Computational Neuroscience: Neuronal Dynamics of Cognition

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Continuum models:
Cortical fields and perception

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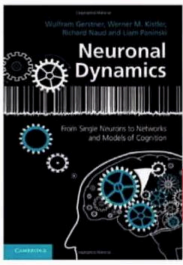
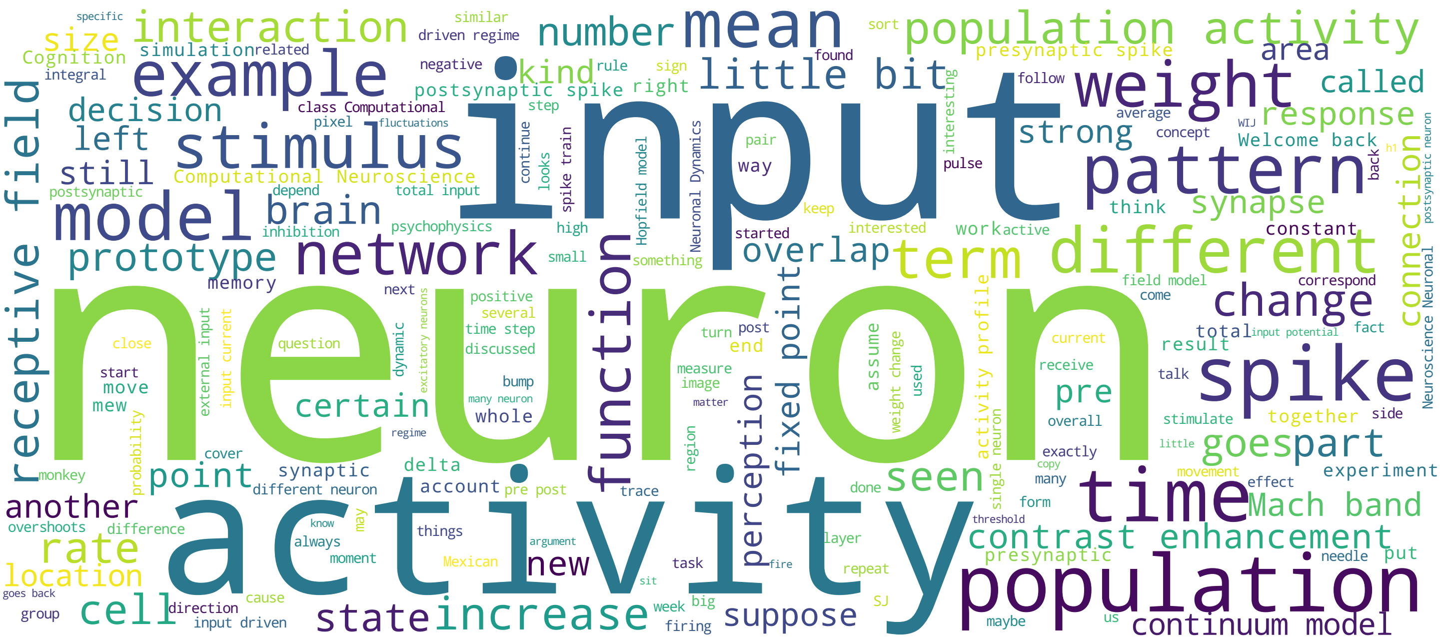
Reading:
NEURONAL DYNAMICS
Ch. 18 +
+Ch. 12.3.7+Ch 15.1-15.2.3

