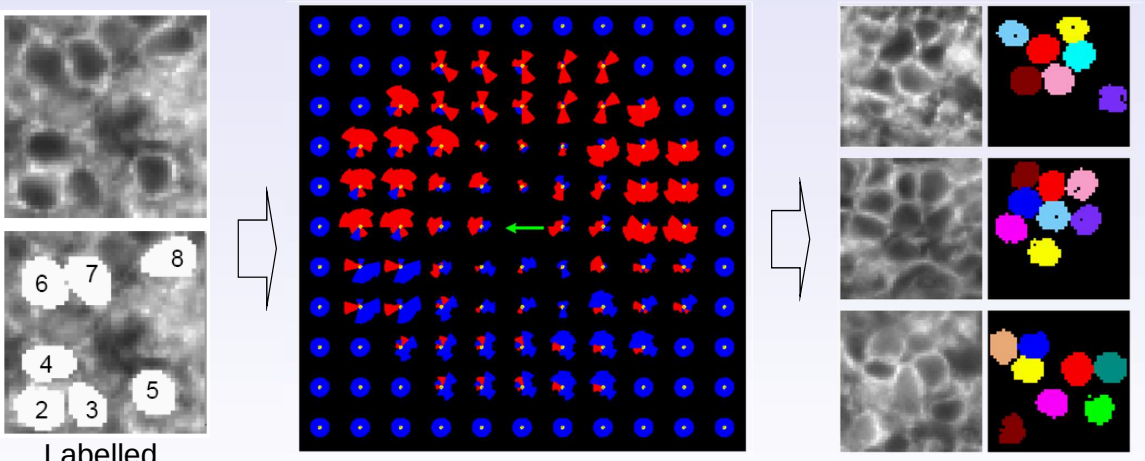
Grouping results



Grouping results



Learning of lateral interactions



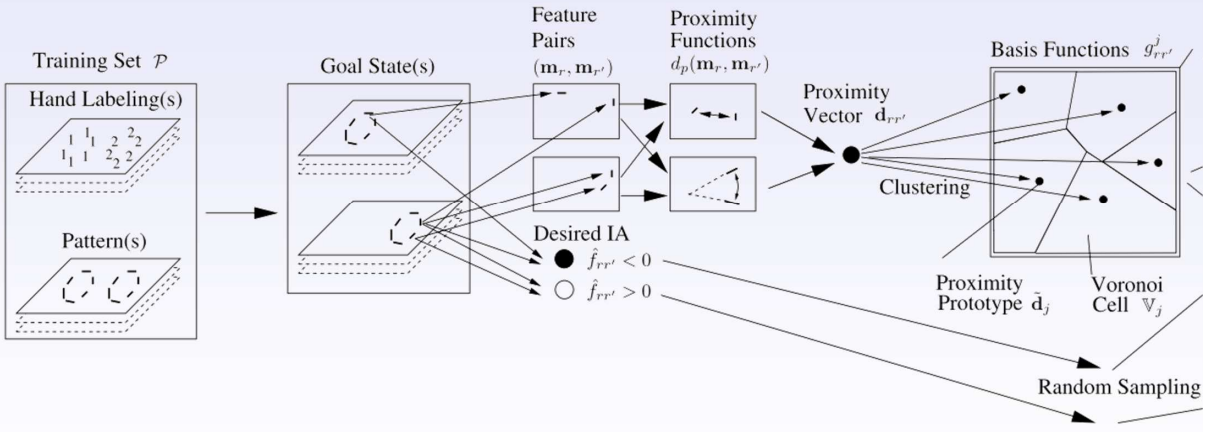
Labelled training data

Learned lateral interaction field

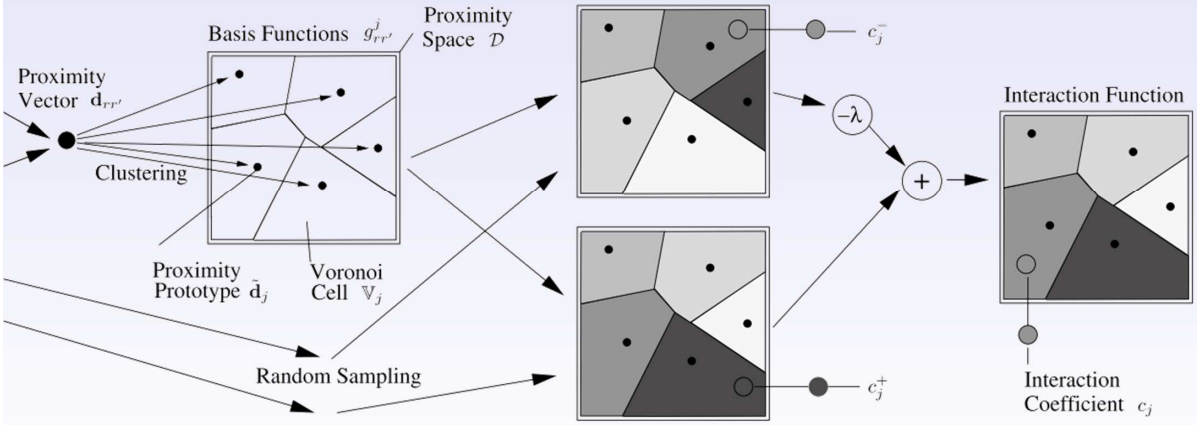
CLM Segmentation on Test Data

(Wersing, Adv. Neur. Inf. Proc. Systems, NIPS. 2000)
(Weng, Wersing, Steil, & Ritter. IEEE Trans. Neural Networks. 2007)

