Computational Neuroscience: Neuronal Dynamics of Cognition

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Continuum models:
Cortical fields and perception

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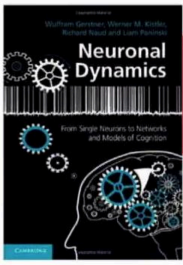
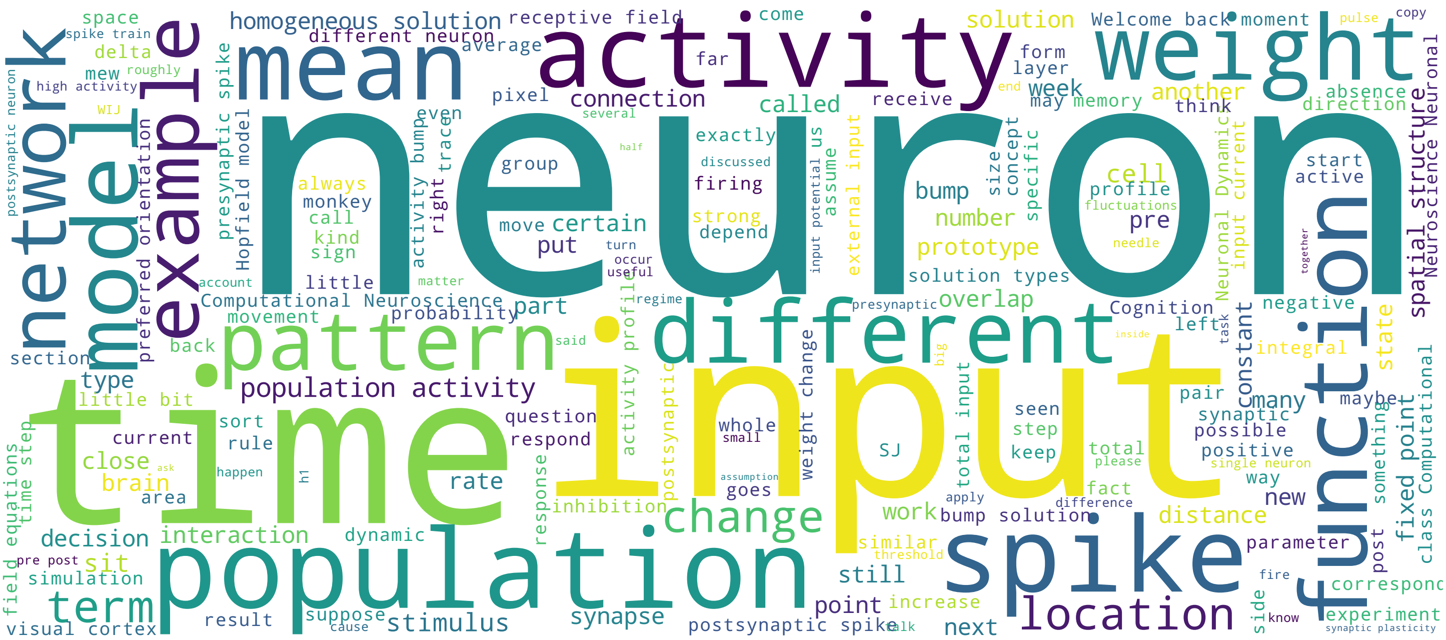
Reading:
NEURONAL DYNAMICS
Ch. 18 +
+Ch. 12.3.7+Ch 15.1-15.2.3

Cambridge Univ. Press



1. **Aims and challenges**
   - review: mean-field arguments
2. **Transients**
   - generalized integrate-and-fire model
   - transients can be sharp or slow
3. **Spatial continuum (cortex)**
   - orientation columns
4. **Spatial continuum (model)**
   - field equations
5. **Solution types**
   - uniform solution
   - bump solution
6. **Perception**
7. **Head direction cells**



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Video

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5. Two Solution Types (ring model)

