Brain Modeling with Brytes
Making Big Brains from a Lot of Little Brains

David Zipser
Institute of Cognitive and Brain Science, University of California Berkeley, 1408 Milvia St, Berkeley, CA 94709, U.S.A.

Keywords: Arm Movements, Brain Models, Distributed Decision Making, Cognitive Control.

Abstract: Brytes are small brains used as subunits to model the cognitive processes of larger, smarter brains. A previously developed model of scratching behaviour that uses brytes to generate the coordinated movements of two arms, one with the itch site the other with the scratching hand is described. Then new strategies are described for using large sets of brytes with virtual locations all over the body to make decisions about whether scratching is safe in the current context and, if so, which appendage to use. Finally, the biological plausibility of brytes is examined in the contest of brain evolution and brain functional architecture.

1 INTRODUCTION

It has long been believed that explaining the extraordinary cognitive abilities of the brain will require the use of large numbers of high-level sub-systems. From Minsky's Society of Mind (Minsky, 1988) to the more recent Mixture of Experts (Jacobs et al, 1991) many such subsystems have been proposed. However, none of these are well suited for building biologically plausible brain models.

I have conjectured that to get the right kind of subunit we should assume that **big brains are made of many smaller brains** (Zipser, 2009, 2010). Computations can then be simplified by distributing them to many brain-like subunits. This approach has already been used to build systems that generate complex motor behaviours. Here I describe how to extend the paradigm to a higher cognitive level that is able to make decisions about when and how to execute a motor behaviour.

Thinking about brains made from brains is confusing so a name is needed to distinguish the subunit brains from the whole brain. I mixed 'brain' with 'byte' and got bryte. Brytes are the little brains of which big brains are made. They have a complete set of all the usual brain-like abilities, but on a small scale and adapted to their role as part of a bigger, smarter brain.

Whole brains, even the brains of primitive animals, are very complex so it is not practical to try to define such a brain mathematically. Instead of such an a priori definition, the computational structure of brytes can be built up incrementally by using them to implement functioning models of successively more complex cognitive tasks. This is the approach taken in this paper

From the bryte point of view brains evolved by incorporating more and more brytes while each of these brytes slowly mutates to compute a different aspect of cognition, Figure.1

From a computational point of view brytes do computations in a distributed way with each bryte contributing to the task. This can only work if there is an efficient way to integrate the contributions of each byte

In this paper I show how local decisions made by large groups of brytes can be combined to decide when an agent can act safely, and how best to accomplish the action. These higher level cognitive decision tasks are built on a previously implemented model that uses distributed sets of brytes to generate the complex coordinated arm movements needed when the hand on one arm scratches an itch on the other arm (Zipser, 2012)

The previously implemented itch-scratching model is reviewed here in some detail to provide a concrete example of how the local computations done by brytes can be integrated to generate the coordinated movement of whole appendages.

Zipser D..
Brain Modeling with Brytes - Making Big Brains from a Lot of Little Brains .
DOI: 10.5220/0005036901240129
In *Proceedings of the International Conference on Neural Computation Theory and Applications* (NCTA-2014), pages 124-129
ISBN: 978-989-758-054-3

