Evolutionary neuroscientists suggest that the brain only developed after animals developed a taste for eating animals. Pity the species of the planet Vegetaria.

This is the third of a series of posts about the evolution of consciousness. In the first post, I laid out a basic theory that goes something like this: consciousness began to evolve about 350 million years ago, when we emerged from the water on to land. Why? By enabling vision to work over distances many times greater than in water, this move gave us the ability to perceive multiple futures. As a result, the ability to consciously plan ahead became important. In my last post, I detailed why long distance vision reigns supreme when it comes to planning (as opposed to other long distance senses such as hearing or sense of smell).

In this post, I want to make the argument more comprehensive. The crucial environmental condition for evolving neural structures to support planning is that there is an interlude—space to breathe—between perception and action. Without such a gap, only simple, fast, and direct transformations between sensory input and motor output can keep an organism safe from predators. But the long-range sensing abilities discussed in the last two posts are just one category of possibilities for such a gap to open: there are other fancy brain abilities unrelated to sensing that can also open this gap.

Here, I consider two such capabilities: memory and communication. An animal can plan to do something based on memory (“I remember good breakfast was always in this direction”), communication (“hey buddy, around the corner is a good place for lunch”), and, as discussed already, perception (“I see something tasty looking over there”). Let’s go through planning via memory and communication, and compare these to the perceptual route. Combined, the three different mechanisms are the very grist of the mill of consciousness-as-planning.

Remembrance of possible futures. If you have an accurate mental map of a space containing memorized landmarks, then you can devise multiple plans without sensing and execute them by going from landmark to landmark, where those landmarks are spaced no further apart than your sensing range (which could now be very short, and even work through touch). For example, imagine the landmarks are bushes of berries, and they are spaced apart a distance equal to or less than the range of the sensory system you are using to perceive the bushes. You’ve visited these bushes so often, you’ve memorized each bush’s position with respect to the others. (Such maps exist in all animal brains where they’ve been looked for. Their neural basis is under intensive investigation. Fairly elaborate ones have even been found in honey bees.)

Now, before you make your first move, you devise a plan for harvesting efficiently: 1) You know that you will be out until dusk, and you want to be able to see your home before it gets too dark, so you decide to start with the furthest bush and end with the bush closest to home; 2) You typically remove all the berries from a bush before moving on, so it’s important not to waste time in revisiting bushes you’ve already picked. So you devise a trajectory through the bushes that has no overlaps. Both aspects of this strategy can be provided by remembering a bush’s position. In fact, birds and bees use strategies of harvesting from plants that avoid revisits, and need to use memory for this.

Communication of possible futures. Bees have fantastic navigational systems that let them roam hundreds of meters from their hive to find a food source and describe its location to their nestmates back home. They use their relatively coarse visual system to obtain a local cue (optic flow) that lets them detect how far they’ve gone, and they sense direction using their ability to sense the angle of polarized light. They come back, and then communicate distance and direction to nest mates via their dance language. This means the hive mind has an extended sensory range and can collectively explore multiple places to find food. The same is true for humans, with their symbol systems. We can go over the hill, come back and tell our friends that there’s an ice cream stand beyond where we can see. (Our ability to review this ice cream stand on Yelp, thereby
enabling anyone in the world to find it on Google Maps, increases humanity’s possible futures exponentially to the point of creating a new phenomenon of choice anxiety. But that’s another post entirely…)

Both memory and communication, then, can extend our perceptual capabilities, and thereby give us the room for multiple possible futures. One of the core parts of the idea I’ve been discussing here about how/why consciousness emerged in animals is that the neural basis for planning would have really been pushed once we had long range vision (after we came up on land). Could the ability to plan have come about because of improved memory or communication abilities, rather than long distance sensing? While possible, this seems unlikely. Here’s why.

A problem for both memory-based and communication-based planning is that they depend on the goal being relatively stable in spatial position. For example, you can plan to go hunting in a place where tend to be are lots of antelopes, but to kill a particular antelope, you can’t hunt purely on the basis of memory—unless it happens to be paralyzed or dead, which is generally not the case. Similarly, bees would not do so well to come home to their nest and communicate the position of a source of nectar if that source of nectar happened to be a very strange plant—a plansect, if you will—that had wings and was constantly moving around.

The point is clear: for stationary food sources or goals, both memory and communication work well in support of planning. But for unpredictable food sources, like the very nutrient rich body of another moving animal, memory and communication can get you part of the way (“antelope over the next hill!”) but can’t close the deal. Planning different possible paths to the most nutritious sources of energy requires long-distance perception.

