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Designing Nature's Way

You have won a new car—any new car you want! What kind of car do you pick? Do you want a racy sports car, with a powerful V-8 engine, 6-speed transmission, power convertible top, navigation system, polished aluminum wheels, and premium sound system with in-dash 6-CD player with MP3? Or maybe you'd rather have a roomy 4-wheel-drive sport utility job that could take you out in the wilds where no other car could go. Or how about a nice luxury sedan that could take you and your family on long trips in quiet, air-conditioned comfort and safety?

There's an automobile for just about any type of transportation need (or dream) you can imagine. Auto designers make a list of needs and wants that a particular type of driver (or buyer) might have, then design a car, truck, or SUV that will sell . . . and, they hope, delight the buyer.

But, of course car designers don't start from scratch each year. They take parts of the previous years' designs that worked well (such as the engine, transmission, brake system, and the particular materials used for each type of part), then add new features or change things slightly to try to improve the finished product. So, in theory, automobiles should get better and better all the time. For the most part, they do. But at some point, designers will run out of new ideas to make the car better and more fit for any particular driver's requirements.

A Different Kind of "Designer"

In the case of cars and other engineered objects, humans go about the design process in a very intentional way. They pretty much know what they are aiming for. They know how to test their designs to see if they will work in the real world. However, in the case of nature, the environment and the "laws of the jungle" make up the list of requirements that living things must meet, as well as the "tests" that they must pass in order to survive. For example, in order for an animal species to survive, individuals must be able to find, eat, digest, and metabolize food; find and drink water; protec themselves from predators and harsh weather; and reproduce, passing along their successful characteristics to their offspring. All the "design accessories," such as eyes, nose, ears, teeth, claws, hooves, spots, stripes, fur, or fancy feathers, contribute to the success of the "design."

The plants and animals we know (and are!) today are the offspring of billions of generations. If each generation had been an exact copy of its parents, then no changes in the instructions for the design, the "blueprint," would ever occur and there would be only one "species" of living thing and it would never change. But changes in the blueprint do occur very frequently. Mistakes are made in the copying process. Harsh environmental influences, such as solar radiation and toxic substances, knock out or distort parts of the blueprint so the design cannot be copied exactly in the next generation. These changes in the instructions are called *mutations*. Most mutations result in "design flaws" in the next generation. But a few mutations actually result in improvements. The resulting offspring are a little more successful at surviving and reproducing than their cousins, and so pass on the mutation to more offspring, thus changing the species the tiniest bit to make it better adapted to its environment.

Lessons from Nature

Sometimes engineers and inventors look to nature for inspiration. For example, how do animals solve the problem of getting from one place to another? Well, nature has come up with all sorts of legs, fins, flippers, wings, pseudopods, undulating muscles, and so on. (It took humans, however, to come up with wheels and roads.) Given billions of years and billions of "trial and error" experiments over billions of generations, natural processes have produced living things that have solved many other complex problems in very effective and efficient ways that humans would probably never have thought of.

Humans cannot think of every possible approach to a problem. Human invention seems to be limited by what has been done before and by our own brains' wiring that makes us want to create things that "look right" and fit into some pigeonhole or category that we already know about. Nature itself doesn't have categories and fixed notions of things. Nature is limited only by the laws of physics. So why can't humans use something like those same natural processes and experiments to design new things?

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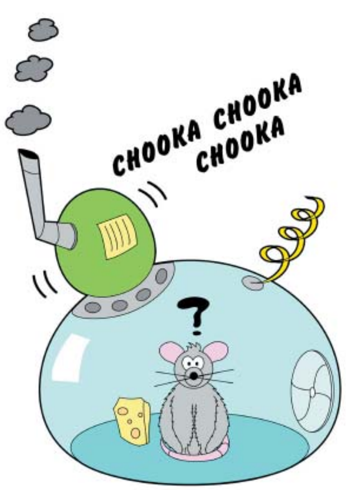
Well, trial and error is not really a very efficient way to design something. It's much better to use your brain and try to figure out what kind of design would work best before you go to all the trouble to build it and test it to see if it would work in the real world.

Evolution in Fast-forward

But what if we could give the "trial and error" design job to a very powerful computer? Suppose we want to design a new kind of mousetrap. We first have to tell the computer about mice and the laws of physics, so it will know what is physically possible out here in the real world (as opposed to inside the computer). Then we tell the computer what we want the mousetrap to do. In other words, we think of a test the computer can run inside itself: the mousetrap must attract a mouse, then trap it without the mouse being able to carry the trap away or escape. Oh, and we don't want to hurt the mouse—just catch it and relocate it from the city to the country. Then the computer could be programmed with a list of materials or tools (and their characteristics) that the computer could use to create the mousetrap: plastic, glass, wood, metal, cheese, etc.