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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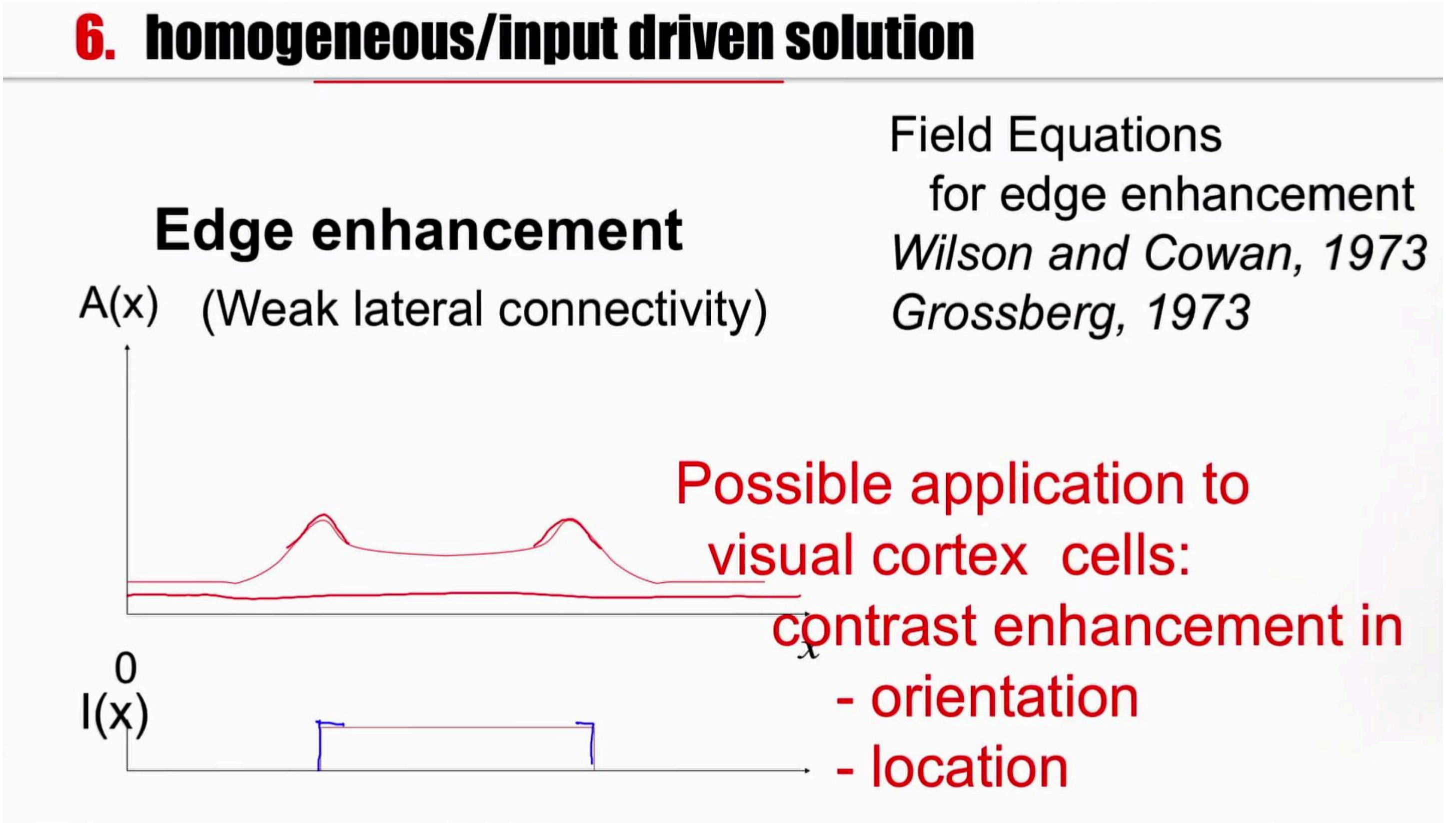


So welcome back to the class Computational Neuroscience: Neuronal Dynamics of Cognition. This week we look at continuum models, and in the previous part we have seen that there are two different solution types. Now, for perception, it's the uniform solution, homogeneous solution, which is of most interest. As we have seen, for no input, the activity would be completely flat as a function of space, signaling that there is no input. But then, if I have an input, then an activity profile develops, and this activity profile will have these little additional peaks around the edges of the input, as we have seen in the previous section. Now this is interesting, it's an effect of contrast enhancement, and contrast enhancement could be in the orientation domain, or simply in the location domain. So signaling the end of the input, signaling a strong change in the input.

