

Empirical Modelling for understanding cell receptive fields in the visual cortex

Abstract

This project involved “translating” Nicholas V Swindale’s 1996 paper “Visual cortex: Looking into a Klein bottle”[4] into an interactive format influenced by Empirical Modelling. The paper is a brief description of the arrangement of some sight-receptive neurons in “cell receptive fields” in the visual cortex of primates. It describes some relatively simple biology and mathematics, and exposes a mapping between connections in primate brains and an interesting shape called a “Klein bottle”. As will be described, the translation was successful and not “lossy”, and the information being in this format is a huge improvement.

Goal

With the large and increasing complexity of modern scientific discourse, it is vital that we make communication about sophisticated systems more efficient. This in mind, there were two central goals to this project: firstly to try out ideas for a new format for discourse, and secondly to teach people something interesting about brains and mathematics, as a “proof of concept” for the new format.

The innovative format consists of a series of closely linked construals, together with a conventional “narration”. The agent is expected to come to make sense of the construals in the normal Empirical Modelling way, but with some extra “scaffolding”. Aside from Empirical Modelling, the inspirations for this format came from three places:

- Bret Victor’s “translation”[6] of a famous paper on network theory into “[sequential art](#)” - a combination of text, pictures, and very small (less than 90x130 pixel) interactive demos.
- The standard “textbook” style of presentation whereby one is alternately told things about a system and is then asked questions about what has been read, with the intention that they do work with pen and paper. There is a ‘playful’ example of this in Douglas Hofstadter’s *Godel Escher Bach*.
- Computer games like *Miegakure* (a game about movement in four spatial dimensions) and *Portal* (which is about creating wormholes in 3D space in order to solve puzzles).

Every individual element of this new format can be found in one of the above, but to my knowledge the combination is novel. Victor’s translation (as well as his paper “Up and down the ladder of abstraction”[7]) is closest to my creation, but unlike mine, his construals do not reward experimentation, and he gives no invitation to discover more from them than the basic necessary elements.

The puzzles games I mentioned, in a strong sense, “communicate” more. They also have the principle that “silence is golden”[3] - the player should be surprised by every new rule and phenomena, and should not have those discoveries “spoiled” by being told about them in words beforehand. At the same time, these games will have structures in place to ensure that the player will not become frustrated by getting stuck on a puzzle: there are “difficulty ramps” in place that will allow understanding to be built up in the most clear and concise manner possible. Partly inspired by this, I decided to use many construals rather than one.

Topology and the brain

“Visual Cortex: Looking into the Klein Bottle” is a straightforward paper by the standards of academic neuroscience - but would still be very confusing for neuroscientists with no understanding of topology, and would be impenetrable for a layperson. But it doesn’t need to be this way: by making use of empirical modelling techniques focussing on dependency, the paper can be translated into a form that can potentially be understood, or at least appreciated, by anyone.

Topology is well-suited to treatment by empirical modelling. It is all about “mapping”, a concept clearly related to dependency, and the objects it considers can be given visual representations that are quite fun to look at. To give a concrete example, something that appears in both Swindale’s paper and the paper by Shigeru Tanaka[5] that it is based on is a depiction of how the Klein bottle can be yielded from the numbers being considered feature. It was worthwhile them doing this, but the effect is much better in my rendition, because the agent can get a much more direct sense of the dependency that the number and shapes have with each other (they also get to see an animation of the Klein bottle, lessening the work that is required for “sense making”). Topology is a profound and often amusing area of mathematics, but it is low on direct practical applications - this application is an exception, and it ought to be capitalized on.

Swindale’s paper, we might say, is about using one dependency to examine another dependency. In the real world, there is a dependency between what neurons in our brains are flashing, and what we are looking at. Tanaka introduced another dependency between what we are looking at and a point on the surface of a Klein bottle. There’s then a dependency between the bottle and the neurons that allows us to study “singularity location”, which is important for neural development.

Translation using EM

The presentation I’ve produced is a series of construals and short remarks, with the core dependencies taking center stage as advised in [Beynon, 2007]. A given construal is made of at least two windows with full dependency; no two construals are completely the same, but contents of a window are often sustained, as are the two most important and prominent observables, orientation (θ in $[0,180]$) and direction (φ in $[0,360]$).

Agency also changes across the presentation, for example: in slide 7 the agent chooses a point on the Klein Bottle and in another window there is a lighting-up of all the neurons that are linked to the chosen co-ordinates. In slide 10 this is reversed: the agent chooses a neuron and sees the point on the Klein bottle that it corresponds to. (The possibility of being able to choose both of these on the same page was considered, but raised awkward questions because of the difference between interacting with one neuron and a plurality of neurons).