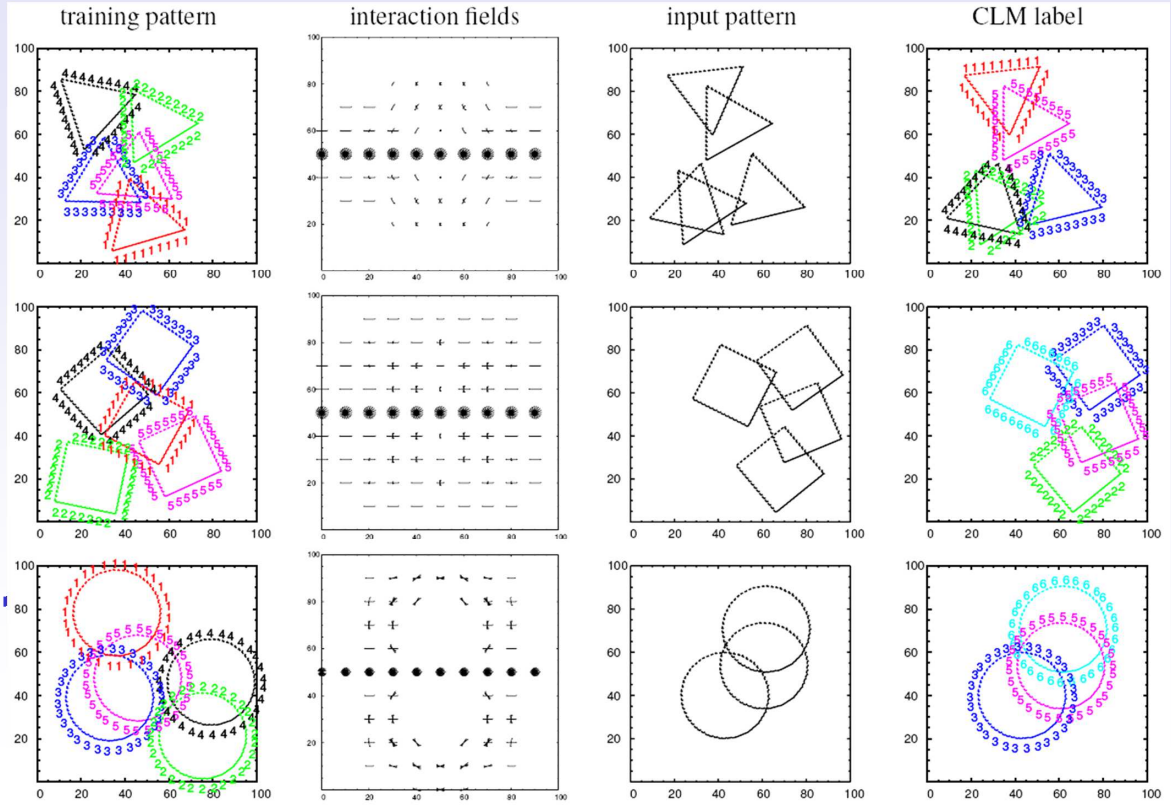
Lateral Interaction Learning (Weng et al. 2007)



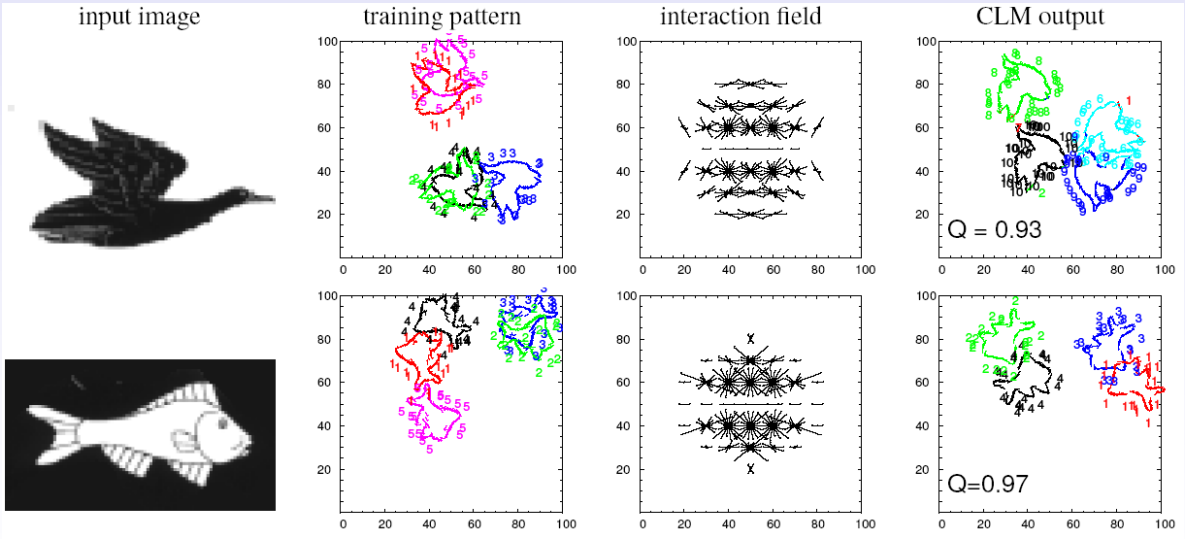
Lateral Interaction Learning (Weng et al. 2007)



Artificial examples



More complex training patterns



Medical image segmentation problem