A simple model for the evolution of irreducible complexity

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Teaching "intelligent design" as an alternative to evolution in biology classes is popular but scientifically unjustifiable. The core argument of intelligent design is that some biological systems are too complex to have evolved. I present a simple computer model for teachers and students illustrating how irreducible complexity can evolve.

Keywords: intelligent design, Behe, simulation, natural selection

During recent years, the teaching of "intelligent design" in biology classes as an alternative to evolutionary theory has attained a high level of popular acceptance (see reviews by Pennock 2003; Schuster 2005). Proponents of intelligent design are commonly perceived by the community (although rarely by scientists) as having scientific credibility. The core argument of intelligent design is that certain biological systems have a property called "irreducible complexity" that cannot evolve by natural selection, and therefore prove the existence of an intelligent designer. This paper describes a simple model which illustrates that irreducible complexity can easily evolve by natural selection. The model, which is available as an online demonstration, may be useful to students and educators who are seeking a clear understanding of the fallacies in intelligent design arguments.

A prominent advocate of intelligent design is Behe (1996), who argues that the evolution of certain biochemical systems via natural selection is impossible because they share a property he terms irreducible complexity, defined as follows:

> "By *irreducibly complex* I mean a single system composed of several well-matched, interacting parts that contribute to the basic function, wherein the removal of any one of the parts causes the system to effectively cease functioning. An irreducibly complex system cannot be produced directly (that is, by continuously improving the initial function, which continues to work by the same mechanism) by slight, successive modifications of a precursor system, because any precursor to an irreducibly complex system that is missing a part is by definition nonfunctional." (Behe 1996, p. 39.)

As others have observed (Orr 1996; Thornhill and Ussery 2000), a central fallacy in Behe's argument is the assumption that the evolutionary precursors of irreducibly complex systems must be "missing a part". This assumption would be true only if natural selection could not remove existing parts from systems. Evolution of irreducible complexity can occur when natural selection or genetic drift removes redundant parts of systems. Such loss of redundancy is likely to be common in nature (Orr 1996).

A number of refutations of both the general argument and specific examples used by Behe have been published (e.g. Orr 1996; Shanks 1999; Weber 1999; Thornhill and Ussery 2000; Aird 2003; Peterson 2002; Lenski et al. 2003; Schuster 2005). However, a simple and transparent demonstration of the evolution of irreducible complexity has been lacking. In this paper I show how natural selection can easily evolve irreducibly complex systems using a simple geometric model. A java version of the model, including full source code, is available at www.complexity.org.au. This allows students to run the simulation and perform evolutionary experiments while observing the results in real time.

Model

Graphs are a useful way to represent complex systems (Green 1994). Within the graph nodes represent parts of the system, and interactions between the parts are represented as edges or vertexes. Here, I consider a system that operates on a regular two-dimensional triangular lattice (as shown in Figure 1). The nodes in this lattice are simple Boolean switches (that is, they have only two possible states, ON and OFF). In this lattice, when two adjacent nodes are in the ON state, an edge automatically forms between them, connecting them. A group of connected nodes forms a system; they are its parts.

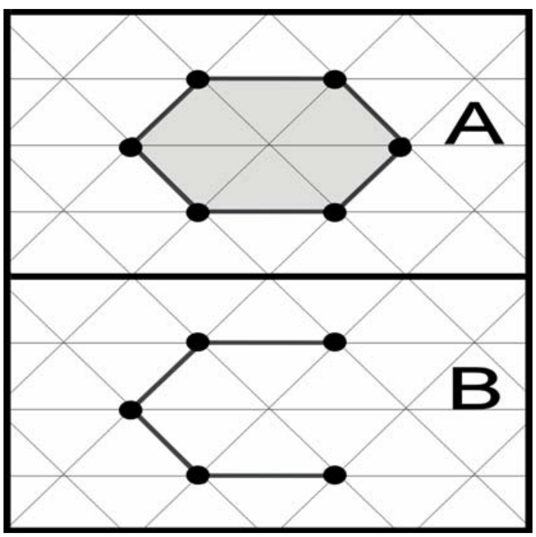

Figure 1. Irreducible complexity in a triangular lattice. (A) A small irreducibly complex closed form. (B) Removal of any single node generates a non-closed form.

Let us suppose that this system performs a function. The only requirement for the system to function is that it must include a closed geometric shape. If the system includes a closed shape (Figure 1A), then it is a functional system; if it does not include a closed shape, then it is a non-functional system (Figure 1B). Further, let us suppose that mutation of the system can only change the state of one node in one time-step, that is, it can switch a single node from ON to OFF, or vice versa.

Given these premises, the shape in Figure 1A meets Behe's criteria for an irreducibly complex system. The system is "composed of several well-matched, interacting parts that contribute to the basic function" (Behe 1996). Crucially, it cannot have evolved by incremental additions because switching off a single node will destroy the system's function entirely (Figure 1B). In accordance with Behe's definition "the removal of any one of the parts causes the system to effectively cease functioning".

