Science AMA Series : I'm Barani Raman, a biomedical engineer at Washington University in St. Louis, I study insect olfactory systems and create "cyborg insects", AMA!

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Abstract

I'm Barani Raman, a biomedical engineer at Washington University in St. Louis. I started my career as a computer engineer trying to develop an "electronic nose," (a non-invasive chemical sensing system). The current state-of-art systems that we fabricate are no match to the capabilities of the biological olfactory system. So, I have been studying the insect olfactory system for the past decade to understand their design and computing principles. Our current approach is two-pronged: (i) conduct basic neuroscience investigation to understand how a relatively simple insect olfactory system works, and from there take inspiration to design the next generation e-noses (ii) take advantage of recent advances in miniaturized, low-power, flexible electronics to create "cyborg insects" and use them as biorobotic sensing systems. Recently, my group has made several important findings regarding how locusts smell, what are some of the neural information processing principles, and what are the rules that govern how neural activity can get translated to behavioral outcomes. AMA! Thank you so much for the interest in understanding my work and all the terrific questions. This was fun and it is good to know what the tax payers care about as well.

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BARANI_RAMAN R/SCIENCE

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Do locusts use smell as their primary mechanism to find food? How are insect olfactory systems different that human? Are they less complicated?

DoShitGardener

Yes, the olfactory sense is a primary sensory modality for invertebrates in general. In addition to foraging for food, they use their olfactory sense for other tasks such as finding mates and for swarming. This is not to say that other sensory modalities are not being used for these tasks. For example, we know that the locusts have a well-developed visual sensory system as well. So, it is good to keep that in mind as there are some ways to ensure fault tolerance in these biological organisms.

There is evidence to suggest that there are striking similarities in the overall organization and some functional principles of vertebrate and invertebrate olfactory systems. This has led to the hypothesis that evolution arrived at possibly an optimal solution for the problem of non-invasive chemical sensing and used the same solution across species and phyla.

Are they less complicated? If you define complexity in terms of number of neurons present in the olfactory centers, then YES. However, fewer neurons does not mean that they can do the basic tasks well. After all insects have lived on this planet longer than us. So they must have something going for them.

Thank you for doing this AMA!

I feel strange asking this question, since insects are awesome, but why did you decide to focus on insects for this effort? Are there specific properties of the insect olfactory system, or insects in general, that you think are best suited for the type of biorobotic system you hope to create? Or was it more that as model systems, insects are small and more convenient to study?

neurobeegirl

Neurobeegirl,

This is my perspective: You need to crawl before you walk, walk before you run. In that sense, I wanted to choose a model organism whose olfactory principles I could understand reasonably well within my lifetime. Also, olfaction being a poorly understood sensory modality, and given that there are similarities between vertebrate and invertebrate olfactory systems, I wanted to study insect olfaction. And so far, I am entirely happy with that decision.

For a long time, my lab has been trying to engineer 'electronic noses' and the solutions we could arrive at, still pale in complexity when compared with the insect olfactory apparatus i.e. their antenna. The idea that we are exploiting here, is the following: we will let the sensory neurons in the insect antenna do the difficult task of converting chemical signals (i.e. odorants) into electrical signals, and we will tap into this signal from the insect brain and directly use this for recognizing different target chemicals of interest. This directly builds on the expertise that we also have in the lab to use insects, as a model organism to study basic computing principles.

Insects being relatively less complex (compared to the vertebrate counterparts), our prior expertise working with them, and availability of the right set of tools/techniques all played a part in the decision to use them for biorobotics.

Excited to see my school represented here!

What do you mean when you say you're trying to understand the computing principles behind the insect olfactory system? Do you mean how insects differentiate between classes of smells?

mmm_toasty

I am glad you are here too! Go Bears! Just so you know, my PhD is in CS too

When you smell a particular odorant, lets say a strawberry, its overall identity (that it is a strawberry) remains the same whether it is coffee shop or grocery shop (i.e. different set of competing molecules present), hot day or a cold day (different temperature), near a coast or in a desert (different humidity levels), morning or evening (at different points in your circadian rhythm), one strawberry or one hundred of them (number of molecules present or intensity of the sensory stimulus present). We (and so do insects) achieve these almost heroic feats of pattern recognition necessary to keep the identity of the strawberry a constant day in and day out. How does this happen? This is just an example of what I mean when I say different computational principles.