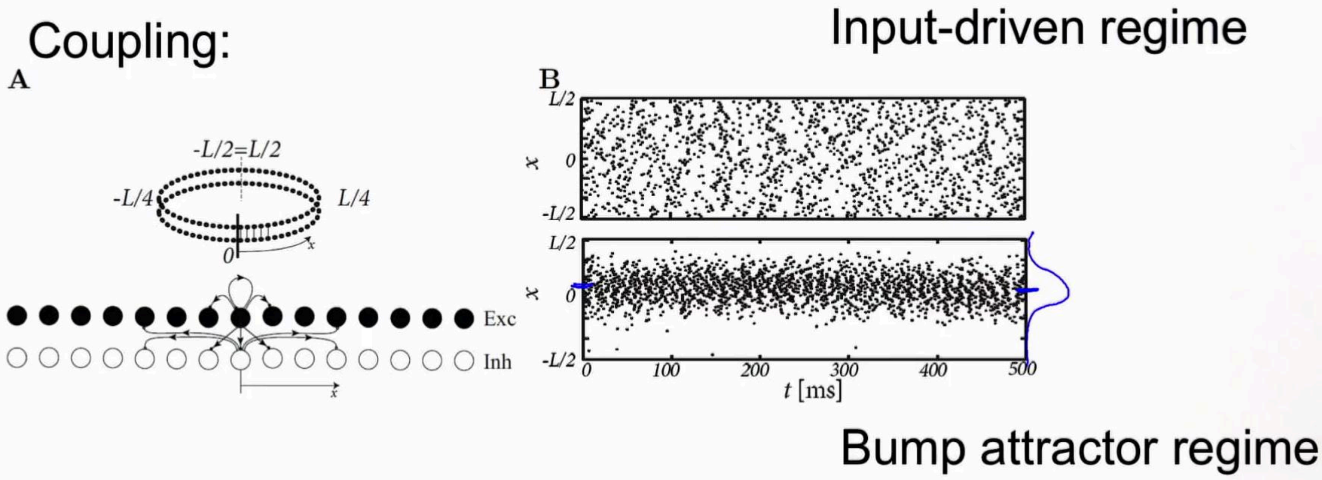


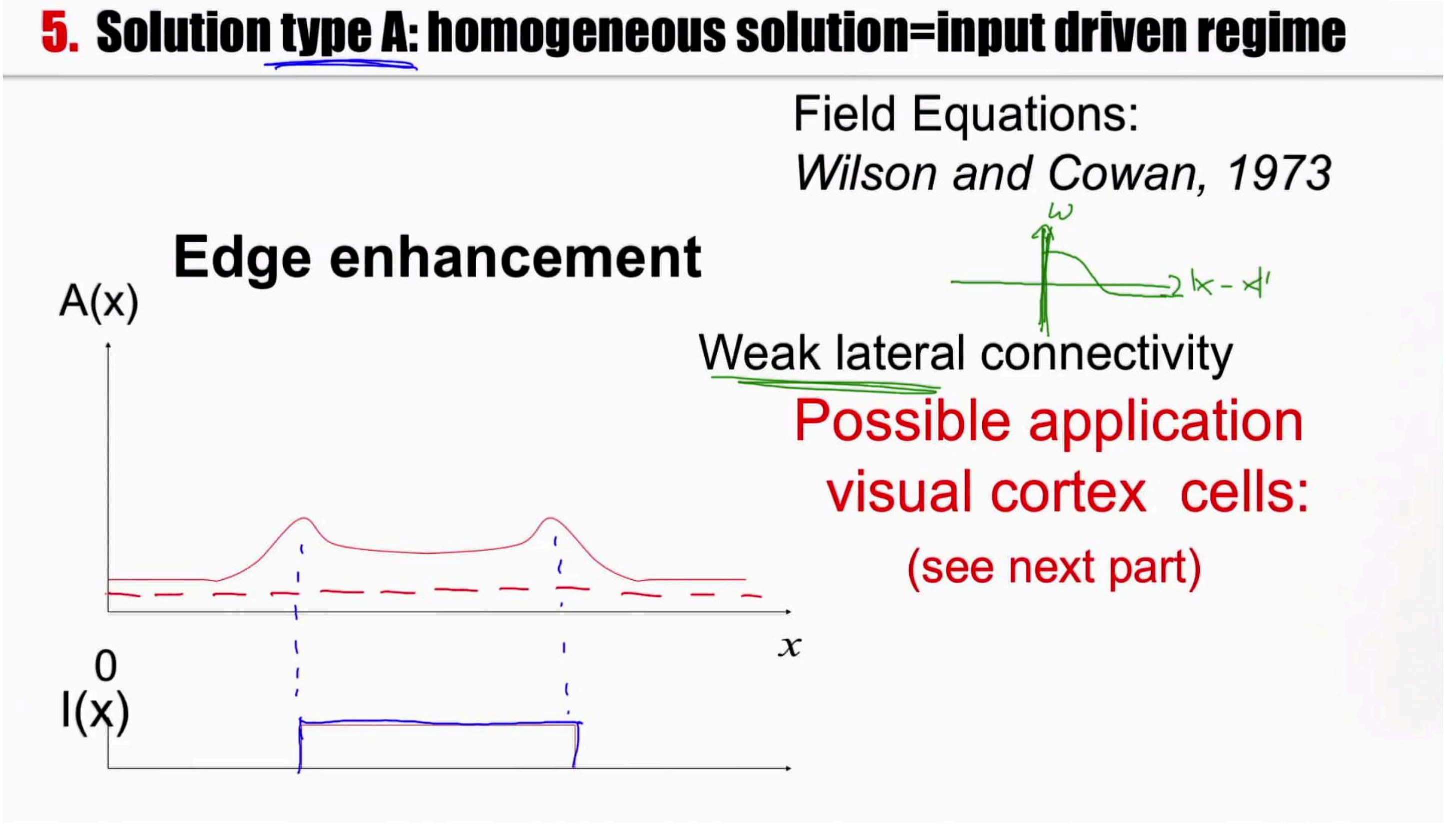
Image: Neuronal Dynamics, Gerstner et al., Cambridge Univ. Press (2014),

