Emergent Sensing Presentation

Fish slide: Good afternoon everyone and welcome to part 2 of room 2's literature review presentations for *Advanced Self-Organizing Social Systems.* My name is Ryan O'Loughlin and I'll be your host. Today we are going to learn about fish. More importantly, we are going to learn about what fish *do.* And more importantly than *that*, we are going to learn about what fish do *together.* And the reason we are doing that, is to investigate the following concept (quoted directly from the paper which will be introduced momentarily).

Quote slide: "Collective intelligence may emerge from interactions between individuals." Please consider this statement carefully and try to keep it in the back of your mind throughout the presentation. You may even want to think of examples where such a property may be observed in humans or other animals, in a related way to how it manifests in the fish of this paper. Time permitting, we can discuss your ideas at the end of the presentation.

Title Slide: The paper at hand goes by the title *Emergent Sensing of Complex Environments by Mobile Animal Groups*, and it is another study done by *Couzin* and friends, whom we have encountered in our lectures on predation. And in fact, we have encountered quite a bit of relevant state-or-the-art in our course so far, with papers like *The simulation of the movement of fish schools* by Huth and Wissel, where the collective motion of fish was modeled on the basis of a few simple rules and as well from Professor Hemelrijk's paper *Self-organized shape and frontal density of fish schools.* So luckily, we have plenty of context for the content presented here. Your presenter is of course me, Ryan O'Loughlin.

Fish Intro Slide: Our fish of interest is the Notemigonus Crysoleucas, but it's friends call it the *Golden Shiner* and it is a small fish—only about 5 cm in length and it prefers *shaded waters.* This fish does *not* like the light. It will avoid regions of high luminosity whenever possible in favor of a darker environment.

Hello Darkness My *Old* Friend

Light Slide: Because the golden shiner can reliably be expected to prefer well-lit areas, we can treat light here as an *environmental cue*, which is an external property that will influence the behaviour of an agent. Light is a particularly convenient environmental cue because it can easily be controlled and manipulated from above—moving light patches around and switch them on and off. And the authors carefully note, that here light can stand in for *any* environmental cue "such as temperature or salinity," and we should expect to find similar results as are presented in what follows. One small critique here would be that light does not necessarily well represent non-continuous environmental cues.

Setup Slide: Here we have some diagrams pulled directly from the methods sections of the paper, wherein we can see a simple example of the "data projector," which projects light from above onto the fish tank in various changing patterns, which can be seen here in the visual spectrum. Notice the Golden Shiners moving into the darkness, but because they are not so easy to see in the visual spectrum, infrared lamps light up the tank from below, unbeknownst to our light-hating fish friends—if only they knew! Cameras record for both these light spectra throughout the experiments. While this setup is a quite clean data-collection mechanism, it may be critiqued for unnaturally reducing fish behaviour to 2-dimensions. It could be that schooling behaviour would change with a third degree of freedom.

Superposition Slide: And here is a quick example of the sort of behaviour we expect to see from the Shiners, superimposed here in green. In the leftmost frame, they are unhappily situated in a light region, and they thus spend the subsequent frames moving toward the darkness as a group. How are they doing this exactly and why do they move in a group?

Gradient Info: The answer to this question is the crux of the experiment. We would like to observe the degree to which a collection of golden shiners can be sensitive to the changing light-gradients in their environment beyond their own individual ability. And furthermore understand the role of social influence on this dynamic.

Experimental Features: We therefore have a number of informative measurements that will aid our understanding of these questions. Our *performance metric Psi* is defined by the level of darkness (1 – Luminosity) averaged across both fish position and time. This will basically describe how well the group has done with accomplishing its collective preference of being in shaded waters for a given trial.

The social vector S sub i is defined by the direction of *conspecifics* for a given fish's location. The word conspecifics simply refers to the influence on an animal agent by adjacent agents of the same species. A simple way to think about this is if all the fish around an agent are moving in one direction, there will be a large social vector for that fish pointing in that direction, which may or may not influence that fish's own behaviour. If there is no particular group direction (or if there are no other fish around), there will not be a strong social vector in any direction. Another critique might be inserted here concerning conspecific range, which the authors have set arbitrarily to seven body-lengths, and claim the range is arbitrary with respect to the result. However, we have seen differently in various models of this course—that range of influence or vision may significantly impact school and flocking behaviour.

The environmental vector G sub i is defined by the direction of steepest ascent toward darkness, with the magnitude of the vector corresponding to the steepness of decrease in luminosity. Be aware this is defined for each individual agent, who only perceives their *local* gradient, which is to say it is defined only for the darkest direction *from that point in space* and not necessarily toward the darkest place in the tank globally. Before moving on, let's get a better intuition about gradient.