However, allowing nodes to be switched either ON or OFF by mutation permits such forms to evolve gradually from initially simple forms (Figure 2). For example, suppose that we begin with three ON nodes forming a triangle (Figure 2A). Mutation allows a single node to be switched ON or OFF at each time-step. Non-functional systems, which are those that do not include a closed geometric shape, do not survive. Switching OFF a node from the initial system would generate a non-functional system, so at this point evolution can only switch ON a node. Switching a randomly chosen node ON creates a second triangle connected to the first (Figure 2B). After several more randomly chosen nodes are progressively switched ON (Figure 2C-2D), some ON nodes may be fully enclosed within the closed geometric form of the system (Figure 2E). Randomly switching OFF these enclosed nodes makes no difference to the system's function; however, once they are switched OFF, these nodes may leave behind a system that will not take a closed form if any further nodes are switched OFF (Figure 2F). Randomly switching single nodes ON and OFF can thus generate the evolutionary pathway illustrated in Figure 2 leading to the same irreducibly complex system seen in Figure 1A.

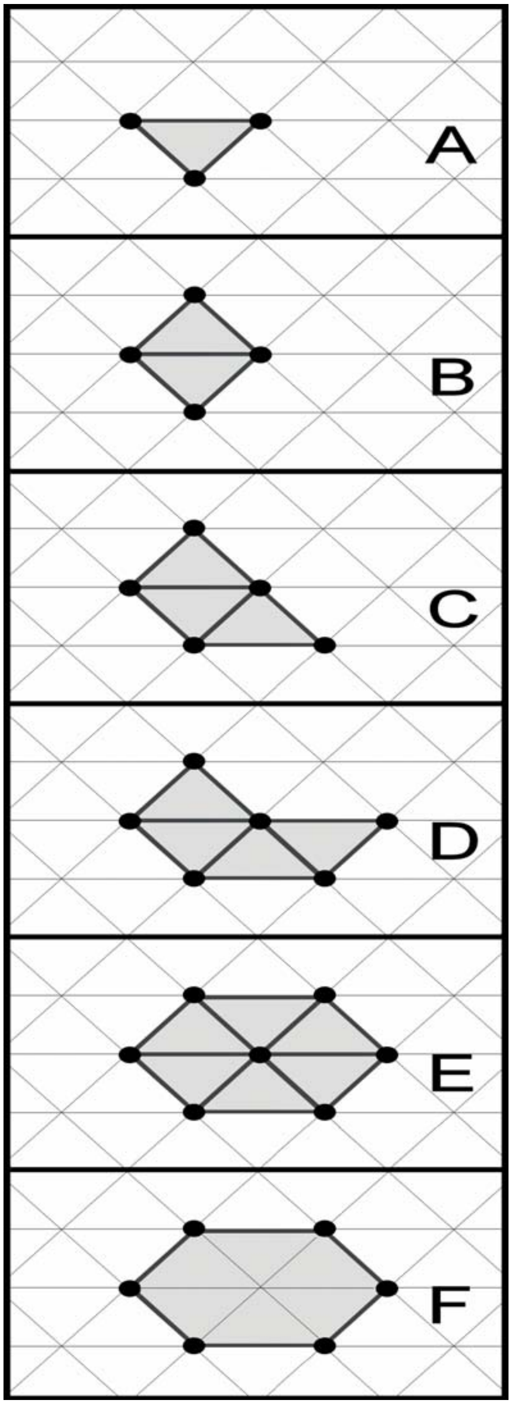

Figure 2. An evolutionary path to irreducible complexity. Starting with system (A), nodes are progressively added (B-E), generating larger forms. The internal node in (E) is redundant and disappears (F).

Suppose that natural selection favors systems whose closed geometric forms encompass a larger area. In this situation, the evolution of progressively larger, more complex forms is virtually inevitable. When systems are also subject to selection for smaller numbers of ON nodes, redundant nodes are likely to be lost through natural selection, potentially leading to irreducible complexity.

The rules described above were embodied in a simulation model. The model began with the minimal parent system illustrated in Figure 2a. Each generation, the parent system was replicated, creating an identical new system, and a single node in the new system was switched on or off at random. If the new system's fitness exceeded the parent system's fitness, the new system became the parent system for the next generation (an event called an *evolutionary step*).

Two rules were used to determine fitness. Firstly, if one system had a larger area than the other, then its fitness was greater. Secondly, if the area of the two systems was equal, but one contained fewer nodes, then this system was fitter. If neither rule indicated a winner, fitness was assigned at random.

Example simulation results

The frequency and size (number of active nodes) of irreducibly complex forms was measured among 500 replicates for 100 evolutionary steps. Irreducible complexity was measured according to Behe's (1996) definition: a form was counted as irreducibly complex if, and only if, removal of any part would render the system non-functional.