Notes

Summary

0m 18s

6. Perception - grid illusion

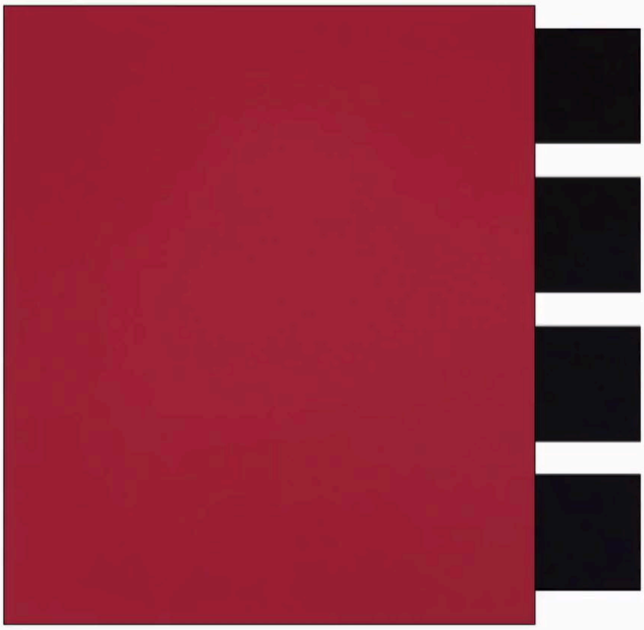


Image: Neuronal Dynamics, Gerstner et al., Cambridge Univ. Press (2014),

So now let's look at this little diagram. So at my home, I have a white phone, the white phone has black keys, and so this is more or less the pattern that I see, and if you stare at it, at least if I stare at it, I see spontaneously black dots at the white crossing points. I'm not sure that you see this as well, but this is a widespread perceptual illusion, this so-called grid illusion, and you can imagine that this is one of these contrast enhancement effects that goes a little bit wrong, that overshoots and that causes this dynamic effect. So if I cover the grid, if I cover most of the black keys, then it's the same image on this side, but this additional edge enhancement effects no longer cause the illusion.

Notes

Summary

1m 02s

6. Perception – Mach bands

Mach, 1865, 1906

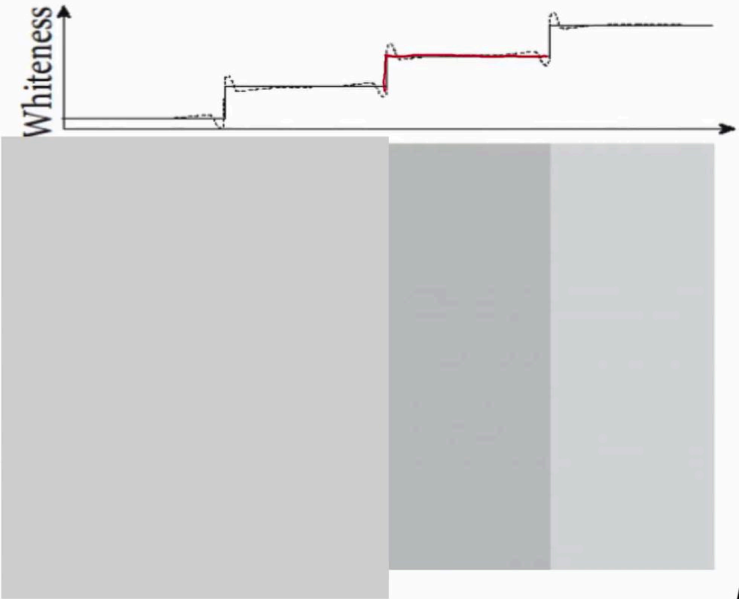


Image: Neuronal Dynamics, Gerstner et al., Cambridge Univ. Press (2014),

Now let's look at this pattern here. Look at this sequence of gray patches. What I see, and what most likely you are going to see, is that it's -- that within each of these gray areas, there is a subjective whiteness profile such that it's a little bit whiter here, and then it goes back. And then it's a little bit whiter again here, and then it goes back. So these are the so-called Mach bands, Mach was a psychophysicist and physicist working between 1815 -- 1850 and 1905, and he was interested in several physical phenomena but also in perception in psychophysics. And these are the Mach bands and it's a visual illusion because if I cover the stripes to the left, you no longer see these overshoots. Now you see that, indeed, this is a gray constant area. This is an area with constant gray value.