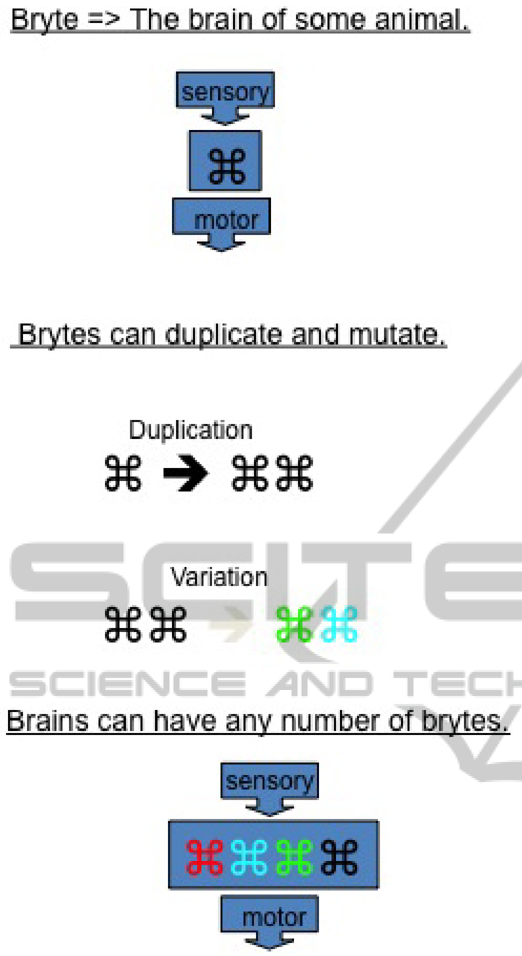

Figure 1: Schematic depiction of brain evolution. The ‘command’ symbol is used to represent a basic unit brain or ‘bryte’. All brytes have access to sensory input and can contribute the final common path for motor output.

2 USING BRYTES TO GENERATE COORDINATED ARM MOVEMENTS

Lets start at the last step in the process of scratching after the decision to scratch has been made and an appendage chosen to do the job. As we scratch an itch on one arm with the opposite hand the scratching arm continuously changes posture to bring the hand to the itch while the itch arm moves to make the itch site more accessible and bring it closer to the scratcher. These coordinated movements are made without the arms touching each other. All the information for this action is available directly within the nervous system so it can be done with the eyes closed—vision is not required.

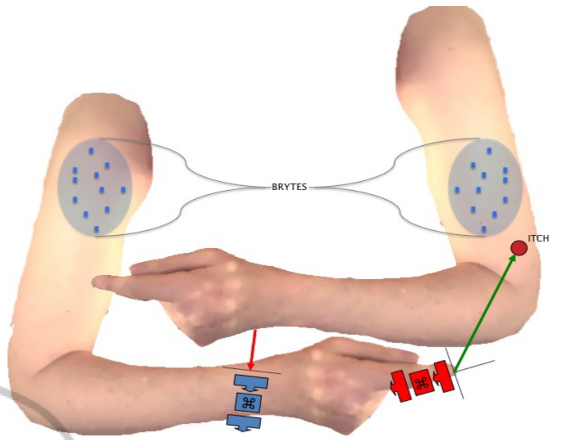

Figure 2: Brytes are physically located in the brain, but can have arbitrary and changing virtual locations in the outside world. In the scratching model many brytes are used with virtual locations all over the arm surface. A sample of this distribution is shown in the blue ovals. Examples of an avoider bryte, blue, and a seeker bryte, red, are shown with the movement vectors they output. The output vectors of all the brytes are summed and passed to the gradient arm movement algorithm to generate movements (See text for details).

These scratching arm movements were previously modelled using brytes as described elsewhere, (Zipser, 2009, 2010), and will be only briefly reviewed here. The model uses a gradient-based optimal control technique for making goal directed movements with multi-jointed (Todorov, 2006: Torres & Zipser, 2002). This technique moves a point on an arm toward, or away from, an external goal point using gradient decent on the function that relates joint angles to the spatial locations of point on the arm. Because the gradient is computed continually and incrementally so the goal can also move. The arm movements are actually controlled for both translation and rotation so both the location and the orientation of the goal can be matched. Movements are generated de novo in real time. No pre-computations, motion capture or learning are used. Most important for the scratching problem is the fact that the gradient is a linear operator so gradients for the movement of different points on an arm toward different goals can be added to get a single movement. This allows moving toward one itch point while avoiding all other points on the contralateral arm.

To understand how brytes are used to do the scratching task, imagine that a single ‘seeker’ bryte with a virtual location on the tip of the scratching finger, red bryte in Figure 2, has access to the spatial location of itself and the moving itch. This bryte can compute how to move to bring itself closer to the itch site on the contralateral arm. This function is coded in parietal cortex neurons (Ferraina et al, 2009). A different seeker bryte at the itch site on the other arm can at the same time move the itch site toward the finger that is trying to scratch it. This will eventually bring the scratcher to the itch, but unfortunately the arms will not only collide, they will also try to move through each other. To prevent this, a several hundred 'avoider' brytes are scattered over the whole surface of both arms. These brytes, blue bryte in Figure 2, have access to the location of many points distributed on the contralateral arm. Using this information each avoider bryte, computes a direction to move away from the other arm so as not to hit it. This function is coded in neurons in pre-motor cortex (Graziano, et al, 1994). The appropriately weighed sum of the movement directions of all these avoider brytes will keep the arms from hitting. When the movements specified by the scratcher brytes are added to those of the avoiders, the two arms move so that the itch is scratched and collisions are avoided.