So welcome back to the class Computational Neuroscience: Neuronal Dynamics of Cognition. This week we work on continuum models, and now that we have derived the field equations, we can look at solution types. So here's an example taken from a simulation. We put the extended neural population on a ring, so we close it down, and then this is my, and we want to use the version with local excitatory interaction and long-range inhibitory interaction with a certain set of parameters for the interaction weights between the different neurons, and what I find is, that as a function of time, the activity looks pretty much constant, and there's a function of space. It looks also constant. So this is the first solution that we call the homogeneous solution, because it has no spatial structure, and it's also the input-driven regime. And then for the same model, just with the slight change of parameters, there's also a second solution where, again, as a function of time, there's hardly any change, but as a function of space, I now have a very sharp peak, sharply peaked profile at a certain location. Locate the medium, would be roughly here. So this is a peak or bump of activity centered just above equals 0.

Notes

Summary

0m 12s



So we can look at both solution types and for the moment I focus on this type A, which means homogeneous solution, and the homogeneous solution means that if I have no input, then the activity would just be flat. So there is no spatial structure. However, if I apply an input, like the input here, then I would see activity profile which has peaks at the corners of my stimulus, and which is overall elevated in the regime where the stimulus is applied. So this regime typically occurs if my connectivity profile for the weights as a structure, so here's the size of the weight, and this is minus ', that's the distance between the two neurons, there's sort of this broad profile and the amplitude is rather small, so it's called a weak lateral connectivity profile.

Notes

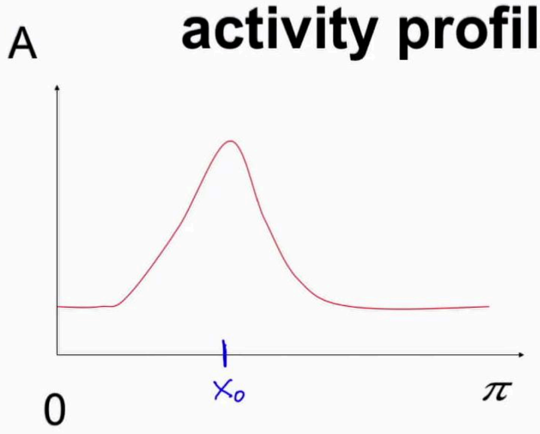
Summary

1m 36s

5. Solution type B: bump solution

Field Equations:
Wilson and Cowan, 1973

Bump formation:
activity profile in the absence of input
strong lateral connectivity