To give the computer a bit of a head start, we come up with quite a few designs of our own. We feed them (that is, the exact measurements, materials, and other characteristics) into the computer, and let the computer run its mousetrap testing program on them. The computer then takes the several designs that did the best, scrambles up their characteristics a little, then generates a new set of designs: Mousetrap Generation #2. The computer then runs the same test on this batch of designs to see which mousetraps would do the best job. It then picks out several of the best designs, mixes them up a little, and spits out another bunch of mousetrap designs: Mousetrap Generation #3. The computer continues testing, picking the best performers, mixing up their traits, and creating yet another generation of designs over and over and over. Eventually, maybe after a million generations, one mousetrap passes the test perfectly and no further designs can do any better. The perfect non-destructive mousetrap! The computer prints out the design specifications, real people build and test it in the real world, and it works! But what does it look like? It just might not look like any mousetrap anyone has ever imagined before!



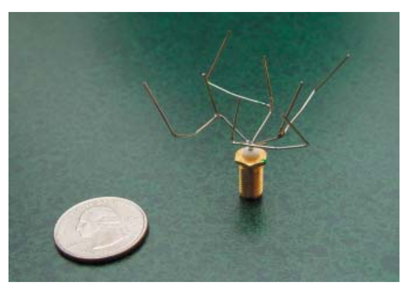
An "Out of the Box" Antenna Design

It is as computers have become very fast and very powerful that designing "nature's way" has become practical. Engineers at NASA's Ames Research Center in Silicon Valley, California, have used the technique of *evolutionary computation*, also called *artificial evolution,* to design a tiny communications antenna to be used in the three small TV-sized satellites of the Space Technology 5 (ST5) mission. Many random designs were tested in a computer—or, actually 35 computers working together. The computer judged their performance against certain goals for the design: efficiency, a narrow or wide broadcast angle, frequency range, and so on.

As in nature, only the best performers were kept, and these served as parents of a new generation. To make the new generation, the traits of the best designs were randomly mixed by the computer to produce fresh, new designs—just as a father and mother's genes are mixed to make unique children. This new generation was again tested in the computer simulation, and the best designs became the parents of yet another generation.

This process was repeated millions of times, until one best design emerged that wouldn't improve any further. With today's fast computers, millions of generations can be simulated in only a day or so.

The result: an excellent antenna with an odd shape no human would, or could, design.



Tiny communications antenna designed by a computer using artificial evolution for Space Technology 5 spacecraft.

Antenna, shown installed on ST5 spacecraft, uses less power, gives more reliable coverage, and is easier to fabricate than the best antenna designed by humans for this spacecraft.

May the Best Face Evolve!

We will see how the computer simulates biological evolution and the laws of natural selection in the following activity. You may be familiar with "smileys," sometimes called "emoticons." These are groupings of punctuation marks on the computer or typewriter to create tiny faces with smiles, frowns, winks, etc. These are often used in e-mail messages to let the reader know the writer is making a joke or is happy or unhappy about something. In this activity, we will put punctuation mark "eyes" and "mouths" together randomly in an attempt to weed out all but the best "face" combination for the purpose of communicating a certain emotion.

Break the class into groups of four players for this activity. (An additional group of one, two or three will work.) Create a set of 8 Image Cards for each group. To create the Image Cards, photocopy the last page of this article, preferably on light card stock, and cut along the lines. Each card has two lower face halves (mouths) and two upper face halves (eyes). Make a photocopy of the Design Card shown on the next to last page of this article for each player. In addition, for each group of four players, make three enlarged copies of the design card. For Part IV, an overhead projector, chalk board, or white board would be useful.

The first step is to **set a design objective.** As a class, decide what emotion you wish your final design to communicate. Choose a feeling or emotion such as indifference, surprise, joy, sadness, confusion, pain, anger, boredom, fear, excitement, sleepiness, innocence, guilt, thoughtfulness, etc.

I. Individually, Evolve a Design with Two Cards

1) Each person picks a pair of Image Cards.

a) With the Image Cards face down on the table, each individual in the group picks two Image Cards at random to form a two-card set.

2) Use these cards to generate a design.

a) Place one card vertically ("portrait" orientation) on a tabletop.

b) Place the second card horizontally ("landscape" orientation) on top of the first, aligning the mouth semicircle on the second card with the eye semicircle on the first one behind it to form a facial expression.

c) Note how well the face from this pair matches the objective emotion.

d) Rotate the "mouth" (top) card to try the other mouth semicircle with the eye semicircle on the bottom card.

e) Note how well this face matches the objective emotion.

3) Evaluate designs and select the better fit.

a) In Sector I of a **Design Card**, write the eyes number and mouth letter of the better match in the boxes and draw the symbols in the face circle.

