Multi-layer fields enable more complex neural dynamics

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... so far we assumed

that a single population of activation variable mediates both the excitatory and the inhibitory coupling required to make peaks attractors
But: Dale’s law

- says: every neuron forms with its axon only one type of synapse on the neurons it projects onto
- and that is either excitatory or inhibitory

This is not actually possible!
inhibitory coupling is mediated by inhibitory interneurons that are excited by the excitatory layer and in turn inhibit the inhibitory layer.
2 layer Amari fields

\[
\tau_u \dot{u}(x,t) = -u(x,t) + h_u + s(x,t) + \int k_{uu}(x-x') g(u(x',t)) \, dx' - \int k_{vv}(x-x') g(v(x',t)) \, dx'
\]

\[
\tau_v \dot{v}(x,t) = -v(x,t) + h_v + \int k_{vu}(x-x') g(u(x',t)) \, dx'
\]

with projection kernels

\[
k_{uu}(x-x') = c_{uu} \cdot \exp \left( -\frac{(x-x')^2}{2\sigma_{uu}^2} \right)
\]
simulation
the fact that inhibition arises only after excitation has been induced has observable consequences in the time course of decision making:

- initially input-dominated
- early excitatory interaction
- late inhibitory interaction

[figure: Wilimzig, Schneider, Schöner, Neural Networks, 2006]
time course of selection

intermediate: dominated by excitatory interaction

early: input driven

late: inhibitory interaction drives selection

[figure: Wilimzig, Schneider, Schöner, Neural Networks, 2006]
early fusion, late selection

Figure 16 Wilimzig Schneider Schöner

[figure: Wilimzig, Schneider, Schöner, Neural Networks, 2006]
fixation and selection

[figure: Wilimzig, Schneider, Schöner, Neural Networks, 2006]
2 layer fields afford oscillations

- => exercise
- (oscillatory states for enhanced coupling among fields)
- (generic nature of oscillations)
mathematical basis of oscillations: limit cycle attractors

Amari 77

\[ \tau \dot{u} = -u + h_u + w_{uu}f(u) - w_{uv}f(v) \]
\[ \tau \dot{v} = -v + h_v + w_{vu}f(u), \]
\( u \) (solid), \( v \) (dashed)

(a)

(b)
mathematical basis of oscillations

\[
\tau \dot{u} = -u + h_u + w_{uu}f(u) - w_{uv}f(v) \\
\tau \dot{v} = -v + h_v + w_{vu}f(u),
\]

- linearize dynamics in each quadrant
- compute fixed point
- if it lies in same quadrant: fixed point attractor
- if it lies in next quadrant: part of a limit cycle
oscillator

\[ v_{inh} \]

\[ u_{exc} \]
two-neuron simulator
Limit cycle oscillators

- are source for stable, autonomously generated time structure in neural dynamics
- used in movement generation
- and coordination…
- “liquid state machines” or “echo-state networks” are an expansion of that idea (not very well defined mathematically)
Active transient

arises when the stable resting state is briefly pushed by input into the fourth quadrant: return on a temporally structured trajectory
start active transient: blue => red
then fall back to blue
self-stabilized state

on: blue => red

on: red => green
CoS

detection CoS: blue => green

set intention: blue => red
Transient detector

2

\( v_{inh} \)

1

\( u_{exc} \)

\( \frac{3}{4} \)

1

2

3

4

onset

blue => red
Change detection

three layer field => simulation
Conclusion

by taking into account Dale’s law, reach much richer neural dynamics that includes

- oscillations: time course generation

- active transient: preserve oscillatory time structure in single-shot time course

- switching an activated node of with a finite/well defined amount of time before switch is achieved: Condition of Satisfaction

- transient detection: make a single, well defined time course from a step change

- change detection