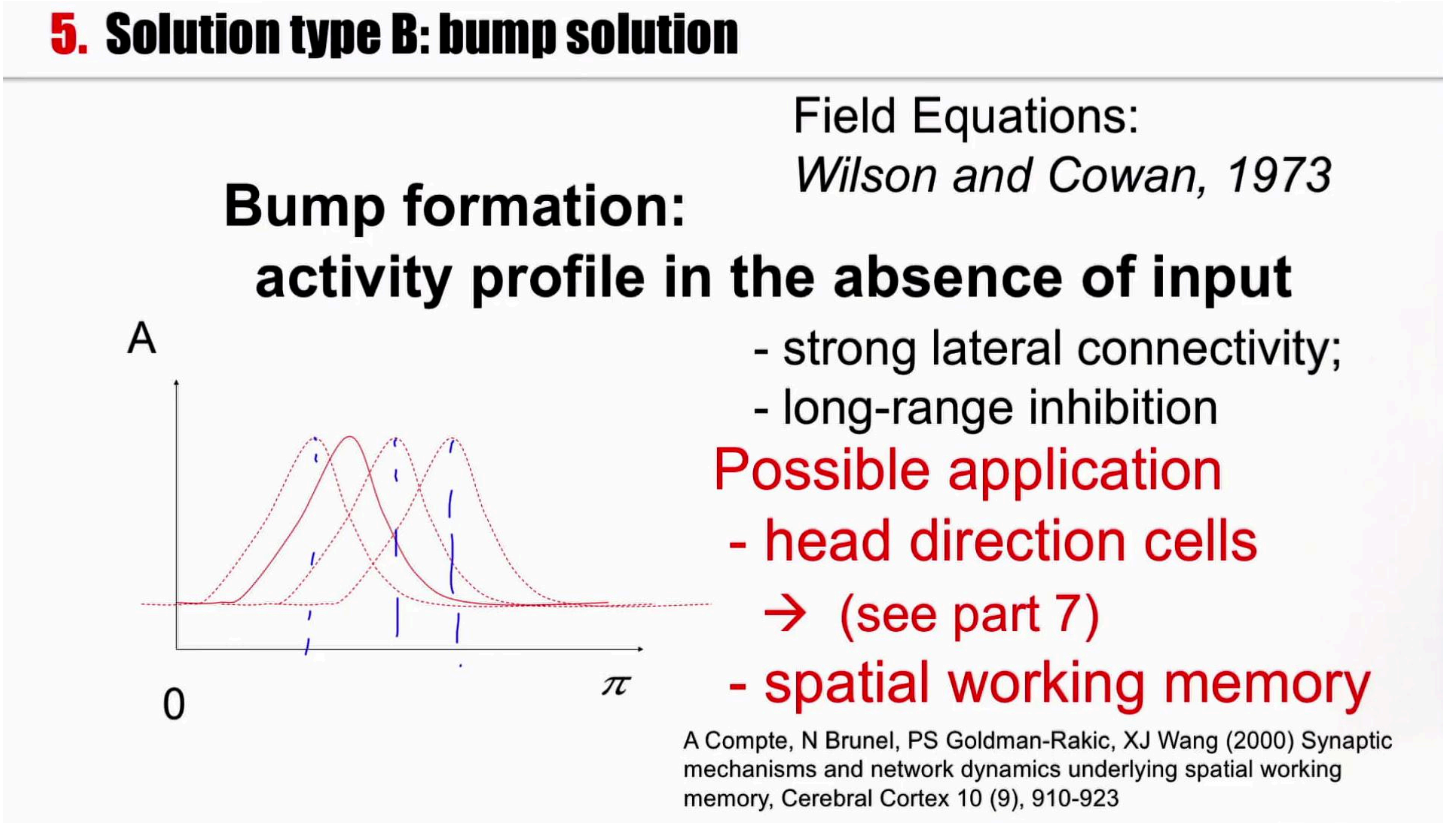


Now the other solution is the bump solution, and here in the absence of any input, for input 0, I can find an activity peak that's very strong around a certain location and say this is my location 0. Now, this location is arbitrary.