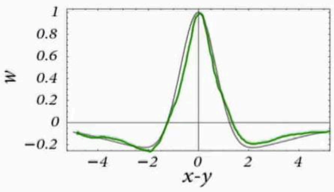
Notes

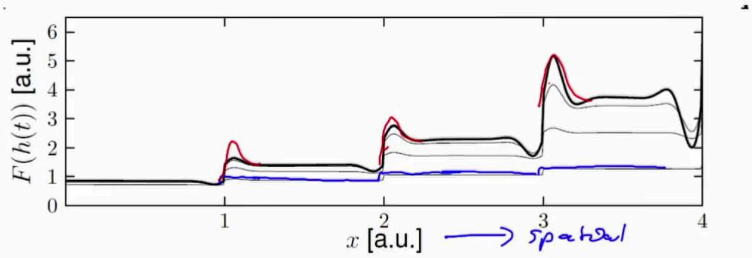
Summary

1m 59s

6. Mach bands in a continuum model

Mexican-hat coupling





ig. 18.9: **A**. Mach bands in a field model with mexican hat

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

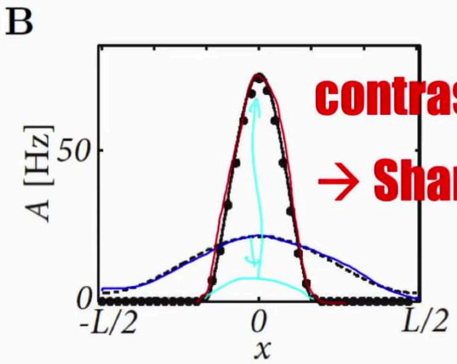
So if we take now our continuum model, in the input-driven regime, in the regime where normally we have a flat solution, and I apply a stimulus that is -- that has these little steps here, so this is my stimulus, and it goes to larger and larger intensity values, then you see these overshoots in the response. So this is my activity at these different locations, so this is my spatial location, and you see these nice overshoots that correspond to the Mach band that we have seen before. And what we used is just a field model, a continuum model with the interaction kernel that had this typical Mexican hat function.

Notes

Summary

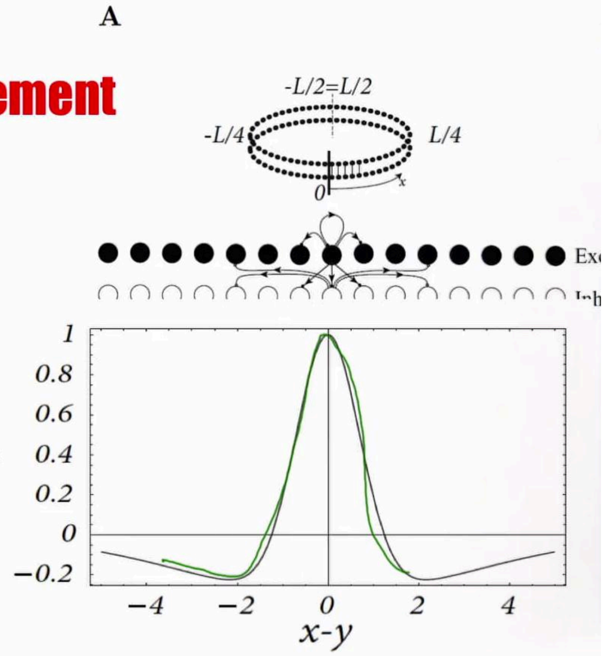
3m 08s

6. Field models and Perception: contrast enhancement



contrast enhancement

→ Sharpening



Shriki et al. (2003):
Ring model in input-driven regime, driven by broad input (dashed line), causes sharp activity bump;
See also: Ben-Yishai et al. 1995; Hansel and Sompolinsky, 1998

For these ring models in the input-driven regime have been widely used and one of the effects is a certain sharpening, it's another way to look at contrast enhancement. So suppose we have a stimulus that's very broad. So, many neurons are externally stimulated. Again, this is the spatial dimension, but the -- on a ring, so the whole thing repeats at L/2, the same as minus L/2. Now, because of the interactions between the different neurons, interactions that follow this Mexican hat kernel, what forms is an activity profile that looks like this sharp bump. You can sort of approximately construct this bump by taking this input profile, shifting it down, such as it looks like this, and now you scale it up with a fixed scaling factor, and you have a good approximation of the final activity profile. The argument I just made qualitatively can be made precise in a very specific model with piecewise linear neurons and this has been done by the theoretical community Ben-Yishai et al., Hansel and Sompolinsky.