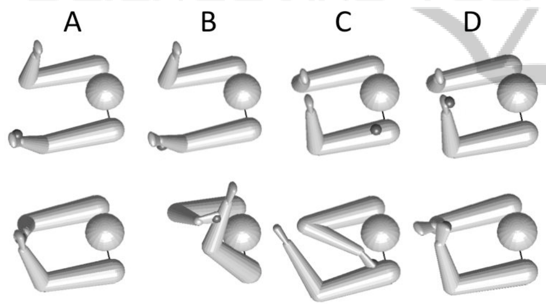

Figure 3: Examples of starting and ending postures of both arms moving to scratch an itch. In A, B and C the movements are successful while in D a local minimum is encountered.

Examples of starting and ending arm postures are show in Figure 3. The important point is that once an itch and scratch site are specified, brytes can be used to get the job done. This depends on having a way to combine together all the computations done by the brytes from their local viewpoints. In this case a simple summing operation was all that is needed.

Sometimes the movement vectors for scratching and avoiding contact cancel and movement is caught in a local minima before reaching the goal, Figure 1D. This problem arises in many behavioural contexts. Particular solutions to individual cases are usually easy to find, but more general cognitive solutions are of more interest. Some of these general solutions to local minima are implemented elsewhere (Zipser, 2009, 2010) in bryte models of grasping in the presents of obstacles.

Movies of the running simulation and a GUI that allows many factors to be manipulated are available on line (http://crcns.org/data-sets/movements/zipser-1/). The code for the simulation of this model is quite concise and the simulation runs rapidly. Those interested in the mathematical details of the simulation and a discussion of how the required information is represented in the nervous system can find them here (Zipser, 2012).

3 DECIDING TO ACT

3.1 Selecting an Appendage to do the Scratching

Suppose you have an itch on your right calf. You could bend over and scratch it with either hand or you could scratch it with the side of your foot on your left leg. How do you know that you have these options, and how do you decide which to use? This is an example of a kind of problem you constantly confront, so finding a fairly general solution is of some interest. One general solution that is often proposed is 'simulation' i.e. imagining what will happen if we do something and then not doing it if it leads to bad results. Since we can apparently do mental simulation, it seems reasonable to use it for this kind of task. But I have found that attempts to model mental simulation always involve some method for evaluating the outcome. In what follows I show that sometimes these 'outcome' evaluations can be done without actually simulating the action. Doing this involves using many distributed brytes that are a bit brighter than the ones used so far.

Each bryte in the coordinated arm movement model made a contribution to the overall movement based on its own point of view, i.e. virtual location. These contributions were combined by summation to get a global movement. In the same spirit, imagine that brytes are distributed with virtual locations over the whole body. If each of these brytes can compute a value that increases with how appropriate it is for it to be the scratcher bryte, then the bryte with the highest value can be chosen to do the task.

How do the brytes compute their own appropriateness? There are innumerable factors that can potentially go into the calculation of appropriateness. For now we will consider only two—a default appropriateness, and distance to the itch. The default value is based roughly on how likely a bryte is to be chosen as the scratcher, i.e. a prior. Brytes on the fingertips would have high defaults while those on the back would have low values. The distance contribution to the appropriateness value simply assumes that being close to the itch makes a bryte more appropriate to be the scratcher. A hypothetical example is given in Figure 4 with only the three most appropriate brytes shown.

