2. Anigraf2: Swimmers
   beginning to move

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2.0 Movement

Cell Anigrafs had very limited behaviors, constrained for didactic purposes to simple ring forms. This simplification hid the potential complexity of designs and behaviors that could be attributed to primitive life forms. Here we begin to expand this repertoire. The component mental organisms, or “agents” will have access to different kinds of interfaces with the environment, with interface hardware that affects the behavior of the system as a whole. Agents will have control over those additions, and will “vote” depending upon the strength of its desire to achieve a preferred goal. In effect, then, we are formalizing a two tier system: one where the interface agent constitutes a member of the social system of all other agents, and another, lower level where each agent controls an effector, but only when approved by all other agents.

One of the most visible and prevalent effectors are flagella or hairy muscular fibers. For example, the single-cell Euglena has a flagellum that waves to pull the creature forward; another simple creature, the paramecium, has a host of hairy superficial fibers that can generate wave-like motions. These appendages can be entirely passive, with the movements initiated only at the point of attachment to the cellular body. More complicated limbs may have additional agents confined to “local” social enterprises that control special sinusoidal motions, such as the movement of wings, fins, legs, and eventually fingers. We begin first, however, with a description of a society of agents that can generate chaotic-like flagellations typical of coelenterates. This little society has simple objectives: to move one way or another.

2.1 Jellyfish

Coelenterates have very primitive neural nets that lie on the rim of a funnel-like body. When activated, this network causes a wave-like motion of tenacles attached to nodes on the rim. The jelly fish is an example. It has an inverted cup-like form with many tenacles emerging from the rim of the cup. Typically the neural elements embedded in the ring appear in multiples of four. Each neuron drives its own tenacle, causing it to flagellate. The anigraf analog is thus a group of agents linked together in a ring-like configuration, such as
those illustrated in Fig. 2.1. Of primary interest is how likely this type of anigraf will generate cycles among actions initiated by the constituent agents.

If the anigraf form is a simple ring, then each agent communicates only with its two neighbors. The probability of cycles was shown previously to reach a peak at 8 - 12 agents (Fig 1.2.) Let us then consider design possibilities for an octagonal jellyfish anigraf, recognizing that both cyclic and non-cyclic outcomes are useful. An example of a cyclic outcome would be a top cycle that moved from one agent to another, rotating around the ring, an hence initiating a circular wave of activity. A non-cyclic outcome, on the other hand, might result in the coordinated constriction of the rim of the coelenterate as it captures a food particle.

Figure 2.1 shows a few modifications of the simple ring, and the probability of top cycles among outcomes using the Condorcet tally, where the weights on nodes (i.e. the strength of the agent’s desires) are chosen from a uniform distribution. If the ring is reconfigured to “wheel”, then the anigraf has one vertex that is adjacent to all others (i.e. the graph is “covered”) and there will never be cycles (p=0.) The next configuration is a regular graph, where each node has a degree of four. The top-cycle probability is about 6%, which is roughly half the cycle probability of the simple ring. Unfortunately, none of these percentages may be high enough to insure that our jellyfish can easily engage in complex, long-cycle flagellated movements.

A simple modification of our communication channels solves this problem: make the communication channels directional. In other words, let preferences be “passed on” from one agent to the neighboring agent, but not vice versa. Depending upon the directionality of the communication channel,
we also will have the great advantage of being able to enforce either clockwise or counter-clockwise cycles among the rim agents. For the jellyfish with a ring of eight agents, clockwise directed communication will produce clockwise cycles 60% of the time; for a ring of twelve agents, the cycle probability rises to 80%. These numbers are approximated very closely for $n>4$ by cycle percentages shown earlier in Fig. 1.5 for random preference orderings. (See also Fig. 2.3.) The difference, however, is that now the shared (directional) anigraf model is respected by all agents when ranking their preferences. Clearly we have the beginnings of a social control system that mimics a physical feedback controller, but here the condition of sharing social preferences is met.

