DFT in two dimensions or more ...

Gregor Schöner
example: retinal pace

- obviously two-dimensional

![Graph showing time progression with color-coded areas](image)

30 - 40 ms  40 - 50 ms  50 - 60 ms  60 - 70 ms  70 - 80 ms

Jancke et al., 1999
example: visual feature map

orientation-retinal location

[Jancke, JNeursci (2000)]
example: visual feature maps

- the neural field representation a single feature (e.g. orientation) as well as retinal location is at least three-dimensional
- cannot be mapped onto cortical surfaces without cuts ...
mathematics of 2D fields

- => simulation
- no problem ... self-stabilized peaks work just fine...
Example: Color-Space field

- 1D spatial location (for illustration)
- 1D color dimension (hue)
- visual input: 2D
- => 2D peaks

[Slides adapted from Sebastian Schneegans, see Schneegans, Lins, Spencer, Chapter 5 of Dynamic Field Theory-A Primer, OUP, 2015]
Example: Color-Space field

- separate fields for 1D spatial location
- and 1D color dimension (hue)
- => combined vs. separate representations

[Slides adapted from Sebastian Schneegans, see Schneegans, Lins, Spencer, Chapter 5 of Dynamic Field Theory-A Primer, OUP, 2015]
Example: Color-Space field

- read-out from 2D to 1D
- by projection
- summing along the other dimension (marginalization)
- or taking the (soft)max

[Slides adapted from Sebastian Schneegans, see Schneegans, Lins, Spencer, Chapter 5 of Dynamic Field Theory-A Primer, OUP, 2015]
Example: Color-Space field

- input from 1D to 2D: ridge input that is constant along the other dimension

[Slides adapted from Sebastian Schneegans, see Schneegans, Lins, Spencer, Chapter 5 of Dynamic Field Theory-A Primer, OUP, 2015]
Example: Color-Space field

- peaks at intersections of ridges: bind two dimensions

[Slides adapted from Sebastian Schneegans, see Schneegans, Lins, Spencer, Chapter 5 of Dynamic Field Theory-A Primer, OUP, 2015]
Example: Color-Space field

- **feature-binding**: multiple ridges lead to binding problem: correspondence problem

[Slides adapted from Sebastian Schneegans, see Schneegans, Lins, Spencer, Chapter 5 of Dynamic Field Theory-A Primer, OUP, 2015]
Example: Color-Space field

- visual search: combine ridge input with 2D input..

[Slides adapted from Sebastian Schneegans, see Schneegans, Lins, Spencer, Chapter 5 of Dynamic Field Theory-A Primer, OUP, 2015]
Example: Color-Space field

Joint selection in 2 1D fields, that are coupled across 2D field

[Slides adapted from Sebastian Schneegans, see Schneegans, Lins, Spencer, Chapter 5 of Dynamic Field Theory-A Primer, OUP, 2015]


In conventional connectionist networks, associative relationships are learned by adjusting synapses between those color and space neurons that have been co-activated.
connections must be learned, so does not account for how “where is the red square” works from current stimulation (seen for the first time ever)
learning multiple associations poses a binding problem:

connectionist associators learn one item at a time and need separate presentation of individual items!

the network may associate blue with left and read with right
more functions for higher-dimensional fields: coordinate transformations

which are analogous to the instantaneous associations between stimulus features demonstrated earlier
coordinate transformations

- eye movement: visual target from retinal representation to head-centered representation for reaching

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
coordinate transformations

- every gaze shift changes the spatial reference frame of the visual perception
- how to memorize location when the reference frame keeps shifting?
- => transformation to gaze-invariant reference frame

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
coordinate transformations

- head movement: transform visual target from retinal representation to body-centered representation
coordinate transformations

- hand movement: transform movement target from body-centered representation to hand-centered representation for reaching

\[ \text{Erlhagen, Schöner, Psych Rev 2002} \]
coordinate transformations

- need mapping between different reference frame: retinocentric (moving with the eye) to body-centered (gaze-invariant)

- mapping is a variable shift, depends on current gaze direction

- as a formula $x_{body} = x_{retinal} + x_{gaze}$

- but how to implement this in DNFs, using space code representations?

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
coordinate transformations

- fixed mapping: neural projection in a neural network
- flexible mapping that depends on gaze/eye position?

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
coordinate transformations

- expand into a 2D field
- free output connectivity to implement any mapping

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
coordinate transformations

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
coordinate transformations

![Diagram showing retinal field and gaze field transformations.](image)

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
coordinate transformations

[A] retinal field
B gaze field
C transformation field

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
coordinate transformations

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
coordinate transformations

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
coordinate transformations

- bi-directional coupling: reversing the transformations

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
spatial remapping during saccades

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
Case Study: Spatial Remapping during Saccades

A retinocentric field

B gaze field

C body-centered field

D transformation field

[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]
Coordinate transformations

- predict retinal location following gaze shift

[Schneegans, Schöner, BC 2012]
accounts for predictive updating of retinal representation

[Schneegans, Schöner, BC 2012]
Scaling dimensionality
multi-dimensional fields represent “bound” feature conjunctions

- the 2D fields representing the combinations of features (e.g., color, orientation, etc) and locations
Scaling dimensionality

- example: 6-dimensional field (as needed for coordinate transformations from 3D to 3D)
- sample each dimension with 100 neurons: $10^{12}$ neurons! problem: entire brain...
很多较低维的字段的组合可能会完成这个任务

=> binding
Feature binding along space

Peaks in different feature-space fields are bound by local excitatory coupling along space.

[Johnson, Spencer, Schöner, NIP 2008]
Memorization of left item

[Slides adapted from Sebastian Schneegans, see Schneegans, Spencer, Schöner, Chapter 9 of Dynamic Field Theory-A Primer, OUP, 2015]
Adding third item to scene

[Slides adapted from Sebastian Schneegans, see Schneegans, Spencer, Schöner, Chapter 9 of Dynamic Field Theory-A Primer, OUP, 2015]
Post sequential memorization of all three items

[Slides adapted from Sebastian Schneegans, see Schneegans, Spencer, Schöner, Chapter 9 of Dynamic Field Theory-A Primer, OUP, 2015]
Scaling

- coordinate transforms as bottle-necks
conclusion: multi-dimensional fields

- enable new cognitive functions that derive from association and cannot be realized by synaptic networks

  - instantaneous association or linkage (referral) enabling dimensional cuing

  - cued recall

  - coordinate transforms instantaneous real-time

  - representing associations, rules etc. in a manner that can be activated/deactivated
conclusions continued

- need to span only a limited number of dimensions (2 and 3), which are expanded by binding through space

- span by small number of neurons
multi-dimensional fields

- help us move toward higher cognition