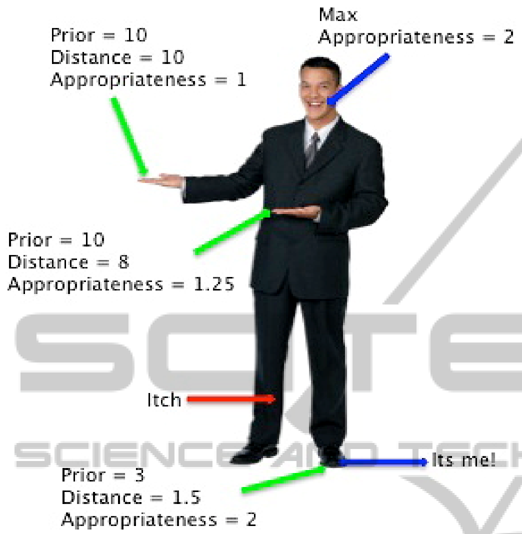

Figure 4: Hypothetical example of the method proposed to select the most appropriate appendage to use for scratching. Only the three brytes with the highest priors are shown. The local estimates of appropriateness are sent to a central location where the maximum value is determined and broadcast to all the brytes. The bryte that produced this value decides that it is the one to do the scratching.

To pick the scratcher bryte, the appropriateness values have to be compared and then the bryte with the largest one informed of its selection. In the arm movement model the gradients were summed to get a value that was then sent to a final path for movement. Here the max rather than the sum is centrally determined and sent to all the brytes. The bryte that has this max value acts as scratcher. Note that all the computations and decisions are made locally except the max operation, which is context, independent.

3.2 Deciding Whether to Make a Movement

How is the decision made that scratching will be safe in the current context? Here also there are many factors, but to illustrate how the bryte paradigm can be used, let us consider just one factor — static stability, i.e. when there is no movement and no net force.

Maintaining static stability requires that the ever-present force of gravity be balanced by a support. The weight of the body on the support produces pressure that is measured by sensors on the body surface. Since body weight is constant, summing all these pressure measurements that there is sufficient support to prevent falling. When we are sitting down, for example the pressure between the chair and our behind is enough to guarantee stability and we can sit safely.

The safety of using a selected appendage for scratching can be determined if brytes on chosen scratcher set the value of pressure they send to a central summing device to zero before any movement is made. This reduces the summed value of support pressure, indicating a possible loss of stability. Broadcasting this value to all the other brytes allows them to detect the possible instability and output a value of pressure they can handle. This is a local computation that depends on factors such as the presence of a support and the strength of the body part the bryte is located on. If the sum of all the increased values the brytes can handle is large enough the scratch will be safe. If, however, the sum of pressure that can be compensated is too low, the scratch is unsafe and can lead to a fall.

If stability is being maintained by standing on the ground or sitting in a chair, there will be no significant change in net force from moving a hand, so using it to scratch will not produce instability. However, if the chosen bryte is at a place that is contributing a lot of force to stability—as in the case of hanging by your finger tips— setting its force vector to zero will have a large affect on the predicted stability. This predicted instability cannot be compensated since no other brytes are in contact with a support. This projected instability can be used to cancel the scratch.

Our brytes are getting brighter. They can direct movement, estimate is effects and help decide what body part should do it. None of these tasks seemed to require a great amount of intelligence on the part of the brytes, but the combined contributions of many local brytes facilitate global cognition that at first appeared quite difficult.

4 BRYTE WAY TO BRAIN EVOLUTION

Are brytes biologically plausible? In the 600 million odd years between the immediate chordate precursor of vertebrates and the advent of humans the brain increased in size about a million fold and got a lot