A periodic wave of tenacle movements is but one of several actions that the jellyfish might engage in. Even if the agents all have identical effectors, all effectors need not perform identical movements, and consequently, all agents need not have identical goals for the system. Some agents might prefer that the jellyfish move to another, more favorable region in its environment (more “food” or perhaps “less hostile”). Another might want to ingest nutrients, another might wish to release a toxin. As in our primitive cell anigraf1, some of these actions might entail a change in shape -- perhaps to be carried out by activating other internal fibers or membrane properties. In a very simple scenario, there could be two types of agents on the coelenterate’s ring network, X and Y, where X agents would create an inward current and Y agents would create outward currents, or tighten the membrane supporting the ring. All these choices entail societal consensus that is reached after conducting the Condorcet tally among the agents. This coelenterate ring of agents can easily be regarded as a very primitive brain.

### 2.2 The Flagellum

Consider next yet another primitive creature, such as the sperm cell or Euglena, where a single flagellum controls movement of a simple, cell-like “body.” If this appendage itself is passive, driven by forces applied to its base, the effect will be as if someone were whipping or twirling a cord. Such a cord will have some kind of natural frequency of motion when torques are applied at one end. As shown by Berg(19xx), these simple creatures have a micron-
sized motor that whips the miniature tail. Let’s say agent A is responsible for initiating movement of this flagellum, thus satisfying an exploratory need to move forward. Then we know from Table 1.3 that if voting strengths of the agents are suitably chosen, cyclic outcomes will occur that will include agent A’s preference for system behavior. The little creature continues to flagellate until new voting strengths are tallied.

A variety of cycles that include A are possible for our Euglena. Consider both hexagonal and pentagonal anigraf forms, as illustrated in Fig. 2.2. Symmetric top cycle activation of agents seems most likely for forward movements, whereas asymmetric cycles offer an option for changing the directions. We can also distinguish top cycles that include the neighbors of A as in the pentagon, or alternately, cycles that exclude these neighbors, as in the left-most hexagon. Each has advantages. For example, switching to other cyclic states may be easier if two members of the symmetric top cycle are non-adjacent to A. On the other hand, when neighbors of A are part of the top cycle, then agents such as C and D in the pentagon, or C and E in the hexagon, are free to reinforce each other’s goals. An additional important benefit of including agents nearest to A is that there is a 10 fold greater possibility of top-cycle activity. Forward or backward movements are thus the most likely. Clearly, even for our little anigraf Euglena, many
Plate 1: Phase Plot Showing Winners for a House Anigraf with weights (6, 3, x = 0-10, y = 0-10, 1). Vertices labeled clockwise beginning with tip of roof. Textured areas are topcycles. (T.J.Purtell, 2004)
different movements seem possible, capable of supporting a variety of behavioral
goals.

2.3 “Smart” Tails

To create creatures with more complex locomotor abilities, we may wish
to control the amplitude or form of the wave of the tail, or bias its body angle
to change heading. These effects can not be accomplished easily by a single,
simple agent at the point of attachment of a passive appendage. Let us then
break the tail into segments, simultaneously creating a chain of agents, each of
whom controls the activation of one segment. Let one of these agents, say \( A \),
be selected as the “head”, using upper case to make this designation. (Fig 2.3.)

Because a chain is just a broken ring, the top cycle behavior of chains is very
similar to that of rings. Our objective is to create a cycle of activity through at
least one part of the \( A,b,\ldots,e \) chain anigraf. In turn, this cycle among agents
will effect a physical movement of the tail or body, such as when a fish swims
or a snake crawls. We assume that the agents are embedded within a flexible
shell that contains contractile tissue such that when an agent is active, muscular
springs will contract to create part of a wave motion. A cycle among agents,
say agents \( A,b,c \) or \( A,b,d \) can drive this kind of behavior.

It is easy to show that if there is no sharing of information between
agents, then there can be no cyclic behavior. Intuitively, if all agents are
independent, then in a pair-wise competition among choices, the agent with
maximum clout will win. Similarly, although less obvious, if all agents share
their current preferences with each other, placing a preference ordering on all
alternatives, then again there can be no cyclic behavior. (Black, 1958; Richards et al, 2002.) Cycles among agent choices are most likely when information is shared only among immediate neighbors. Furthermore, like the jellyfish, cycles will become even more common if the communication channels are directional.

Figure 2.4 Illustrates. With undirected communications between neighboring agents, the top-cycle probability reaches a maximum of about 15% for a chain of 10 – 12 agents (diamonds.) If directionality is introduced into the social network (plusses), then cycle probability rises 5-fold to 60 – 70%, increasing further as the chain length increases, eventually reaching 1 as the asymptote. Directed ring anigrafs behave similarly (open circles.) Anigraf social networks composed of chains thus have a high potential for eliciting periodic activities. Even rather small 8-chain anigraf worms with directional communications can initiate 5-cycle waves such as AbdecA.