Notes

Summary

4m 03s

6: Field models and Perception: surround suppresion

Ozeki et al. (2009):

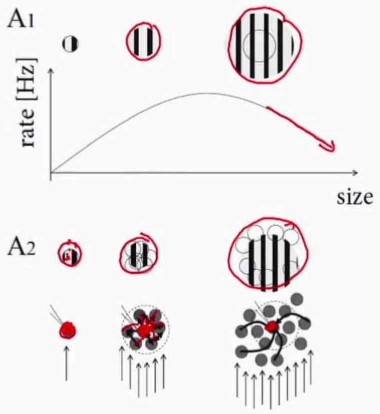


Fig. 18.12: Surround suppression.

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

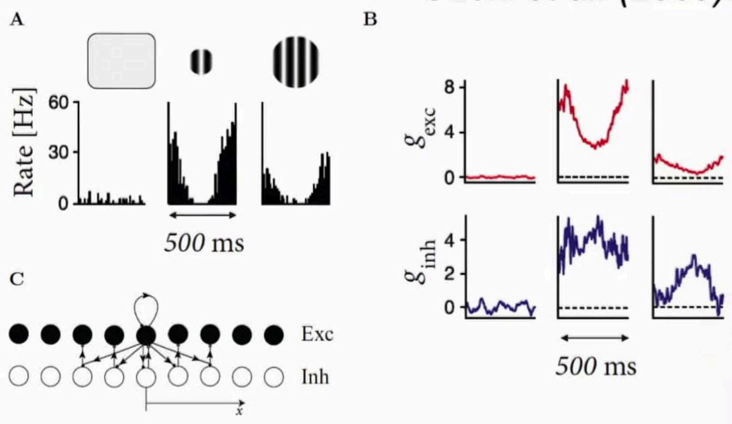


Fig. 18.13: Network stabilized by local inhibition. The schematic model could potentially explain why larger gratings lead not only to less excitatory input g_{exc}, but also to less inhibitory input g_{inh}. **A**. The firing rate as a function of the phase of the moving grating for the three stimulus conditions (blank screen, small and large grating). **B**.Top: Excitatory input into the cell. Bottom: Inhibitory input into the same cell. As in A, left, middle and right correspond to a blank screen, a small grating and or a large grating. Note that the larger grating leads to a reduction of both excitation and inhibition; adapted from (Ozeki et al., 2009). **C**. Network model with long range excitation and local inhibition. Excitatory neurons within a local population excite themselves (feedback arrow), and also send excitatory input to inhibitory cells (downward arrows). Inhibitory neurons project to local excitatory neurons.

Now another effect that's related to perception is measured at the level of individual neurons, and it's called surround suppression. So, what do we need? Suppose I have one neuron, this neuron here, and I've found that its receptive field on the visual screen is best stimulated by a vertical light bar, out of grid. So, if I present dots inside this receptive field, I would see excitation in this region, and suppression in this region. But now I can make the stimulus just bigger, and one way to think about this is that now you stimulate not just this neuron, but you also stimulate the neighbouring neurons, which will have similar receptive fields. And now, if these neurons have positive interactions with each other, then if I continue to measure the same neuron, I measure this neuron, which is sitting here, then I will see that the total activity of this neuron will increase. Now we can go on and we can make the stimulus even bigger, but if we do this, then we also stimulate neurons that are further out, and what we find is that the activity of this neuron here, always the same neuron sitting in the middle goes down again.

Notes

Summary

5m 36s

6: Field models and Perception: surround suppresion

Ozeki et al. (2009):

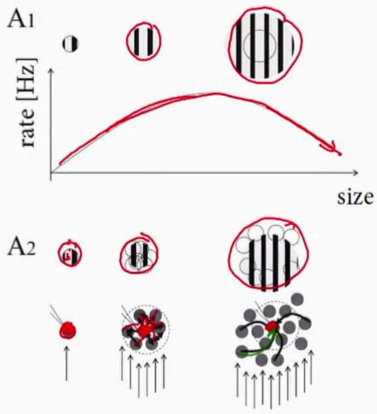


Fig. 18.12: Surround suppression.