**Perception of possible futures.** I therefore hypothesize that the biggest payoffs to our early land-based ancestors came from advances in long-range perception combined with small buffer of working memory to hold some different possible futures being considered. This combination lets you hunt a moving animal that may be devious and require rapid contemplation of multiple possible approaches to capture.

If this logic is correct, then consciousness may only come about in a world where animals developed a taste for eating other animals. Interestingly, experts in the evolution of the nervous system have suggested that it was only after animals started preying upon one another that diffuse neural nets (similar to those in sponges and jelly fish) condensed into what we now know as the brain over 500 million years ago (e.g., Northcutt and Gans’ “New Head Hypothesis” from the early 1980s). However, by my argument, carnivory alone would not have been sufficient for the birth of full-fledged awareness: you and your prey need to move onto land, where you can see it from a distance and envision several ways of successfully capturing it. Once weighing these various options becomes useful, evolution can work its powerful ways in slowly accreting the necessary neural structures for thinking about these futures.

Image courtesy of GeoKansas.

August 8th, 2011 by Malcolm MacIver in Biology, Mind & Brain, Neuroscience | 10 comments | RSS feed | Trackback >

10 Responses to “Why Did Consciousness Evolve, and How Can We Modify It, Pt. III: Memory, Communication, and Perception”

1. Andre Salazar Says:  
   August 8th, 2011 at 2:28 am

   Question: What would your definition of consciousness be and how would one know if we achieved it? It seems as if consciousness in this article would be a perception of future, and the ability to communicate using memory. However one may define consciousness differently and therefor your hypothesis would go something like: due to a taste for food we were able to become an increasigly more complex animal. However complexity and consciousness are two different things.

2. Torbjörn Larsson, OM Says:  
   August 8th, 2011 at 8:48 am

   No, I can’t see how that possibly would work.

   First off, there are every reason to think that squids, fishes et cetera have consciousness, however it is defined. They
do display all of our behaviors up to and including social behavior, play and tool use. At what trait do we draw a line, and why?

A simple definition of consciousness could be “having a brain and being awake”.*

Second, and here is my real problem with this: **simply having a cortex is enough to have generic symbolic thinking emerge spontaneously.** A cortex is a structure shared among all vertebrates, and has a homology in the mushroom bodies of invertebrates. So this is a very old trait dating back before the vertebrate/invertebrate split, or at least ~ 520 My says google.

Symbolic thinking means a neural net learns, i.e. remembers. And it neatly solves the overtraining problem of generic neural nets, so having a selective advantage in discrimination which _could_ explain its evolution (or be a just-so story).

A third problem for consciousness-as-planning is that recent experiments on rats IIRC shows that they incessantly models their spatial behavior in both directions. To figure out where they should go, they have to keep figuring out where they came from. So planning (and dreaming) emerges from the need to make better decisions on motor functions. (Well, duh.)

This behavior also predicts the generic mechanism for modeling ‘self’, and post-motor behavior model sufficiently self-consistent [sic!] ‘decisions’, that is used by more complex behaving animals. This is the more common idea of consciousness, I think.

A fourth problem for consciousness-as-planning-from-land-vision would be the necessary convergent evolution in land vertebrates and land invertebrates, assuming planning in bees is accepted.

My guess is that “consciousness” is anthropomorphizing on brain function. It is an implicit version of the old “homunculus” idea. Maybe it _is_ a **“homunculus argument”**?

* Interestingly, this could be “sufficiently awake”. AFAIU they can now see how parts of brains microsleeps if we are tired.

3. 3. *Michael Fisher* Says:  
*August 8th, 2011 at 2:13 pm*

I agree with Andre

Also IF consciousness is self awareness, then I am fond of the idea that, in a social animal (that sexually reproduces) it is advantageous to be able to interpret & predict the mind states of potential mates & competitors for potential mates. This sexual selection pressure adds an extra layer above the mere planning of the hunt for food.

4. 4. *Malcolm MacIver* Says:  
*August 8th, 2011 at 5:31 pm*

@Andre & @Michael – the definition of consciousness is highly contentious. In my first two posts, I carefully spell out what definition I’m working with, and make it clear that this working definition is limited (as any working definition needs to be, since consciousness means so many different things). Also – I agree that the need for social animals to manipulate through deception, and to cooperate, would add a new abstract level over which planning could occur. I suspect, though, that it’s not the first realm in which planning first blossomed.

5. 5. *Tom Harriss* Says:  
*August 8th, 2011 at 9:01 pm*

So animals that never leave the water don’t develop the traits you discuss? What about an advanced thinker like a dolphin?

