Cognition and its Computation
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Lecture - 56
Topics in Current Research - I

Welcome, we are in the final week of our course on Cognition and its Computation. And this week, we will be discussing some of the open questions that are related to cognition and in general the computation and neurobiology behind cognitive aspects. And we will try to provide a more general perspective of the items that we have covered throughout the course.

And basically come up with the ways we can approach to answer the questions that we have developed and the questions that we have only partially answered and so on. So, the biggest drawback in the field of cognitive science and neuroscience in general and its computational aspect; currently is that there are no real physical laws that can be used to actually predict behavior in such neural systems.

So, it is probably true overall in biology and neuroscience is no different in that respect and the closest something that is that comes to a law in biology is probably Darwin's theory of evolution. Well, it is not really a law, it is a theory. And so, similarly in neuroscience we currently lack that kind of principles, general principles behind every aspect of computation that goes on in the brain in terms of neurons or in terms of synapses or in terms of networks or a system as a whole.

While, there are many questions related to diseases of course, which are present and many many of the neuro developmental and neurodegenerative diseases are beyond our understanding in the sense that we have no cure for those diseases. So, those are also open questions, but we are trying to address this more from a theoretical angle, more from a computational angle as to cognition and its computation as to what principles are behind these computations or observations on cognition.

So, if we start with the idea of stimulus representation in the sensory world or in sensory stimuli impinging onto our peripheral receptors and then they are being transduced into electrical signals and then they are broken up into simpler components or rather very simple components like frequency in the auditory system like a single pixel in the visual system, the light in the single pixel; similarly the pressure or temperature or the vibration or the movement on the skin at a particular small location.

And then gradually in the hierarchy what we know so far is that, these small pieces of information are put together in some way that finally, forms the percept of the object that we are perceiving or in fact the entire sensory world is broken up into many such objects. And in fact we have the holistic representation of these objects and even the holistic representation of the entire environment in our brain in some form.

So, the representation of this percept is definitely unknown; all that we understand or believe is that, the percept is formed in the distributed activity of many neurons simultaneously in our network and it is it arises from these simple or rather from these very small broken up pieces of the entire sensory world. So, can we actually address this problem as to how these little pieces of receptive fields need to be combined in order to form the percept of objects or things that we are interested in a particular sensory environment.

So, to this effect, I will refer to two particular lines of work that have been done; one by Olshausen and field.

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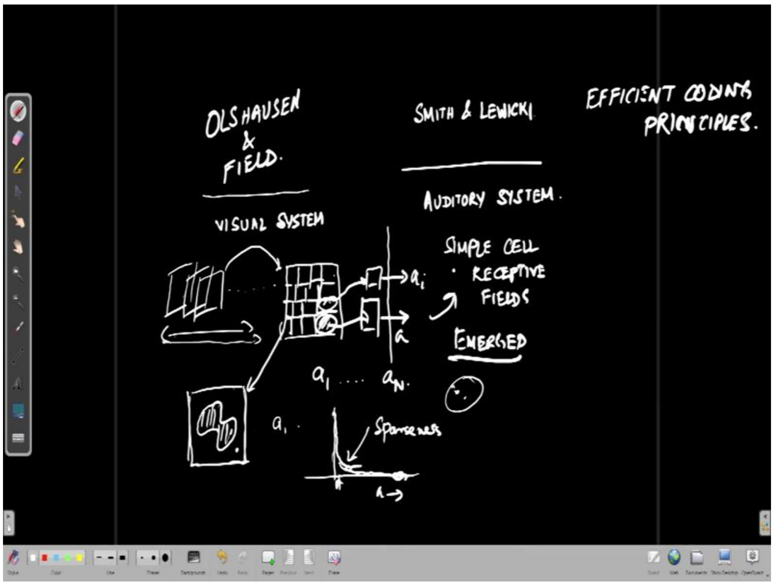

So, let me write down Olshausen and field; this is work in the visual system. And there is another work by Smith and Lewicki, that work is in the auditory system. And these two particular lines of work actually try to address the question that we have been just discussing as to whether we can come up with principles that can guide us in order to understand what the receptive fields along the visual pathway or along the auditory pathway should be to finally form the percept or finally form percept of different objects in the visual field, visual field or in the auditory field.

So, these two lines of work have only scratched the surface in those terms. So, particularly if we talk of the Olshausen and field work what they have shown is that, if you start with huge set of natural images; so each square block I am drawing here is representing an image and we have a huge set of them.

And what they did is ask the question; if we have some units or processing elements or something akin to a neuron, that is processing the different regions of those images. So, this is now one of those images and we have the corresponding units or processing units that are taking only this part of the image and producing and processing it and producing an output.

Similarly, another unit is taking this part of the image as input, processing it, producing an output which is the activity of these neurons or units this here is the activity. So, for the ith such unit, the activity is a i; that is that could be rate that could be some other measure of response, in this case they assumed it is something akin to rate.

And so, the question they now asked is that, given such multiple such processing units from let us say a 1 to a n, a 1 to let us say a finite number N capital N; if we if we constrain the units to be active in a sparse manner. So, the idea here is basically that only a very few of the units are active when a particular signal is present or when a signal that is matched to the receptive field of the unit is present in its in the block that it is processing.