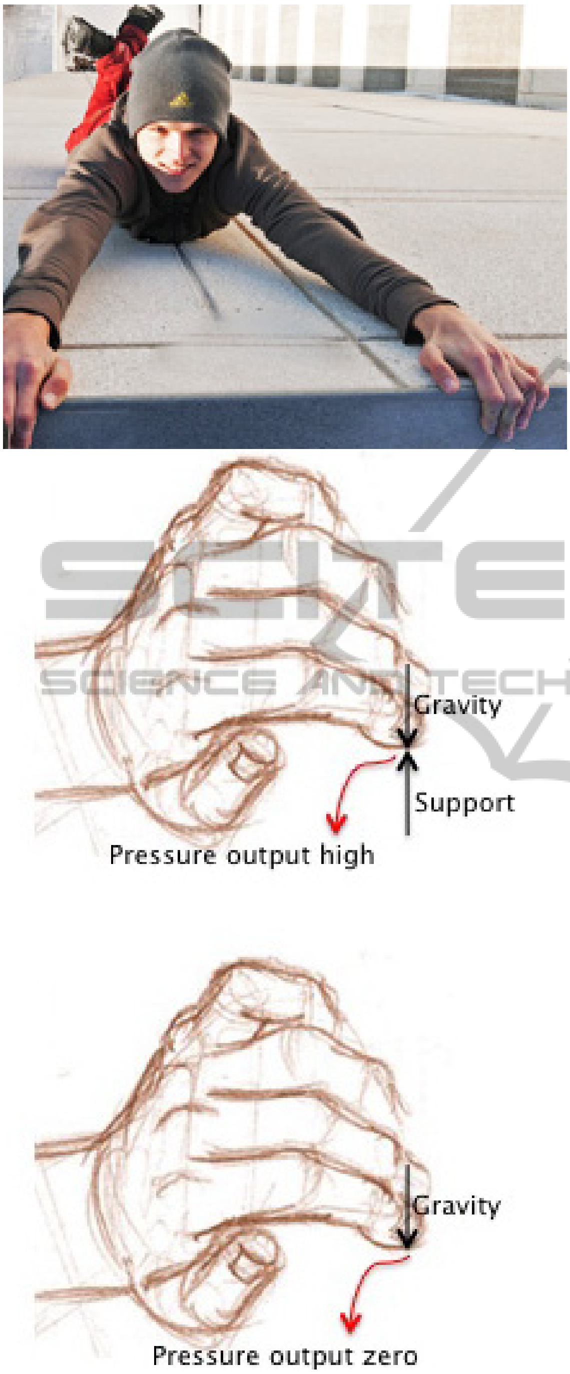

Figure 5: Is it safe to Scratch? The top hand shows the situation as it currently exists for the person in the photograph. The hands grasping the top of the wall provide contact with a support that cancels gravity. The bottom sketch shows what happens if the hand is selected to do the scratching, the brytes at the fingertips determine that movement will remove support. Setting their pressure outputs to zero before movement will lower the global pressure sum by half, allowing the movement to be cancelled.

smarter. The brains of the vertebrate precursor had some distinctly vertebrate features as can be seen in their surviving descendants, i.e. 20 or so species of a minnow like sea creature called Amphioxus.

The rate of brain evolution has continually sped up. Only 3% of the time from Amphioxus to humans separates us from our common ancestor with the chimpanzee. During these 16 million years the brain nearly quadrupled in size adding about three times as many neurons as had been added in the preceding 600,000,000 years. To account for this rapid increase in size and intelligence it is reasonable to assume that evolution has used some efficient strategies for improving things fast.

One simple, but very powerful way evolution has been accelerated is genome duplication. Animals are generally diploid--they have two copies of each chromosome. Each time a cell divides all its chromosomes are replicated so there is a time before cell separation when there are 4 copies of each chromosome in a single cell. Occasionally all four copies go to the same daughter cell and it becomes tetraploid. If this occurs during the formation of a gamete the whole organism becomes tetraploid. Since no bad genes have been added, tetraploids are often completely viable. This new copy of the genome facilitates evolution because it can be 'experimented' with without damaging the basic genetic kit of the original organism. Recent genetic analysis has found that the genome of Amphioxus doubled two times on the way to vertebrates. Amphioxus has six chromosomes we have 23 plus the runt Y chromosome.

If the genome can get more versatile by doubling, perhaps the brain can get bigger and smatter by a similar process. This actually happened in going from Amphioxus to the earliest vertebrates. Amphioxus is bilaterally symmetrical, but does not have paired structures. It has one brain, one frontal eye, etc. Vertebrates on the other hand have a right and left brain, two eyes and other paired structures. The doubling part seems straight forward, perhaps a single developmental mutation. However, the modifications required to make this work are not trivial since they include a requirement that the two new brains don't give conflicting behavioural signals, Figure 2. Note that doubling the brain did not require doubling the genome. It could have been accomplished with just a few small changes.