Of course, segregating odorants based on their classes (fruit vs nutty) is also another computation that these circuits have to also address. While we know we can do this, and we have behavioral data to show that locusts can do some of these tasks as well, we want to understand how neural circuits perform them. Since you are computer science major, think of them as a deep-learning neural network if you wish, what are the organization (architecture/connectivity), and plasticity rules (what should be your objective function that you want maximize or minimize) that are needed to perform these tasks. One additional thing to consider because you are studying a biological system is to ground the same with constraints from biology of course).

I know that with cochlear implants, that it is meant to simulate a range of tones that can help mimic natural hearing. While this is an effective method of restoring SOME hearing back to someone who does not have the ability to hear, it significantly limits the ability to differentiate from 10,000 frequencies down to about 256. Is there a similar effect that happens with the olfactory sense where it can provide a supplement of detection but does not match the similar ability of the biological sense? What improvements have you made to your original design to help reduce the limitations of your "cyborg sense"?

GreenKrusader

GreenKrusader,

Interesting point-of-view. You are talking more about a prosthetic device for smelling. So far, the problems that we have considered have focused on taking advantage of the sophisticated sensory systems these insects have, and not to augment them in any way. Nevertheless the point you raise in an interesting one.

I am not aware that there is a prosthetic nose. I would expect designing one would be challenging.

First of all, unlike hearing where we know what the hair cells are doing (picking up vibrations in a specific frequency range), we don't fully understand what is being detected by the olfactory sensors.

Even if we determine what molecular features are important, we don't have a repertoire of artificial transducers that matches the sensor array in your nose. In humans, there are roughly ~1000 genes that encode for proteins that do create the magic of smell. We express ~300-350 of them and the remaining are pseudogenes (i.e. not being used anymore). What this means is that you have 300-350 different types of transducers or sensors in your nose. On top of that there is redundancy (multiple copies of the same thing). So, we have a problem determining what must be transmitted to the higher centers in the brain.

We have the transducers in olfactory epithelium (at the roof of your nose) and the higher-processing centers at the base of your frontal lobe. When people become anosmic (lose their sense of smell), for example due to head injury, the wires (axons) that connect the transducers in your nose with the brain are severed. They do regenerate after some time. If they don't, the better bet is to transmit information to these higher centers (else the signal won't reach the brain), but access to them would be more difficult.

Even if you do all this, as I mentioned, because the artificial device would lack the sophistication of their biological counterparts, I would still expect them to do a poorer job. Much worse than the cochlear implants you talk about.

Hi

Very interesting research indeed.

What's the future potential applications of cyborg insects besides being being biosensors? Are you considering going beyond the olfactory to the ophthalmic systems, or other senses? Have you consider other types of animals?

Thanks for doing this!

mvea

Thank you,

Our interests in this area are multi-fold. From a basic science point-of-view, we would like to understand how odorants are received and processed when the insects are freely moving and behaving. If we understand enough of the biological solution, the hope would be to replicate the same principles and achieve similar capabilities in an engineered device. There are a number of applications for such a device in medical diagnostics, homeland security, human-computer interfaces, robotics and environmental monitoring.

So far we have focused exclusively on the olfactory sense. Since we still have not understood enough :), we are going for depth rather than breadth. So, at least for the next few years, my lab will continue to focus on this fascinating sensory modality.

I have also worked with moths (Maduca sexta) in the past. We have recently begun using fruit flies (Drosophila melanogaster) as a model system. The amazing genetic tool kit available in this model system will help us explore potential causal links between neural computations and behavioral outcomes.

Do you ever have a moment of pause, and think, "maybe this is cruel to the insect?"

I'm not saying it is, I just know this would cross my mind.

Gyrod

Thank you for this question. This is a very important one as well.

Just to let you know, I have been a vegetarian all life long, and try not to harm any other beings including the insects! So, it took a lot of thinking at my end to even get into animal-based research.

My lab, and so does everyone doing animal research, follow strict moral and ethical codes with regard what experiments are being done on them, and how humanely they are handled before, during and after the experiments. We make sure that every insect used for experiments does contribute something to the advancement of science.

Turning insects into high-flying bio robotic sensing systems seems like a very cool idea!

Do you think understanding the olfactory system of insects can have any life-changing outcomes for humans? .... i.e. Sensing danger, detecting harsh chemicals/ carbon monoxide.

molothoff-cocktail

Thank you! I certainly hope so.

As I mentioned in another response, if we understand enough of the biological solution, the hope would be to replicate the same principles and achieve similar capabilities in an engineered device.