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

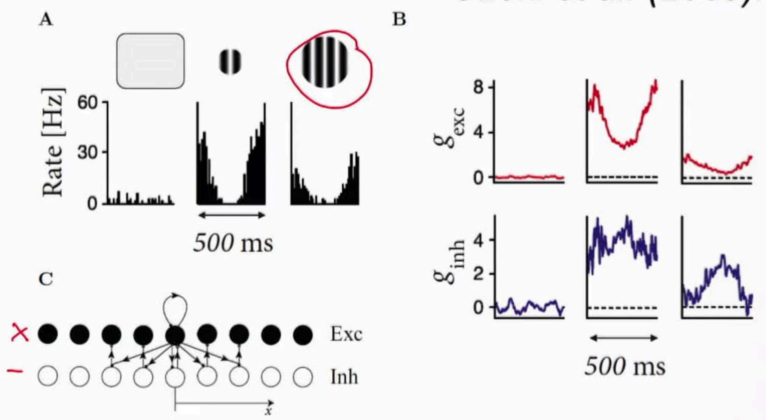


Fig. 18.13: Network stabilized by local inhibition. The schematic model could potentially explain why larger gratings lead not only to less excitatory input g_{exc}, but also to less inhibitory input g_{inh}. **A**. The firing rate as a function of the phase of the moving grating for the three stimulus conditions (blank screen, small and large grating). **B**.Top: Excitatory input into the cell. Bottom: Inhibitory input into the same cell. As in A, left, middle and right correspond to a blank screen, a small grating and or a large grating. Note that the larger grating leads to a reduction of both excitation and inhibition; adapted from (Ozeki et al., 2009). **C**. Network model with long range excitation and local inhibition. Excitatory neurons within a local population excite themselves (feedback arrow), and also send excitatory input to inhibitory cells (downward arrows). Inhibitory neurons project to local excitatory neurons.

So, this suggests that the other neurons effectively have an inhibitory connection on our central neuron, so that overall, this pattern can be accounted for if we assume that we have a Mexican hat-like interaction profile, an effective Mexican hat-like interaction profile because in reality, excitatory neurons and inhibitory neurons are, of course, separated. Now, things are not as simple as this because what you see is that if we move up here, it's not just excitation that increases, but at the same time also inhibition increases. In experiments, but this can also be done in a simulation of neurons. So if we increase the size of the stimulation, excitation increases, that's excitatory conductance, and so does inhibition. And if we increase even further, excitation goes down and inhibition goes down as well. But the net effect still is that overall the rate first increases and then goes down.

Notes

Summary

6m 57s

6. Field models and Perception

Psychophysics:

-contrast enhancement is a stable psychophysical phenomenon

-Mach bands are but one example

Neuronal:

-the activity of V1 cell first increases and then decreases with size of stimulus

-both excitatory and inhibitory input into a cell show similar changes

Modeling

-continuum model with Mexican-hat interaction in the input-driven regime for Mach bands

- Receptive Field tuning: contrast enhancement = ‘sharpening’

So let me sum up. We started with a bit of psychophysics, and, indeed, contrast enhancement is a stable psychophysical phenomenon. Mach bands are just one example of this general setup. Now, on the neuronal level, I discussed at the end a little bit the activity of V1 cells and we found that if we increase the size of the stimulus, the activity first increases and then decreases. And, interestingly, both excitatory and inhibitory input into the cell show this kind of properties, they go up together, they go down together. Now, the modelling side, this phenomena can be accounted for by our continuum model with Mexican hat interactions. For this perception, for this perceptual phenomena, for this phenomena of psychophysics, it's good to use a model in the input-driven regime, and then you can account for Mach bands. The same kind of model, if you adjust for a little bit of biological parameters, can also account for receptive field tuning, and we see that this kind of contrast enhancement is related to a sharpening effect of receptive fields.

Notes

Summary

8m 13s