This all leads to a Faraday-like experiential intuition building process for the agent, made easier by the scaffolding of the narration and early examples - I believe that without the scaffolding, many would find the content inaccessible. It may be argued that having all the construals on separate pages may lead to the agent perceiving them as not being as closely linked as they are. But I would draw attention to the fact that the agent is able and encouraged to go back-and-forth between the pages. The construals could also be connected better if scrolling, rather than “page turning”, could be the method of progress.

Swindale’s paper contains 2,600 words; my version has about 1500, and in addition provides an introduction to neurons. Much of the information in the paper is now “implicit” in the construals. An agent who would be interested in the construals would inevitably discover the content in them. An example would be on page 7: many agents (including one of the people who tested it) would likely be interested in what happens if yellow and white lines overlap, i.e. certain neurons would be firing twice as much as usual. They will find that this setup would be linked to the sight of the albatross flying in a direction that is orthogonal to its orientation, a fact which is mentioned in the paper. The narration contains “nudges” towards discoveries like this.

One aspect of the translation was making it less “abstract”: the paper only talks about straight lines and their orientation and direction. After some consideration and work, an image of an albatross in flight was imported, giving agents a clear, recognizable referent that was also visually appealing and easy to animate.

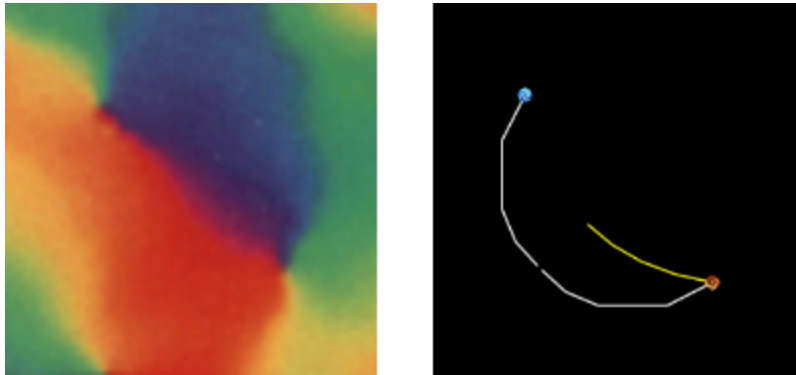


Figure 1: Two renditions of a pair of singularities in a field of neurons. Left: depicted by Gary G Blasdel[2], we are required to interpret areas colored red as “neurons receptive to 100 degree orientation”, orange as “receptive to 110 orientation”, yellow as 120 orientation, etc. Right: my more intuitive rendition, where there is a clear dependency between an agent-chosen orientation, and positions of the lines (“lit up neurons”)

Work with EM tools and possible improvements

Being able to set up and change dependencies quickly made “mapping” as easy as it possibly could be. Being 3D, “animation” of the Klein bottle was still complex and involved a lot of confusion, but the problems were eventually solved.

Going from the 2D co-ordinates to the 2D picture of all the neurons that are lighting up on the receptive field was also complex and slow, but the efficient dependency was again very helpful. Having said that, some of the dependencies do use to a stepwise “update” function. The receptive field transformation done in the program can only be at best an approximation; to get an accurate picture one would need an almost comprehensive understanding of the human brain. There are some improvements I could have made though: the response could be made faster, it could incorporate more singularities, take more samples, have better “singularity-angling”, and be altered visually to be more representative.

One original idea was that the whole presentation would be an insight into the brain of a particular monkey, which would be seen on screen. I lost sight of this idea, instead focussing on the elegance of the four-section screen division. It would be a good idea to have the monkey in it though, mostly to maintain clarity about what the agent is looking at, and partly to give the presentation some character.

Other visual improvements would have required 3D capabilities. Ideally the Klein Bottle depicted in the program would rotate so that the agent could get a better idea of its esoteric shape, and ideally you’d be able to do the same thing to a mobius strip and a torus, in order to see its relation to the bottle. In addition to making things clearer, this would also make the presentation more fun and responsive.

Aside from minor technical hiccoughs, the biggest drawbacks of JS-EDEN were the fact that mouse information disappears near pictures (which required compromises to be made), and the minimal support for sound. In general there is a lot that could make the presentation more engaging and responsive-feeling (“fun”), including sound and puzzles. But there is already whimsy and much intellectual nourishment in it - after testing it on a few people, I believe the content of the paper was communicated to them, and much better than it would have been had they read the paper. In light of this I call the project a success.

References:

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