There are other underappreciated applications of olfaction as well. For example, researchers have shown that patients suffering from certain illness have exhaled breath with altered composition (example correlation between acetone concentration in breath and blood sugar levels). There have been reports of dogs being able to sniff out these differences. How controlled these experiments were and whether are not it is repeat of 'Hans the counting horse' but with dogs, I am not sure. But medical diagnostics would definitely be an area where an electronic nose will be quite handy.

Also, some of the ideas you mention have in fact been explored before as well. For example, coal miners sometime back, used to take a small bird (a canary) with them when they enter mines. The idea is exactly what you mention. If there are toxic gases, it would affect the smaller organism first. All we are trying to do is to extend this concept and make it more sophisticated.

Can you talk a bit about potential applications for an electronic nose? Would such a "nose" be more efficient at detecting harmful gases, molds, etc.? Would it have forensic investigation applications?

firedrops

There are a number of examples. I will cover some atypical ones, since you covered some standard ones.

Food industry: You can potentially use an electronic nose to know when to stop roasting a food object (say your donuts or fries) to standardize the cooking approach. Or know when to throw away something because it is rotten (we do it all the time with milk in our fridge).

Health industry: Imagine you are running on a treadmill for weight loss. Wouldn't it be nice to know when you start burning more fat? As your body starts burning fat, the breath acetone levels increases (ketosis). A breathalyzer in your treadmill to inform you when you are done with your warm up and are in a fat burning mode would be handy, don't you think?

Medical diagnosis: To recognize an infection or onset of disease early. And to stop medication at appropriate time point so there is no over-medication (may be important for preventing creation of drug resistant microbes).

Forensic - if you have seen/heard a dog being used because it has superior sense of smell, then you can potential use an electronic nose to the same.

Thanks for coming by! Can you please tell us a bit about potential future applications of e-noses? Could they perform some of the functions we currently use working dogs for?

asbruckman

It has been a pleasure Prof. Asbruckman!

I have covered a number of applications in some of previous answers. So will keep that brief: homeland security (detecting explosives, land mines and such), medical diagnostics (breathalyzer), presence of toxic chemicals (canary-in-the coal mine approach), environmental monitoring, food industry, perfume industry, detecting gas leaks and such.

That would be the hope. We will have a electornic nose capable of achieving the capabilities that a canine olfactory system possess. But, I will tell you that will be one hell of a gold standard to beat. I will be happy if we can do as well as these locusts and fruit flies :)

Will the cyborgs be autonomous? Wired to a processor or wireless? I'm just thinks no about data transmission etc.

Rhymnoceros

The way we are envisioning, it will at least be semi-automated. This is mainly because we would like these cyborg insects to spend a lot of time collecting signals and samples from a region of interest.

Both data logging, on-line processing and wireless transmission are being explored.

Thanks for doing an AMA!

You mentioned above that your lab has made interesting discoveries on how locusts smell and I understand that the "cyborg insects" you're developing use locusts as well. I was wondering what made you decide to study the locust's olfactory system and its potential as cyborgs instead of a different insect species, such as cockroaches or fruit flies.

As an aside, the e-noses kind of remind of Google's April 1st prank from a few years back, the "Google Nose".

elegant_madness1

Yes, I have done most of my studies with locusts. They are a terrific model organism. They are quite sturdy and can quickly recover from invasive surgical procedures. I think cockroaches might also be capable but not fruit flies. We have done a lot of electrophysiological characterization of different neural circuits in their olfactory pathway. So, we wanted to take advantage of our prior expertise. In addition, locusts do have a rich repertoire of odor-evoked behavior.

If I said I have an electronic nose that does what the locusts can do, then I am definitely pranking you as well :).

Thank you for tackling this very difficult project of classifying the olfactory sense into computable quanta and qualia.

chamaelleon

Thanks for your comments. It is not just me. I have a terrific team of young and aspiring researchers working with me on this work as well. They all deserve the credit for the same.

In addition to us, there are other groups studying invertebrate and vertebrate olfaction as well. It is one of the trendy sensory systems these days.

I read somewhere, though I forget where, that oralfactory systems are basically quantum chemistry black magic. How true is this?

Cronanius

I think I know what you are talking about. I think you are referring to Luca Turin's theory of how the olfactory receptors in your nose are sensing molecular vibrations. The black magic part might be the 'inelastic electron tunneling' part of how this could be achieved. The predictions from this theory were tested by Leslie Voshall and her group at Rockefeller U. and shown to be inconsistent in human psychophysical studies. Luca and his team are yet to show empirical results to counter this and prove their hypothesis.