So, let us say a 1 is the activity of the first unit and it responds best to some white object that has this particular shape with dark surround, let us just assume that. So, if the image in that block turns out to be close to this or rather the dot product of the image in that particular block; let us say this is the first block and this receptive field is high, then the a 1 output is very high.

And so, the constraint is that, given the out activity a 1 to a N; I should be able to reconstruct the original image given the activity of those units. And overall across the entire set of images, the distribution of activity a 1 to a N should be sparse in the sense that at a time only a very few of them are active.

So, for every image, only a very few of them active highly and the others are not active or close to zero; that is for any image the distribution would look is heavy tailed. So, this is the activity of the items and most of them is at zero with a very long and heavy tail. So, very few of them have very high activity and most of them are in neurosis.

So, in other words, this is a way to constrain the amount of energy being used by the units to represent all the images. So, since activity or spiking would require energy, this is a very sensible constraint that we want to minimize the use of energy and yet be able to represent the entire information that is present in the sensory world.

And that being able to represent the image in the sensory world shows that, if I have the; if I have the activities present, I should be able to reconstruct the image or there should be minimal error in the reconstruction from the activities versus the original image in each and every case. So, the average error is very low across all the set of images.

And this is essentially an optimization problem and by using different constraints or types of this sparseness criteria and different kinds of activation functions; what Olshausen and field were able to show is that, the resulting receptive fields that this blocks of units have are very much like the simple cell receptive fields of the visual system.

So, with this criteria or with this principle that I should be able to reconstruct the original image and be and yet use minimal amount of energy or in other words the activity is sparse; we can show they showed rather that the kind of receptive fields that we obtain for each of these units are like the simple cells that is they are orientation selective. That is they are selective to bars of dark or bright surrounded by the opposite shade.

So, the these kind of simple cell receptive fields emerged from this optimization. So, this kind of approach solved, as I said only scratched the surface of the overall problem that is; but it is a very good start, the problem is that this has not been taken up beyond this too much.

And because it is difficult to go beyond the simple cells and come up with criteria as to what is it that the activity reconstruction is minimizing. So, essentially what the problem is that, the neural activity is not really trying to reconstruct the entire image that we are seeing; it is true that we are able to reconstruct the image in terms of the values of each pixel, but the percept is not those values of the pixels.

The percept that we have is likely not, I should not say is not the values of the swift pixels; I should rather say that it is likely not the values of the pixels. If you think about it when you see an image, the perception does it really in for us does it really mean that we have high values, medium values, low values or higher values of pixels in that region and different pixel values in that region.

Which is what this problem solved; the way they approach the problem, which is exactly what they try to do. This worked only up to the simple cell level, because that is probably what is expected at the earliest levels of the processing; because simple cells or v 1 a simple cell receptive fields are only about one stage away from the retina, that at that level this method worked in the sense that it is a representation of minimal breaking up into elements from the entire image.

So, to go beyond this, we is an open question and it we do think that approaching a prob the problems in this manner would ultimately provide general principles in terms of understanding how sensory representation and perception works. We are far off from that kind of idea of perception or principles behind perception; but we require processes akin to this in order to understand perception and representation and then perception.

So, in the auditory system, the particular work that we mentioned about which is from Smith and Lewicki, they also approached the problem in a very similar manner and ask the question based on efficient coding principles. So, again this is also a similar idea and they are again it was about being able to reconstruct the original sound waveform from efficient spike codes of the spike codes of gamma tone like filters or filters of a filter bank that is getting the sound waveform as inputs.

Again in this case they started with set of natural sounds and looked at different categories also of natural sounds. And in terms of processing speech what they came up with is that, the filters that were obtained were akin to or very well matched to the kind of filters that represent auditory in our fibers; that is the filter bandwidth impulse response of those filters, which were like gamma tone filters as is observed in actual auditory nerve fibers.

And it had a very good degree of match in terms of how the filter bandwidths change with different frequency just like in the auditory system and all those were predicted based on these similar efficient coding principles and reconstruction of the stimulus waveform.

Now, again as we mentioned for the visual system problem, we when we are hearing a sound; we are not probably trying to reconstruct the waveform, I mean again definitely based on the activity of neurons as we have seen in the case of attention and others based on the neural activity or EEG signals or ECoG signals we can reconstruct the original signals, that were the waveforms or the low frequency envelope of the waveforms.

It is not exactly that which is the percept; so it still remains to be seen how to define what the neurons are finally representing. Definitely being able to decode the waveform or some aspects of the waveform is good, but may not be sufficient to describe percept. So, this this kind of principle based approach to representation and perception is a very open question in terms of the beginning aspects of cognition, where we had talked about representation of sensory inputs in the different sensory pathways.

And we need work along these lines in order to come up with general principles, so that we can then extend this these ideas beyond these parametric systems like the visual system, auditory system (Refer Time: 22:13) sensory system and go into how olfactory or the gustatory systems are organized and actually also be able to predict the sensory representation in other species, which deal with other kinds of sensory environments in their natural world.

So, with that we will end our first open question lecture and we take up a few other questions in the later lectures.

Thank you.