Current state of research - approx. 5 relevant publication. one page max

Description of questions - originality and significance to the field (approx. 2 pages)

Methods (clearly described) - two pages

Not required:

comprehensive bibliography

time plan

Research outline (five pages max)

* **The current state of research** should first be briefly described and underpinned by approximately five relevant publications from the research area. (one page max)
* The outline should focus on a clear **description of the questions** you intend to address in your research, their **originality and significance** for the advancement of the research field. (approx. two pages)
* Furthermore, the academic **methods** to be used to achieve these goals should be clearly described. (approx. two pages)
* A comprehensive bibliography and a detailed time plan are not required.
* The research outline should comprise approximately five pages in total. Should you significantly exceed this length, you may be asked to cut it down to approximately five pages.
* For the purposes of evaluation it must be clearly demonstrated that you yourself have drawn up the main contents independently and agreed them beforehand with your host. Any contents contributed by the host institute must be attributed accordingly.

From Christopher Harris’ blog:

Overall, fish and mammals have similar brain topologies. The fish forebrain pushes forward during development rather than wrapping itself around the lower brain regions as it does in mammals ('eversion' rather than 'evagination'). The fish pallium is nevertheless homologous to the mammalian cortex, with distinct sensory and motor regions, although in fish a disproportionate amount of visual processing takes place in the tectum, a homologue of the mammalian superior colliculus ([Salas et al., 2003](http://www.ncbi.nlm.nih.gov/pubmed/12937346)). Likewise, the subpallium of fish corresponds to the mammalian basal nuclei, including the striatum, the key recipient of dopaminergic reward in the mammalian brain. So far so good; most forebrain structures involved in reward processing appear to be conserved among vertebrates, and cognitive abilities previously thought of as exclusive to 'higher' animals (i.e. birds and mammals) are now being studied also in fish ([Salas et al., 2003](http://www.ncbi.nlm.nih.gov/pubmed/12937346)).

However, the fish dopamine supply is all over the place, quite literally. Dopamine neurons are found throughout the zebrafish brain, *except for* the midbrain, where almost all mammalian dopamine neurons are located. A few dopaminergic clusters in the hypothalamic region project to the subpallium/striatum and were previously thought to be homologous to the mammalian mesolimbic dopamine system, but more recent research has debunked this view ([Schweitzer et al., 2011](http://www.ncbi.nlm.nih.gov/pubmed/21567980); [Tay et al., 2011](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3105308/)). There simply is no mesencephalic dopamine system in the zebrafish brain. Nevertheless, fish *are* capable of both classical and operant reward conditionning ([Valente et al., 2011](http://rubenportugues.net/valente_et_al.pdf)), including dopamine-dependent place preference, and even intracranial self-stimulation ([Boyd & Gardner, 1962](http://www.ncbi.nlm.nih.gov/pubmed/13872148)), so what gives?

As far as I can tell, dopaminergic reward mechanisms remain remarkably poorly understood in the zebrafish, despite intense research in recent years on the neurobiology and genetics of this model system. Most of the dopamine in the zebrafish subpallium/striatum appears to originate in local dopaminergic projections from neurons whose cell bodies are distributed throughout the subpallium/striatum ([Tay et al., 2011](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3105308/)). These neurons look like plausible mediators of reward, but their input, physiology and function remains unknown(!). The function of the ascending dopaminergic fibres that project to the subpallium/striatum is also not known. Moreover, pretectal dopamine neurons arborize extensively in the tectum, suggesting a possible role in visually guided reward-seeking behaviour, such as hunting.   
  
Plenty of reward-related research to be done in other words, but what do we make of this? [Hills (2006)](http://csjarchive.cogsci.rpi.edu/2006v30/1/s15516709HCOG0000_50/s15516709HCOG0000_50.pdf) argues that the evolution from anamniotes (fish and amphibians) to amniotes (reptiles, birds and mammals) involved a number of changes regarding dopamine and reward-processing, including: 

* The number of cortical imputs to the striatum increased significantly
* The number of dopaminergic inputs to the striatum increased significantly
* The synaptic machinery that allows dopamine to modulate cortical input to the striatum expanded to include DARPP-32
* The dopaminergic signal transitioned from representing the presence of food to representing the expectation of reward more generally

As a consequence of these changes, Hills argues, amniotes were able to apply the neural mechanisms of foraging (e.g. 'area-restricted search', the ancestral function of dopamine, present even in worms and mollusks ([Barron et al., 2010](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2967375/))) to search for *any* kind of information or goal, whether internal or external to the brain; a profoundly powerful adaptation. In addition to the four changes suggested by Hills I would add: 

* Dopaminergic cell clusters became centralized in the midbrain

This centralization, together with some specific adaptations, such as gap junctions connecting dopaminergic axons, allowed amniote brains to generate a single, scalar reward signal that adjusts dopamine concentrations homogenously throughout the forebrain.   
  