Notes

Summary

2m 46s



The activity profile could also sit at any other location. It could sit here, or it could sit there, or it could sit there. So I have a translation invariance, but the shape of the profile is always the same. Now, this kind of bump formation might be very useful for spatial working memory in particular head direction cells and we'll look at this in part 7 later this week.

Notes

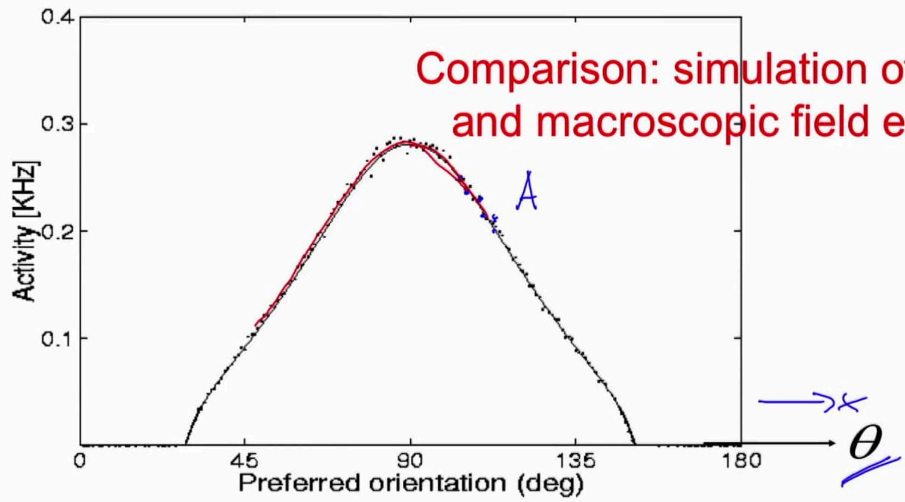
Summary

3m 10s

5. Solution type B: bump solution

Spiridon&Gerstner

$$A(\theta,t) = A(\theta)$$



Continuum: stationary profile

Image: Neuronal Dynamics, Gerstner et al., Cambridge Univ. Press (2014),

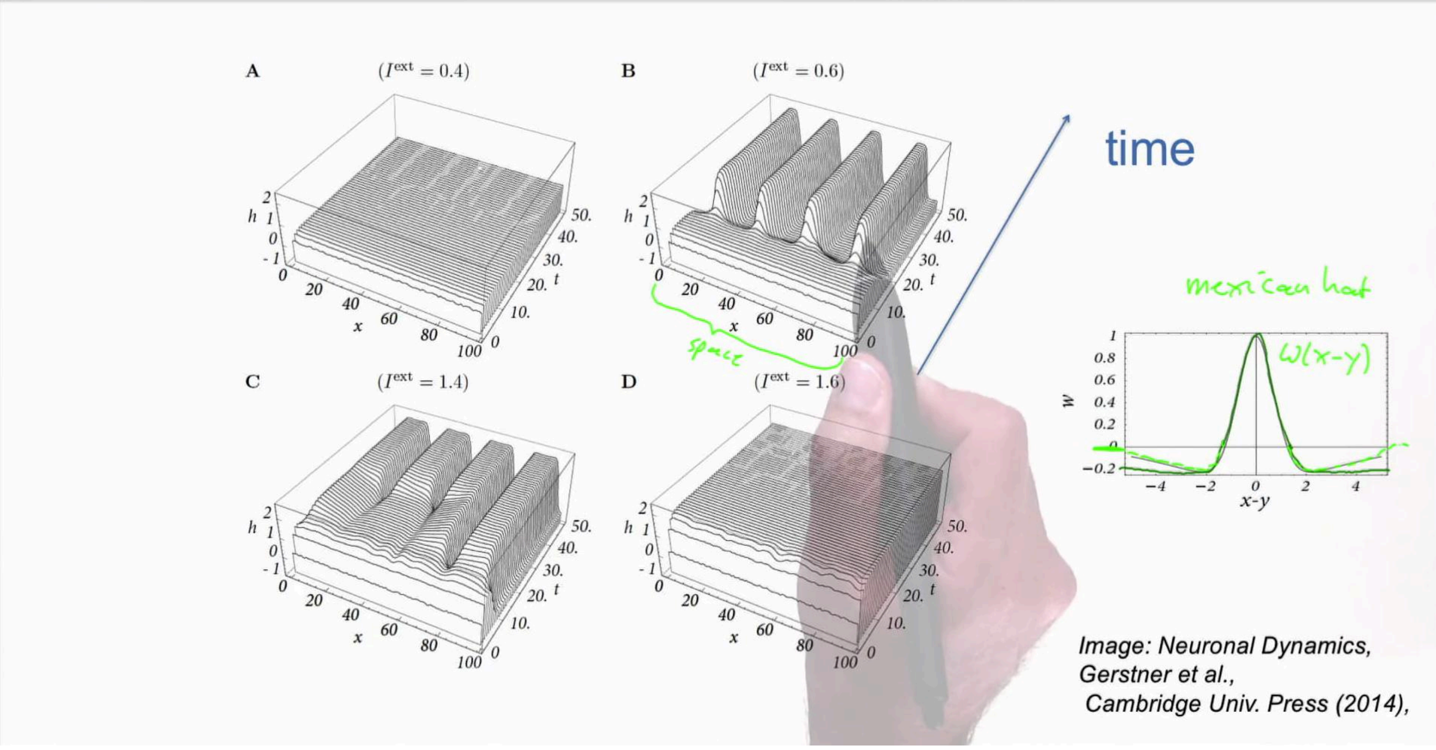
So far I just had schematic figures. Now here is such an activity profile in a bump solution for a network of generalised integrate-and-fire neurons, exactly the type of neurons that we have seen earlier this week. The dots here correspond to simulation results, it's the activity A as a function of the location , or we can interpret this as the preferred orientation of cells in visual cortex Now the solid line corresponds to a solution that's calculated from the field equations. And you see that the simulation nicely matches the solution of the field equations for this bump solution.

