2. The paper we’re going to discuss in this presentation comes out of an approach to cognitive science called minimal cognition. Essentially, psychologist typically start at a high level—the human brain—and try to figure out the less complex processes. Minimal cognition goes the other way: figure out the minimal biological system to which the notion of cognition applied and work our way up from there.

3. Here is a schematic of the different levels of learning. This isn’t meant to draw hard lines on different categories, but rather to show the general growing complexity of different behaviors. Now, according to the minimal cognition, we should start at the bottom, at the most simple forms of learning. And we should look for minimal cognition in the minimal biological system. And we’re going to do this with single cells. One single-celled organism that’s drawn a lot of attention in recent years is the slime mold

4. So you may be asking yourself what exactly a slime mold is. Well…

5. This is one, which kindly posed with me in Germany this summer.

6. This might give you a better view. You can see the main portion of the slime mold, which is on top of a food source. Further up are pseudopods it has sent out to explore the environment. On the right is extracellular slime it has left behind.

7. So slime molds are one cell, although that cell can grow very large and can fuse together at points, and therefore they can have multiple nuclei. Obviously, being a single cell, the slime mold has no brain, and no nervous system. One property that has gotten a lot of attention lately is how the slime mold moves. Essentially, a slime mold contains many oscillators, which are little mechanisms that push back and forth based on some internal frequency. When the oscillators encounter a stimulant, like food, the oscillations increase in frequency, causing the neighbor oscillators to also increase in frequency. This allows the slime mold the move in that direction. They move at about 4 cm an hours.

8. So what can slime mold do? They can actually do quite a lot. There’s been research to show that slime molds can solve mazes, avoid becoming trapped, making irrational decision, and anticipate period events. This is all fascinating research, that we don’t have time to talk about right now. But what’s interesting is that none of these cool behaviors actually requires the slime mold to learn.

9.

10. So back to our learning chart. If we want to show that a single-celled organism can learn, we should probably make the first attempt with the less complex behaviors. And that’s exactly what researchers did: they attempted to show that slime molds can learn through habituation.

11. So, all of you are probably familiar with habituation at least a little. As a review, habituation requires two phases: one where a particular stimulus that once elicited a response, after repeated applications the response declines. Secondly, there also must be a period of spontaneous recovery, meaning that if the stimulus is withheld for a while and then reapplied, the response should come back.

12. So this is the paper we’re going to be looking at: title, authors. The authors must show those two phases: habitaution and spontaneous recovery. They also have to rule out other explanations, like motor or sensory fatigue. We don’t want it to be that the slime molds are just not paying attention in general, we want them to be habituated to a particular stimulus.

13. So here’s the paradigm they used. On one side of an petri dish is deposited a slime mold, on the other side a food source. In the middle is an agar bridge that the slime mold must cross to get to the food. When the bridge is just agar, this is super easy. This is our control condition.

14. There are also two experimental conditions. In these two conditions, a chemical has been laced through the bridge: quinine and caffeine. These are deterrents to the slime mold and they will resist going over the bridge. However, since there is not enough quinine or caffeine to actually hurt the slime mold it is perfectly possible for the slime mold to make it across the bridge to the food. The hypothesis of the study is that the slime molds in the experimental condition should habituate to the chemical on the bridge and, over time, stop reacting adversely to it.

15. So here’s what was actually done. It’s a 9 day experiment. Days 1 through 5 is the habituation phase, meaning that all three groups have to attempt to cross their assigned bridges, whether caffeine, quinine, or plain agar for the control group. They predict a decrease in responsiveness to caffeine and quinine during this time. On day 6 is the first test. Some of the slime molds will be exposed to a different type of bridge. So for example, some of the quinine molds will have to cross a caffeine bridge or vice versa. This is where the experimenters can rule out sensory or motor fatigue; if the molds that have been habituated to quinine, for example, still react negatively to caffeine, they show stimulus specific reactivity. Day 7-8 is the recovery phase, where all molds crossed just plain agar bridges (and so they are not exposed to the stimulus). Day 9 they are tested again to see if they have recovered the negative response to caffeine and quinine. If habituation occurred, the slime molds should respond negatively again after the recovery phase.