I think what I need to ask now is: how does the more ancient dopamine reward system of fish actually work; what forms of reward-processing is it capable of; and does its distributed anatomy offer any advantages to the animal or to attempts to understand the neural basis of reward-based cognition?

projects:

mimic presence of predators with optogenetic activation of ORNs

induced learning with closed-loop optogenetic activation of dopaminergic pathways

* first find dopaminergic reward neurons
* silence to find what is actually rewarding about collective behaviour
* activate to create fictive learning regimes

group-level decision making with modified VCRDM

* Goal 1: to demonstrate emergent intelligence of large animal groups by group-size dependent improvement in a challenging discrimination task.
  + Schadlen’s group uses the coherence of visual stimuli to precisely vary the difficulty of decisions, in order to observe the integration of conflicting information in neural networks in a drift-diffusion model.
  + We hypothesize that groups of schooling fish integrate conflicting information in an analogous process to neural integrators
  + Many fish species exhibit strong negative phototaxis, as demonstrated in Berdahl et al 2013
  + give a rotating stimulus, fish will follow
  + give conflicting ones, group should distinguish majority direction
    - first establish that groups perform more accurately than alone
    - with high res tracking, observe the formation of emergent decisions
* Goal 2: to use schooling fish as a model of complex information integration and observe the resolution of complex conflicts.
  + In goal 1, we will demonstrate the ability of this system to integrate complex information and establish a method for guiding fish behaviour
  + Using moving light patterns, steer fish schools into configurations that will cause conflicts.
  + The system should operate with dual-phase evolution. By steering fish with projections, we should be able to induce fragmented and connected states and observe the transitions between them.
  + Dual-phase evolution vs Self-organized criticality
* Goal 3: System memory (hysteresis)

1. Demonstrate that large groups can interpret global trends from locally-noisy stimuli through VCRDM
   * Establish the method of using visual stimuli to drive behaviour of schooling fist (cite Berdahl and pilot experiments).
   * Explore the relationship between group size and stimulus coherence to identify the efficacy of collective decision making.
   * Compare the relationship from (2) across species to demonstrate the importance of the “biological filter”. The parameters that vary between species will give some indication of the function of the filter.
   * Hysteresis
2. Characterize individual responses to stimuli to interpret “filter” functions of fish.
   * What specific sensory inputs lead to distinct and/or stereotyped behavioural responses in individuals and groups?
   * Explore the function of the network from one level up, interpeting how filtered information is processed.
   * Are there higher-level functions of collectives that are due to the processing of filtered information? In other words, what phenomena of collectives cannot be explained by purely physical interactions?
3. Use visual stimuli to create critical network environments.
   * Using knowledge of behavioural responses to visual stimuli, first establish configurations with high conflict, then observe the resolution back to low-conflict states.

Emergence:

Through mechanistic understanding of binary decision making by various collective systems, we will learn complementary concepts about emergent intelligence. Each system can provide a structured view of the solution, although some aspects of the solution are obscured due to experimental limitations.

Whether in swarms of animals, networks of neurons, or colliding molecules, emergent properties of “repeated systems” share commonalities across scales. Concepts of emergence, no matter from whence they are derived, are relevant to other collective systems.

Emergent properties can inform about the inherent properties of agents that are not easily observed or recognized at the individual level.

There are advantages to using biological systems over computer generated models.

Scaled examples of analogous phenomena:

* Water molecules flowing into a drain. Brownian motion, latent flow, and weak centripetal forces act on still water. Rotational flow emerges as the only non-random force (earth’s rotation) from the weakest forces applied billions of times. (Shapiro, A.H (1962). “Bath-tub Vortex”. Nature, 196(4859):1080-1081.)
* Neural processing of noisy signals (ex VCRDM). Local estimates are summed and integrated, and majority emerges.
* Milling fish.
* SEED-SCALE

Top-down feedback in emergent systems

can lead to scale-dependent properties (See, e.g., [*Korotayev, A.*](https://en.wikipedia.org/wiki/Andrey_Korotayev); Malkov, A.; Khaltourina, D. (2006),[*Introduction to Social Macrodynamics: Compact Macromodels of the World System Growth*](http://cliodynamics.ru/index.php?option=com_content&task=view&id=124&Itemid=70), Moscow: URSS,[*ISBN*](https://en.wikipedia.org/wiki/International_Standard_Book_Number) [*5-484-00414-4*](https://en.wikipedia.org/wiki/Special:BookSources/5-484-00414-4)

)

Current state of Research:

Five publications:

1. Something from Schadlen
2. Berdahl
3. Ioannou 2016

**Emergent information processing**

Throughout the natural world, we observe phenomena that result from the collection of many small entities to a larger, emergent entity. For example, the structural properties of water prescribe molecular interactions that ultimately give rise to the characteristic shape of snow flakes. In this case, the supervening properties of snowflakes emerge from the local interactions of water molecules on a micro scale, without information or supervision on a macro scale. These emergent properties are novel, and not observed in the water molecules themselves. Thus, decentralized processes that assemble entities into supervening entities form the basis of emergence.