Notes

Summary

3m 38s

5. Solution types: multiple bump solutions with local interaction



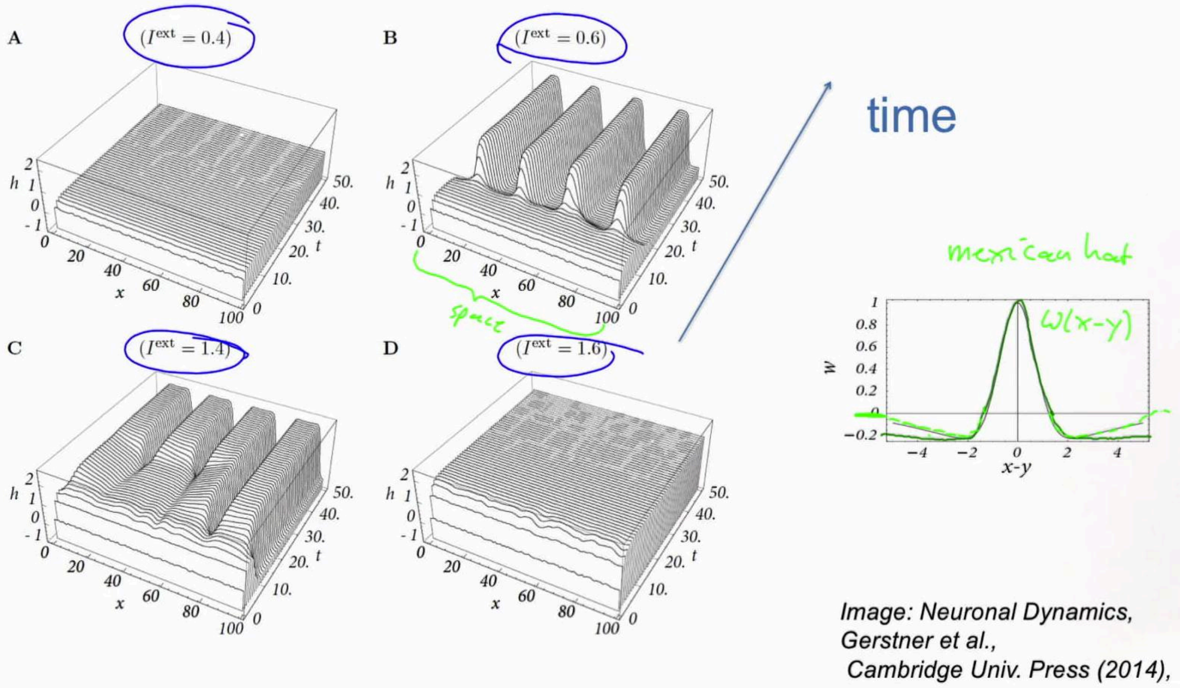
I already mentioned the Mexican hat profile with local interaction and further our inhibition. Now to get the bumps on the previous slide, it was a very large peak compared to the one we had earlier for the homogeneous solution, and then it continued, the inhibitory part continued to both sides over very long distance, in fact, infinitely long. And in this case, the bump solution is a single bump. However, if you have an activity profile like the one indicated here where the inhibition also has only some finite range, then it's possible that as a function of space, multiple activity bumps will form. So what we see here is the time axis, here is the space axis, this is the space axis, and we see that several bumps, the activity -- one activity bump sits here, the next one sits here, the next one sits here. Intuitively, if the activity -- if the interaction profile, the w of minus falls off at some distance here, a distance of 5, then it's possible at a distance of 10 to have the next activity bump.

Notes

Summary

4m 29s

5. Solution types: multiple bump solutions with local interaction



Now in this case, for this dash line here, for the same interaction profile, and for weak input, we find that there's the homogeneous solution; if we have a somewhat stronger input, then these multiple bumps evolve as a function of time and becomes stable solutions; if the external input is even stronger, the bumps remain, but they get a little bit broader; and for super strong input, it's just a very high activity state, a homogeneous high activity solution that is stable.

Notes

Summary

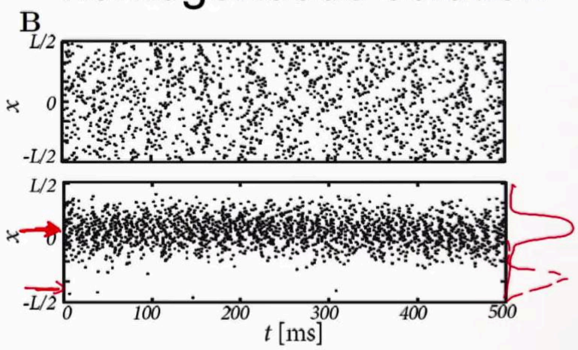
5m 57s

5. Two Solution Types (ring model)

Two stationary solution types:

- homogeneous for flat input
  → responds to input
- bump attractor for flat input
  → moves to location of input