6. 6. *Malcolm MacIver* Says:  
*August 9th, 2011 at 7:31 am*
@Tom – Dolphins were land mammals that, evolutionarily speaking, are late in coming back to water. They’ve evolved the one type of imaging system that works well in water — high frequency active sonar — giving them far better range/acuity than animals with vision in water, though still short of visual range on land. There’s more on this point in the comments to post 1 and in the body of post 2.

7. marco casteleijn Says:
August 10th, 2011 at 2:39 am

“The point is clear: for stationary food sources or goals, both memory and communication work well in support of planning. But for unpredictable food sources, like the very nutrient rich body of another moving animal, memory and communication can get you part of the way (“antelope over the next hill!”) but can’t close the deal. Planning different possible paths to the most nutritious sources of energy requires long-distance perception”

Comment on this:

This is of course partially true. Animals who feed on animals are thought by memory and communication that other animals feed on stationary food sources. Also water holes are concentrated food sources for hunters.

On your three posts in general:

Very interesting view on the topic. However, following your argument it may be more nuanced then stated. Some consciousness must have developed earlier. I agree with the earlier commenters here that ” Anything that we are aware of at a given moment forms part of our consciousness (yes I looked at wiki)”, but you are here more focusing on actions and planning as an inter communication of the self.

So now if we create a mostly visual, artificial neuron-network twice and let it teach itself how to feed (e.g. find light to load battery), remember its actions (i.e. recording its “thought”), be hunted (and react to that), and put one in water and one on land. In your opinion #2 would become a consciousness being? If so we have a record on what that is. Get funding and send it to science ;o)

Last comment on “hive”, some research indicates that group thinking reduces the ability of the species to be more creative. Sparks of brilliance (which may lead to jumps in evolutions) are repressed since other similar ideas of just less equal brilliance take over (leading to steps in evolution or even halting evolution). What is your take on this?

- Marco Casteleijn -fellow scientist

8. mildly interested Says:
August 12th, 2011 at 3:00 am

Yes, the argument, eloquent though it may be, suffers from some classic issues:

1. although referencing the scientific/evolutionary background, it is speculative only; where’s the studies that demonstrate your points?
2. the old sticky problem of creating a definition of “consciousness” that the rest of us can’t poke holes in (not that our definitions would be any more resistant to a barrage of critique from our peers, just stating how difficult that really is to do).

Torbjorn in #2 also falls on an old sword: the requirement that “awake” be present to declare consciousness. Of course the obvious counter would be to ask if dreaming is not also a type of consciousness? And there’s the fact that all the animals we agree have consciousness depend on sleep and dreaming to maintain the integrity of their consciousness. That would have to be explained.

So I love the eloquence of the argument, and in particular I loved the last installment where you explained how the ability to see a long distance (which necessarily came after getting out of the water) played such an important role in the development of land animals.

But I think to postulate that long-distance vision was primary to evolving consciousness puts the cart before the horse. Even consciousness-as-planning, the definition you seem to prefer, is not necessarily dependent upon a land-based existence. Sharks, among other predatory fish, seem to be able to track prey over long distances, and create a strategy of attack, and they have never been land-based.
9. **Malcolm MacIver Says:**

@Marco – on your hive point: Tension between being an individual and part of a collective runs very deep. It’s a tension we had to resolve in becoming multicellular – formerly autonomous single celled animals had to give up all kinds of capabilities to have the benefit of being in a group. But that move to collectivism has led to amazing things — imagine how much less biodiversity there would be if there were no multicellular creatures. Similarly, although creative breakthroughs are often thought in the “lone creative genius” mold, closer examination shows they are often part of an ecosystem of similar ideas and people which made the leap much less singular than we like to romanticize after the fact.

@Mildly – right, completely speculative. I’ve some ideas for sources for corroboration/disproof, one of which I’m pursuing. Regarding sharks: My claim is that mechanisms for planning would have been under substantially higher selection pressure once we have “room” for such planning to occur. I believe that the transition on to land marks a giant change in how much room we had to plan over. Sharks and other water borne animals are largely trapped in a reactive bubble, for the reasons I’ve put forward already. Tracking is far from planning. A bacteria can track a gradient of chemicals for a large distance. I have not seen compelling evidence of shark strategizing over significant distances.

10. **Sophie Sofasaurus Says:**

What about octopus intelligence?


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- **Malcolm Maclver** is a bioengineer at Northwestern University who studies the neural and biomechanical basis of animal intelligence. He consults for sci-fi films (*Tron Legacy*, Joss Whedon's *The Avengers*), and was the science advisor for *Caprica*. He covers AI and robotics for Science Not Fiction.

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