Gradient Slide: Please note, this plot is *not a result from the paper.* In fact, any of my fellow machine learners will surely recognize this slide as an archetypical visualization for gradient descent. We can use it here to imagine the behaviour of a *solitary* fish over time. Realize that in our case, the z axis might correspond to luminosity and the x-y axes to positions in the tank as seen from a bird's-eye-view. Imagining the dark blue regions to be the lowest light levels, and the red regions to be the highest (although you could just as easily imagine the opposite) we can see how from any given position, the gradient vector can change based on the *steepest direction toward darkness.* If a fish were to be influenced solely by the gradient vector of its position, we can see how it might follow a path similar to this one. Realize that the gradient vectors themselves would also express magnitude. Also consider, in terms of the x-y coordinates this is not necessarily the quickest path toward the darkest region, but it is the only one a fish could find on its own from that starting location, because it *cannot sense the global-gradient, only the local gradient of its location.*

Vector Field Slide: Again, we here have an abstract example of gradient that is not a result from the presented paper. We would simply like to better visualize the effect conspecifics might have on fish behaviour. Now our gradient vectors are projected onto the 2-D x-y plane, but you could just as well imagine them on the 3-D gradient above. We as well might imagine a perfect grid of fish in the tank, each with their own their own gradient vectors (the colors have changed, but that is not relevant here). Notice, that all the fish together are in a sense able to represent the global gradient with their combined local gradients. However, the fish are not a hive mind so they do not all have access to this information, but what they do have access to is *conspecifics.* This is to say they are aware of the motion of the fish around them, who are themselves responding to their local gradients. If every fish weights a certain portion of their own motion not only with the influence of their local gradient, but also with the input of fish movement around them (defined by their social vector), they are thus responding indirectly to a larger sampling of the gradient than they could on their own. Remember the social vector is defined by a summation of the difference of a given fish's position with the position of the fish around it in a given range, over the magnitude of that difference. It therefore points in the direction that would best align it with the movement of its neighbours and because these neighbours may be incorporating their own local gradient information into their movement, any single fish now has more information about their environment through conspecifics. Let's now see if this theory "holds water" experimentally.

Group Performance: As it turns out, fish are on average better able to accomplish their goal of being in darker waters *when in a larger group*. This result is somewhat confounding, because due to repulsion there is actually less "dark-real estate" available for any given fish to spend time in ~~*and* they are partially ignoring light-gradient information and instead allowing some portion of their movement to be determined by their neighbour~~. Yet, in the end, this results in more time spent in the dark! Note the red line corresponds to a simulation the same research group carried out in a related paper, which achieved similar results. The black points are average performances for given group sizes with double standard error for error bars and the shaded blue region is the 95% confidence interval.

Speed and Light: It is also found that fish swim more slowly in the dark than they do in the light. This makes sense because, when in the dark, they are already where they want to be (why swim away?) and when they are in the light, they would prefer to not be there, so of course they are in a hurry to be somewhere else. This behavioural finding comes with some interesting emergent consequences. Due to conspecifics, the social attraction of fish-in-the-light to fish-in-the-dark will manifest more quickly than visa-versa, creating a *turning* motion of the group toward the fish in the darker regions, conveniently resulting in the desired outcome of more fish being in the dark. The question then becomes, how strong is the influence of conspecifics?

Social Vector Results: As it turns out, the greater the magnitude of the social vector, the higher the correlation found between acceleration and social vector direction. This result is embodied by the blue line. Note the magnitude of the social vector does not influence the degree to which fish respond to their local gradient, which is the red line.

Gradient Vector Results: The correlation of acceleration with vector direction is as well positively influenced by a growing environmental vector magnitude *up to a certain point.* The reason this relationship is not monotonic, according to the authors, is that after a certain magnitude, the difference in luminosity is most likely due to noise and is difficult to perceive continuously. The gray dots here are results for solitary fish, which perform similarly with respect to the environmental vector. Therefore, this relationship is independent of conspecifics.

Concluding Remarks: This now brings us to some concluding remarks. In terms of accomplishing their goals of being in darker waters, Golden Shiners perform better in a group (and the larger the group, the better). This is because, as a group, *a sense for the global gradient emerges through conspecifics.* This sense is does not exist in individual fish, but only within the interactions between many individual fish together. We therefore observe that a group of Golden Shiners is *more than the sum of its parts.* How cool is that.

Thank you for your time and attention!

Questions: If there are any questions directly related to the paper, now is the time to ask them. Otherwise, we may take a moment to discuss this property of emergent intelligence in general. Can you think of any examples of emergent sensing in humans? What do you feel influences you more personally, environmental or social cues? In what ways might humans deliberately cultivate emergent intelligence in the future?

- Political sentiment? Policy versus social pressure?
- Are we more likely to participate in a seemingly dangerous activity like skydiving or drugs if we know many others are doing it? Conspecifics versus environment.

Okay thanks again and have a great day everyone! Good luck with your presentations!