Input-driven regime: homogeneous solution



Bump attractor regime

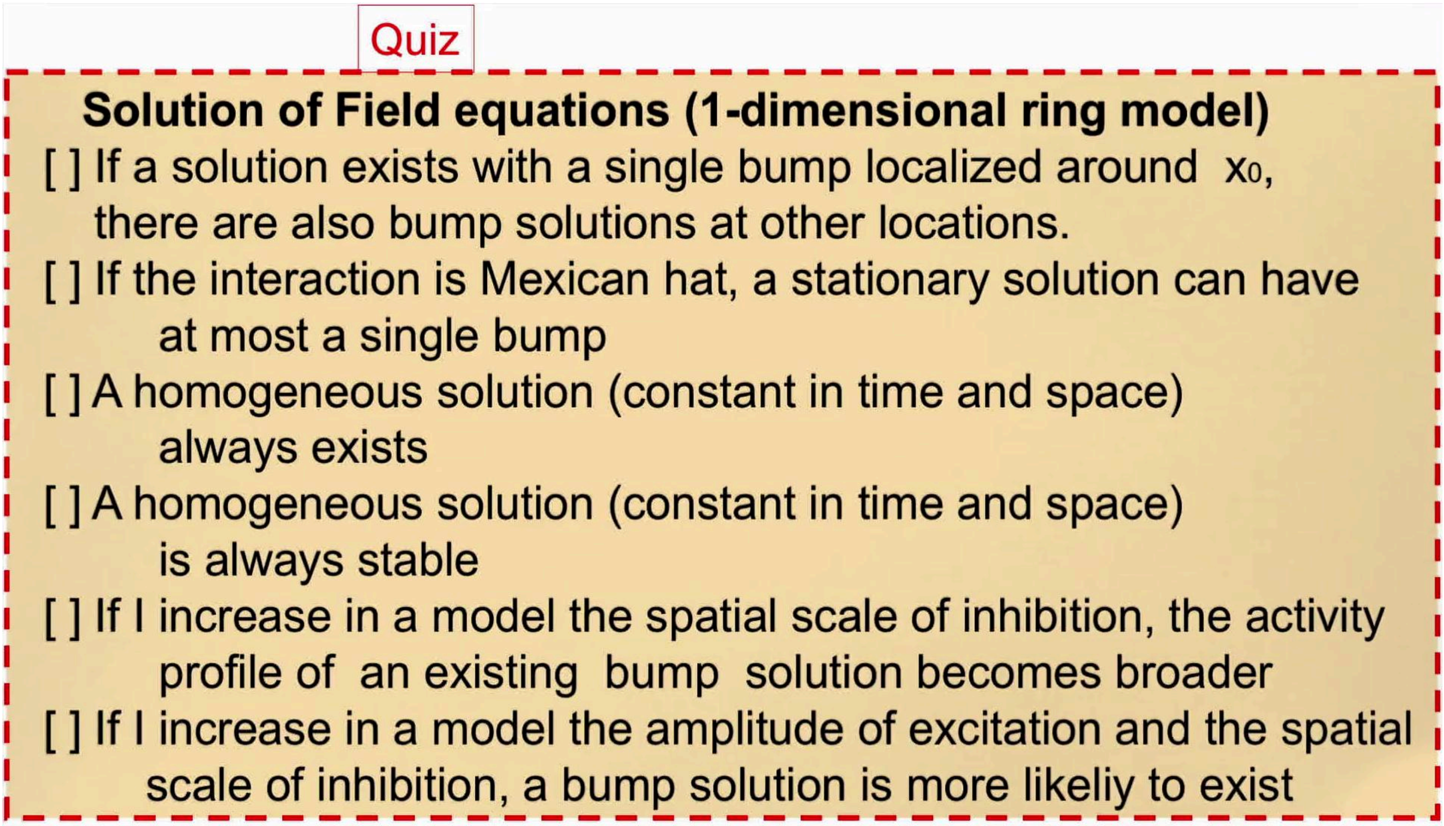
Image: Neuronal Dynamics, Gerstner et al., Cambridge Univ. Press (2014),

So, let me sum up. The field equations have two types of stationary solution. There's a homogeneous solution, which means no spatial structure, and this occurs in the absence of input, or for flat input, and the input has no spatial structure, and then if the input develops a spatial structure, then the homogeneous solution becomes inhomogeneous, and it responds to the input. And we have seen one of the features is a contrast enhancement. Now, the other solution is that even in the absence of input, or for flat input with no structure, spontaneously a bump forms. This is my bump profile. Now, if I have an input, then the bump would occur at the location where the input is. So if I initialise here, by putting an input pulse at this location, then the bump would appear around here. If I initialise somewhere else, the bump would sit over there. So we have these two different solution types, both are stationary solutions, both can be stable solutions. In the next two sections, we are going to apply these different solution types to cognitive and perceptual phenomena.

Notes

Summary

6m 31s



But before we go there, please take your time and have a look at the quiz.

Notes

Summary

7m 48s