Figure 3 shows some examples of irreducibly complex systems generated using the model. The size of irreducibly complex forms increased progressively as evolutionary time passed (Figure 4). However, the relative increase in size gradually declined. The largest irreducibly complex system observed (30 nodes) evolved after 95 evolutionary steps; the smallest (6 nodes) after 6 steps. Figure 5 shows the cumulative frequency of irreducibly complex forms over 100 evolutionary steps. In total, 282 irreducibly complex forms were produced in the 500 replicates within 100 evolutionary steps. The rate of evolution of new irreducibly complex forms slowly decreased as the number of evolutionary steps increased. This occurred because larger systems, which evolved later in the simulation, had smaller perimeter to area ratios, so that larger systems needed to switch off greater numbers of nodes in order to become irreducibly complex.

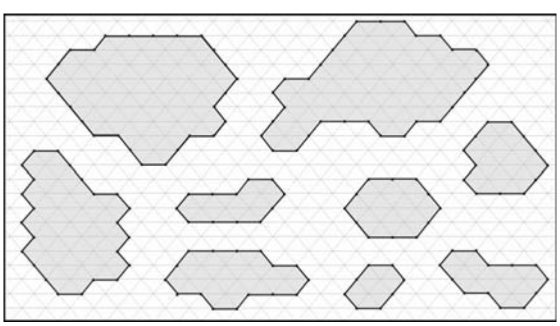

Figure 3. Some irreducibly complex forms evolved by the model.

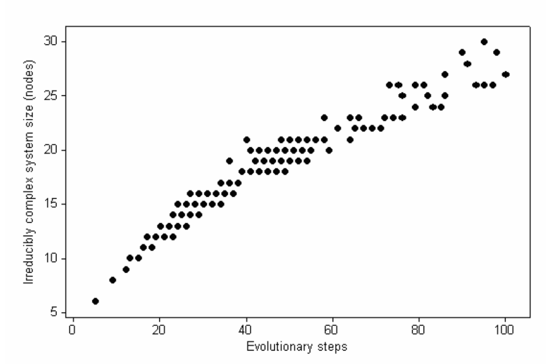

Figure 4. Size of irreducibly complex systems at each evolutionary step.

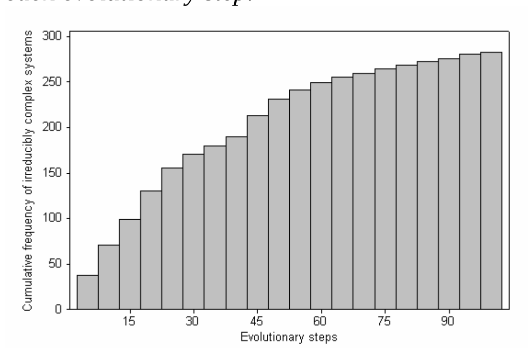

Figure 5. Cumulative occurrence of irreducibly complex systems over time.

Conclusions

The simulation results demonstrate that irreducible complexity evolves easily in a simple model in response to natural selection favoring larger systems with fewer parts. Over the short period studied (100 evolutionary steps), complexity continually increased. Even within this short time, the evolved systems acquired levels of complexity similar to those of systems commonly cited as examples of irreducible complexity. Irreducibly complex systems produced by the model contained between 6 and 30 parts; the bacterial flagellum requires around 33 parts (Weber 1999); the mousetrap only 5 (Behe 1996).

Traditionally, scientists have avoided direct response to intelligent design claims, reasoning that these views are founded in faith rather than empirical data and are therefore unworthy of scientific attention. Moreover, many argue that response to intelligent design risks fostering the illusion these ideas genuinely challenge science. However, these concerns must be balanced against another danger: the failure of communication. A recent survey indicates that around 86% of Americans explicitly believe in intelligent design, with 64% favoring teaching of creationism in schools and 38% opposing the teaching of evolution (Pew Research Center 2005). These figures imply that the strength of evolutionary theory, and the failings of the intelligent design movement, are not being communicated within the American teaching system.

It would be naïve to expect that the broader community can be insulated from the attitudes that result from this widespread disregard for the scientific consensus. As Dobzhansky (1973) cogently stated: "Nothing in biology makes sense, except in the light of evolution". Students taught to deny evolutionary theory are bereft of the most useful tool available for biological reasoning. Worse, they are taught a misunderstanding of the scientific method which may undermine their ability to reason about important issues arising from science. Given that the majority of Americans dismiss the scientific consensus on the origins of life, should we be surprised if they are equally indifferent to the scientific consensus that pollution is causing catastrophic global climate change?

One possible response to this problem is to develop communication tools which clearly show the falsity of intelligent design arguments. The current model aims to achieve this. The simulation allows evolution to be observed in action, and the simplicity of the model should make it accessible to a wide audience.

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