16. So now we’ll walk through these two molds’ nine-day journey. On the left is a control mold, and on the right is a quinine mold. The A or Q in the corner indicate what type of bridge they were presented with on that day. There were a few ways the researchers measured how reactive the slime molds were to the stimulus. The one we’re looking at here is how large their pseudopod is. If the slime mold is comfortable crossing the bridge, they will send out a large, spread-out pseudopod, as you can see in the control condition. If the slime mold reacts adversely to the bridge, they will send out a thin, snaking pseudopod, as you can see in the first day in the quinine condition. You can also see that the pseudopod gets larger and larger with each successive day in the quinine condition, indicating that the pseudopod is reacting less and less to the chemical.

17. So on the first test day, in these two slime molds, the control slime mod had to cross an quinine bridge, and you can see it reacts very negatively, since this is its first time being exposed to the quinine bridge. It acts like the right-side mold did on day 1. In the recovery phase both slime mods crossed plain agar, and you can see they did quite well. On day 9 was test 2, where is was seen if they slime molds had recovered their adverse response to the chemical. In the quinine mold, when given quinine again after the recovery phase, it is clear that there is an adverse reaction there. In fact, it looks very similar to the control mold.

18. Here are the results across all the slime molds. So you can see that the size of the pseudopods increases over the habituation phase in the Quinine and Caffeine molds and then drops significantly after the recovery phase. Pseudopod size was also low when the quinine or caffeine slime molds were exposed to the other experimental condition. You can see it here…

19. So, the authors drew the conclusion that habituation did occur in slime molds, and that habituation was stimulus specific, so it wasn’t the case that there was sensory or motor fatigue. Moreover, the decrease in responsiveness followed an inverse power function of the number of repellent presentations, which is very typical of habituation in other organisms, like humans.

25. So, what *can* slime molds do? We already talked about a few things, like solving mazes, avoiding becoming trapped, making irrational decisions, and anticipating periodic events. We can now add habituate to a stimulus and spontaneously recover to the list. This habituation research lead to other studies in that same year that showed that these slime molds can pass on that habituation behavior to other slime molds through fusion, which goes beyond the time that we have but is extremely interesting. So slime molds should more complex behavior than one might expect.

26.

27. And these behaviors can lead us to make some broader conclusions. Some researchers have proposed that non-associative learning processes are present in all eukaryotes, not just all neural organisms. Further, we might conclude that the mechanisms that lead to more complex learning like associative learning or non-elemental discrimination predate the evolution of a nervous system. This suggests that the information processing mechanisms in neural organisms are analogous to non-neural organisms. There are also obviously implications for minimal cognition approaches. Asking what slime molds or other single-celled organisms can do is a very interesting question and it’s obviously led to a lot of fruitful research. However, there is a very obvious follow-up question that, to me at least, might be more interesting. And that is:

28. what *can’t* slime molds do.

29. Well, there’s no clear evidence that slime molds can learn through associative processes, although there has not been much research in this area. And it’s just hard to tell, in general, what *can’t* something do, because negative results aren’t really published. But I think this question, what can’t single-celled organisms do, is one that is really worth pursuing. We’ve spent a lot of time in this class emphasizing the similarities between cognition in humans and other animals at different points on the tree of life, but we are different organisms, with different capabilities and evolutionary timelines. Humans and slime molds, although more similar than one might have predicted, are not the same; we’re not just big slime molds. This means that studying our differences can be just as informative as studying our similarities. So for example, if we know what can’t slime molds do, that may better help us understand…

30. What we gain cognitively, from having many cells and, further,

31. what we gain from having a nervous system. The title of this presentation is ‘no brain, no problem.’ It’s like, who needs brains? Well, we do. I don’t have to cite too much to say that if we don’t have brains we don’t work very well. These systems are very expensive; if we can accomplish so much with just a single cell, why do we have them?

32. So this brings us back to our learning chart. Now we can place some organisms on it, mature humans with the most complex behaviors, ducklings as we saw on Thursday with concept learning, plant can learn through associative learning which I’m sure we will hear about, and finally slime molds with non-associative learning.

33. So I wrap up with this quote by Jonathon Keats, at the Plasmodium Symposium. Quote. We became multicellular because it allowed us to better adapt to our environment, and learning is part of that adaptation. Building cognition up from the bottom allows us to better understands these building blocks that aggregate to form us. Further research with slime molds and other simple organisms may help us understand ourselves better, especially if we better understand the limits of individual cells.