## DFT coupling among higher-dimensional fields

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# Central idea: DFT reaches higher cognition by combining

- I Space: fields representation lowdimensional features spaces
- 2 Dynamics: inducing selective peaks through the instabilities ...
- 3 Coupling fields that span different lowdimensional feature spaces
- (4 Autonomous sequence generation)

# Central idea: DFT reaches higher cognition by combining

- I Space: fields representation lowdimensional features spaces we covered 1+2
- 2 Dynamics: inducing selective peaks through the instabilities ....
- 3 Coupling fields that span different lowdimensional feature spaces
- (4 Autonomous sequence generation)

we will cover 3 later

#### Roadmap Foundations 2: Space-time coupling

Background: different notions of binding
Joint representations and coupling patterns
Binding through space/ordinal dimension
Coordinate transforms

## Intuition for "binding"





red cutter horizontally aligned

where is the red cutter?



where is the red cutter?



#### what was here?



#### the red cutter



## Binding

classical notion: features shape, color, orientation, and location are all "bound" together..





- notion that fea an object are bound...
- (could be also simply due to the fact that objects are localized, so features are bound to a location)

#### the round object is blue



[Faubel, 2008]

## Binding to categories

the "S" is green

## CUOSL



## Such binding is flexible

feature combinations never seen before may be bound

## mis-bindings may occur in "illusory conjunctions" (a)

yellow **blue** 



I) scene presented, then

removed

- 2) report first the numbers (tosigenerate a delay)
- **X** 3) then report object features (shape, open/ closed, color)



[Treisman, 1998]

## Treisman's Feature Integration Theory (FIT)

- "binding through space"
- combines neural notions (attention, feature maps)
- with information processing notions (files store feature combinations)



[Treisman, 1998]

Binding in higher cognition: Vector Symbolic Architectures (VSA)

concepts represented by activation vectors:

 $x_{\text{John}}, x_{\text{Mary}}, \dots$ 

y<sub>lover</sub>, y<sub>beloved</sub>



[Levy, Gayler, 2008]

## Binding in VSA

### represent "John loves" by binding x<sub>John</sub> to y<sub>LOVER</sub>

e.g. as a direct product



[Levy, Gayler, 2008]

## Binding in DFT

- we will consider different forms of binding
- and the processes that bring these about, and make use of bindings
- these notions are not perfectly aligned with the classical notions
- but provide, in some cases, a neural process account of classical notions

#### Roadmap Foundations 2: Space-time coupling

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## Joint representations: "anatomical" binding

#### enables cognitive operations by

- coupling different fields over different low-dimensional spaces
- and using the dynamic instabilities to create peaks/ operate on peaks

## Joint representations of different feature dimensions



# Based on neurons that are tuned to multiple different feature dimensions

example: receptive field + direction tuning
 => combines visual space and orientation



[Hubel, Wiesel, 1962]

## Joint space-feature representation

- In a joint representation, localized peaks represent instances in which the different features dimensions are "anatomical bound"
- fixed: need the neural substrate every possible bound state



[Schneegans et al., Ch 5 of DFT Primer, 2016]

## Extract features: unbinding

projecting to lowerdimensional fields by summing along the marginalized dimensions

contraction mapping



[Schneegans et al., Ch 5 of DFT Primer, 2016]

## Contraction coupling



[Sabinasz, Richter, Schöner, Cog. Neurodyn. 2023]

### **Bind features**

#### project lower-dimension field onto higherdimensional field: expansion mapping



## **Bind features**



=> bind individual features into bound (joint) representations

enables the generation of mental maps

[Schneegans et al., Ch 5 of DFT Primer, 2016]

## Expansion coupling



[Sabinasz, Richter, Schöner, Cog. Neurodyn. 2023]

## Coupling patterns used later

one-to-one mapping



[Sabinasz, Richter, Schöner, Cog. Neurodyn. 2023]

## Binding problem

- this binding operation runs into the binding problem
- solution: bind one object at a time
- => attentional bottleneck



[Schneegans et al., Ch 5 of DFT Primer, 2016]

## Cued selection

- an operation that uses joint and individual representations
- combining expansion and contraction



[Schneegans et al., Ch 5 of DFT Primer, 2016]

## **Role-filler** binding

in relational/action phrases, concepts appear in roles:

e.g. target, reference, agent, tool, ...

#### 

[Sabinasz, Richter, Schöner: Cog Neurodyn 2023]



## **Role-filler** binding

color concepts... grounded in feature fields



- roles: reference, target, agent, tool, ...

  - joint representation of roles and concepts



[Sabinasz, Richter, Schöner: Cog Neurodyn 2023]

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