2.4 Cooperative vs Competitive Networks

Anigrafs with directed, rather than with bi-directional communication channels come at a cost. Such networks marginalize one of our key
assumptions about social awareness. Because information is passed only one way and not back and forth, the sharing of knowledge and preferences within the system is quite limited. Such networks resemble those with feedback loops. As a species, anigraf creatures with directed networks thus are second class citizens and lie somewhere between a fully aware (bi-directional) anigraf and Braitenberg’s more reflexive vehicles.

To clarify this connection, consider how we might shut down or control top-cycle activity, especially if it leads to chaos. Rather than removing directionality, a simpler solution is to shut down the voting weights of the agents (or, equivalently, assign equal weights.) This is easy to implement through either global inhibition or inhibitory feedback loops among agents. As the exchange of information among agents is reduced to zero, the probability of top cycles decreases and can be driven below the bi-directional result shown in Fig 2.4. (The inhibitory case plotted shows the attenuation effects, but not the limiting result.) The more agents whose clouts have been reduced to zero, the greater the chance of one agent getting its way. Our directed anigraf has then been morphed into a kind of hybrid between a Braitenberg vehicle and the truly social, bidirectional anigraf.

2.5 Brain Types

An obvious extension to swimmers (or crawlers) is to modify the neural network at the “head” end of the undulating chain. Already we have seen that simple head designs, such as pentagons or hexagons, allows tail motion to be turned on or off simply by setting the voting power of agent A to zero (Fig 2.2.) In Fig. 2.5 we illustrate further anigraf forms for “heads” attached to smart tails that consist of a chain of three or four agents. Consider the forked head. The notion is that activation of the left (G) or the right (F) member of the fork will tighten a muscle and cause the head to turn. Let this change in “head orientation” happen in the presence of the Acd cycle which is driving the anigraf forward. Hence we need either an Acd cycle in the presence of a dominant G activation. Possibilities are AGcd, AcGd, or AcdG.
To set up the first of these cycles, the following Condorcet comparisons must result when the votes are tallied:

\[ A > d; \quad G > A; \quad c > G; \quad d > c; \quad \{A, G, c, d\} > b, F. \]

To mimic a very simple voting system, let the strengths of the agent’s desires take on one of three levels: noise, middle, saturated, or 1, 3, 6 (See appendix 3 for an elaboration using three continuous distribution functions with analogous mean values.) One voting regime that satisfies these conditions is \{1,6,3,1,1,6\} respectively for agents \{A, G, F, b, c, d\}.

It is easy to imagine other kinds of behaviors that might be associated with different “brain types”. A three-fork at the head end could activate not only turning to the left or right, but also perhaps local lunging by the middle agent H in the presence of the Abd swim. Such activation weights correspond to lunging forward to grasp a prey. More complex ring networks might provide potential for agents with sensory apparatus that triggers either body or tail movements once the adequate stimulus is sensed.

For example, one obvious manipulation of the “head” is to add edges that join symmetric agents/nodes. In a Hexagon Anigraf (see frontpiece), adding the edge BF will affect the preference orderings not only for B and F, but also C and E as well. Consequently, the cyclic probabilities change because
agent’s preference orders are altered. If the edge BE is added instead, bisecting the Hexagon, then we have a symmetry between ABC and FED, and we obtain still another behavior. Surprisingly, this latter addition will prohibit cycles, whereas the first increases the cyclic possibilities.

For very large rings, a potentially useful modification is to add edges that create local bridges, as in regular graphs, or distant bridges to create "small world rings." Each has quite different cyclic behavior. Another weird brain design might be to have two directional rings as illustrated in the front panel, with bridges between pairs of nodes on each ring. Or, two directional rings joined like Siamese twins. Turning rings on or off could cause opposite cycles, asymmetric body movements, etc. But even with such more complex “brains”, these swimmers or crawlers execute only with wave-like movements of their chain-like tails. The specific “brain type” will have marginal influence on this coordination. Hence, when all is said and done, these anigraf swimmers have only a modicum of social consciousness among its network of agents.