This original doubling took place when the brain was a tiny fraction of its current size. We know from Amphioxus that this brain already had many of the basic features of modern vertebrate brains. The bryte POV suggests that our current brain is made from

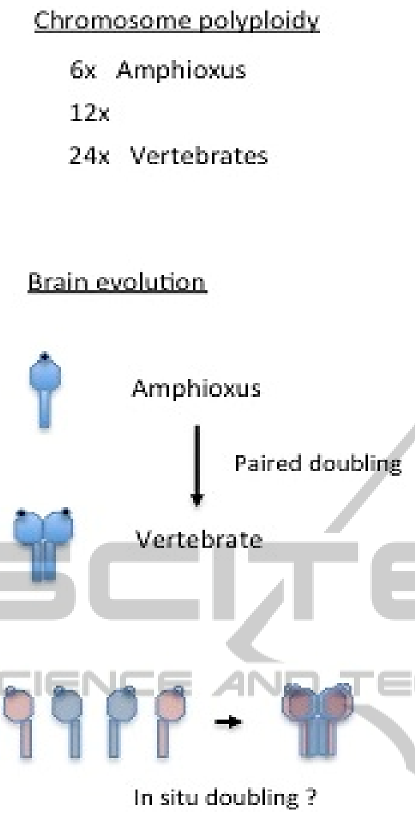

Figure 6: The top of the figure illustrates the two doublings of the genome in the 100,000,000 or so years that separated pre-vertebrate chordates from vertebrates. The doubling of the brain that occurred in the same time interval is shown below it. Below that one step in the hypothesised increase in be number of basic brain units or brytes is shown.

subunits corresponding to a huge number of these early brains. As with chromosomes, making an exact copy of an existing structure will not lead to disruption, but provides an extra copy of a functioning subunit to experiment with. Note that unlike the genome, the bryte hypothesis is that the brain evolves by adding additional copies of a small basic unit brain, not by doubling the whole brain—except in the first step. Of course, the subunit brains, i.e. brytes, get modified in the course of time in ways to increase their computational power and facilitate their interaction.

The brain architecture that results from bryte duplication is not inconstant with existing brains. Figure 2 shows that in situ multiplication of subunit brains maps onto the brain structure if we slice the brain 'vertically' so that each slice has a bit of all the principle brain parts such as cerebral cortex, cerebellum, basal ganglia, etc..

5 CONCLUSION

My goal here has been to show that the odd point of view that big smart brains can be constructed from large numbers of smaller simpler brains is computationally useful and biologically plausible. Even from the few things that have been presented here -- scratching an itch, and hints at possible biological plausibility— it can reasonably be concluded that the bryte point of view can be extended to account for more challenging aspects of cognition. Consider that most of the computations used here for scratching are also components of other tasks. And there are many aspects of brain function that have not been used at all—most notably vision. There are many avenues to extend the bryte paradigm and only time will tell if they lead to some really new insights.

ACKNOWLEDGEMENTS

I want to thank thr Redwood Center for Theoretical Neuroscienc at UC Berkeley for providing me with a venue to air my ideas and for their usefull feedback.

REFERENCES

Ferraina, S., E. Brunamonti, M. A. Giusti, S. Costa, A. Genovesio, and R. Caminiti, 2009. Reaching in Depth: Hand Position Dominates over Binocular Eye Position in the Rostral Superio Parietal Lobule. *The Journal of Neuroscience* 29(37):11461.

Graziano, et al., 1994. Coding of visual space by premotor neurons. *Science* 11: 1054-1057.

Minsky, M, 1998. *The Society of Mind*. Simon and Schuster, New York.

Todorov, E ., 2006. Optimality principles in sensorimotor control. *Nature Neuroscience* 7:907-915.

Torres, E. B., Zipser, D., 2002. Reaching to Grasp with a Multi-jointed Arm (I): A Computational Model. *Journal of Neurophysiology* 88: 1-13.

Jacobs, R., Jordan, M. I., Nowlan. S. J. and Hinton, G. E., 1991. Adaptive mixtures of local experts. *Neural Computation*, 3, 79-87.

Zipser, D., 2009, 2010 Brytes or How to make big brains out of lots of small brains, parts 1, 2, 3 - *Redwood Center for Theoretical Neuroscience. archive.org/search.php?query=david+zipser.*

Zipser, D., 2012. Distributed Control of Complex Arm Movements in *Living Machines* Springer-*Verlag Berlin Heidelberg, 309-320.*