Emergence is pervasive in living systems. Many animal species engage in sophisticated collective behaviours, such as swarms, flocks, or colonies, from which new functions emerge.

Intelligence:

Slime moulds solve mazes (Reid and Beekman 2013).

Animal groups engage in collective behaviours that often exhibit emergent properties. Although the motivation toward collective behaviour varies from one species to another, that supervene the capabilities of the individual animals themselves.

**Collective Intelligence in Fish Models**

The field of collective intelligence has been studied for over a century (REF Galton 1907 (foundin in Ionnou 2016)). Despite its longevity, a fundamental component of collective intelligence, the mechanism of improved cognitive performance, remains difficult to discern. Ioannou (2016) summarized this fault, and divided the mechanisms into four broad categories: individual-level, centralization, leadership, and swarm intelligence. Individual-level cognitive abilities derive from individuals' re-allocating cognitive processes in response to group size. Centralization and leadership both involve groups selectively processing or distributing information from selected individuals. Swarm intelligence, on the other hand, occurs when information flows throughout the group and no individuals are particularly influential. Ioannou argues that only swarm intelligence is a truly emergent property (\*\*\*DOUBLE CHECK THIS). Examples of swarm intelligence are prominent in some species, mostly social insects, but the existence of swarm intelligence remains a topic of debate for others, particularly schools of fish.

Studies of fish schooling have mainly focused on performance of a few ecologically relevant tasks, such as predation response or foraging. In these tasks, some animals receive strong cues, and others receive little to no information. This unequal distribution of information results in obligatory leader-follower relationships. It is therefore impossible to distinguish between models of centralization/leadership or distributed (aka “swarm”) intelligence. As a notable exception, Berdahl *et al* (201X, REF) demonstrated collective perception in fish schools by exposing the group to patterned light/shade gradients. In this study, the collective responses to local light intensity affected an emergent optimization response. Importantly, the information was distributed across the entire group; decentralized information was processed in a decentralized way to produce a meaningful response. Therefore, with the appropriate experimental design, the collective behaviour of fish can serve as a model of swarm intelligence.

QUESTIONS

Can

SINGLE PAGE VERSION:

Throughout the natural world, we observe emergent phenomena that derive from the collective activity of smaller entities. For example, snowflakes take their characteristic geometry due to the millions of molecular interactions of water molecules. Emergence is a powerful process that is prominent in both physical and biological processes. Animal groups

result from the collection of many small entities to a larger, emergent entity. Emergence is a powerful process,

collective behaviour and collective intelligence

fish as a model system

analogy to neural processing

collective problem solving and/or processing

cyclones/vortices

slime moulds

“link individual interaction mechanisms to emergent collective patterns. “ (Reid and Latty, 2016)

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Research questions:

Previous studies of collective intelligence have focused on ecologically important areas, including perception, problem solving, and decision-making. Most of these studies involve tasks that rely on the transfer of information within a group to generate a collective response. Still others have focused on the relationship between group sizes and the speed and accuracy of collective decisions.

However, the true essence and power of collective intelligence have not yet been demonstrated in biological systems. Here, I propose a novel method to study collective decision-making and conflict resolution.

Perhaps the most impressive example of emergence comes from meteorology. The Coriolis effects, prevailing rotational direction of hurricanes and cyclones, are caused by the rotation of the Earth. Despite local turbulence around the globe, the rotation of the Earth places small yet unequal forces on the atmosphere. These ubiquitous, directed forces emerge from the noisy air currents to produce weather patterns that affect the entire globe. In broad terms, this example demonstrates how emergence can be used to detect low amplitude signals in noisy systems. Indeed, an inter-galactic hitchhiker could determine whether it has landed in the Northern or Southern hemisphere simply by pulling the plug in the bathtub (Shapiro, 1962).

Emergence is an extremely powerful mechanism for extracting weak signals from noisy systems. For example, cyclonic weather systems rotate in directions defined by the Coriolis effect, or the force of the Earth's rotation. The Coriolis effect is extremely weak relative to other air currents, but it is slightly imbalanced relative to other forces. Despite the turbulent atmosphere, rotating cyclones robustly report the rotation of the Earth through emergence.

Emergence is an extremely powerful mechanism for extracting weak signals from noisy systems. For example, despite turbulent air currents, rotating cyclones robustly report the direction of rotation of the Earth due to the Coriolis effect on the atmosphere.