4) Generate a second design.

a) Reverse the pair of Image Cards, placing the second card vertically (doesn't matter which "eyes" are up) and the first card horizontally on top of it (doesn't matter which "mouth" is up). Repeat Steps 2c – 2e.

5) Evaluate and select the better fit.

a) In Sector II of the Design Card, write the eyes number and mouth letter of the better match in the boxes and draw the symbols in the face circle.

6) Select the better design.

a) Compare Faces I and II with the objective emotion.

b) Check (√) the small circle next to the better matching face.

7) Generate new designs.

a) In Sector III, write the eyes number of Face I and the mouth letter of Face II.

b) In Sector IV, write the eyes number of Face II and the mouth letter of Face I.

c) Draw the corresponding faces in each sector.

8) Select the better design.

a) Compare Faces III and IV with the objective emotion.

b) Check (√) the small circle next to the better matching face.

9) Select the best design from your image card set.

a) Compare the checked faces with the objective emotion.

b) Add a second check (√√) in the small circle next to the better matching face.

c) **This is the best design that your image card set has produced.**

II. As a Group, Generate a New, Improved Design to Better Fit the Objective

1) **Evolve a new design from the group's completed Design Cards.**

From the completed Design Cards of any two players, one person in the group records both double-checked designs on one of the enlarged Design Cards, where all can see, as follows:

a) In Sector I, write the eyes number and the mouth letter of the first double-checked design.

b) In Sector II, write the eyes number and the mouth letter of the second double-checked design.

c) Draw the corresponding faces in each sector.

2) Select the better design.

a) Compare Faces I and II with the objective emotion. The whole group can vote on which design is better.

b) Check (√) the small circle next to the better matching face.

3) Evolve new designs.

a) In Sector III, write the eyes number of Face I and the mouth letter of Face II.

b) In Sector IV, write the eyes number of Face II and the mouth letter of Face I.

c) Draw the corresponding faces in each sector.

4) Select the better design.

a) The group can compare Faces III and IV with the objective emotion and vote on which is better.

b) Check (√) the small circle next to the better matching face.

5) Select the best design of these image card sets.

a) As a group, compare the checked faces with the objective emotion and vote on which is a better match.

b) Add a second check (√√) in the small circle next to the better matching face.

c) **This is the best design evolved from multiple Image Card sets.**

6) **Repeat Part II, Steps 1 through 5** with the two remaining players in the group. If there is only a single player remaining, enter only the player's double checked selection, draw it and check it.

7) **Evolve the group's optimum match to the design objective from its card deck.**

With the third Design Card, summarize the previous two Design Cards in the same way and, as a group, vote to select the optimum design.

III. Evolve the Best Design for the Class

1) **The teacher draws a Design Card on the board.**

2) **Evolve the better of two groups' designs.**

Using an overhead projector (if available), and the final best Design Cards from any two of the groups, repeat Part II to evolve the better design. The whole class can vote on which designs are better.

3) **Evolve the better of another two groups' designs.**

Repeat Step 2 with another two groups' best designs.

4) **Evolve the best design.**

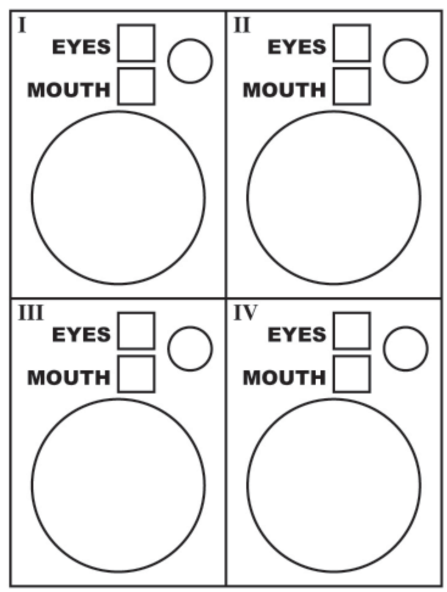
Continue in this way evolving better designs until all groups' designs have been "tested" and the single optimum match to the design objective has been found.

IV. Choose Another Design Objective

Choose another design objective with a different feeling or emotion and you can evolve a totally new and different result.

Find Out More

The Space Technology 5 mission is part of NASA's New Millennium Program, whose job it is to find and test out in space the new technologies that will be needed in future space missions. For more about artificial evolution, see http://ic.arc.nasa.gov/projects/esg. For more about Space Technology 5, see http://nmp.nasa.gov/st5. For an animation that helps explain how ST5's antennas send pictures through space, go to http://spaceplace.nasa.gov/en/kids/st5xband/st5xband.shtml.



Design Card

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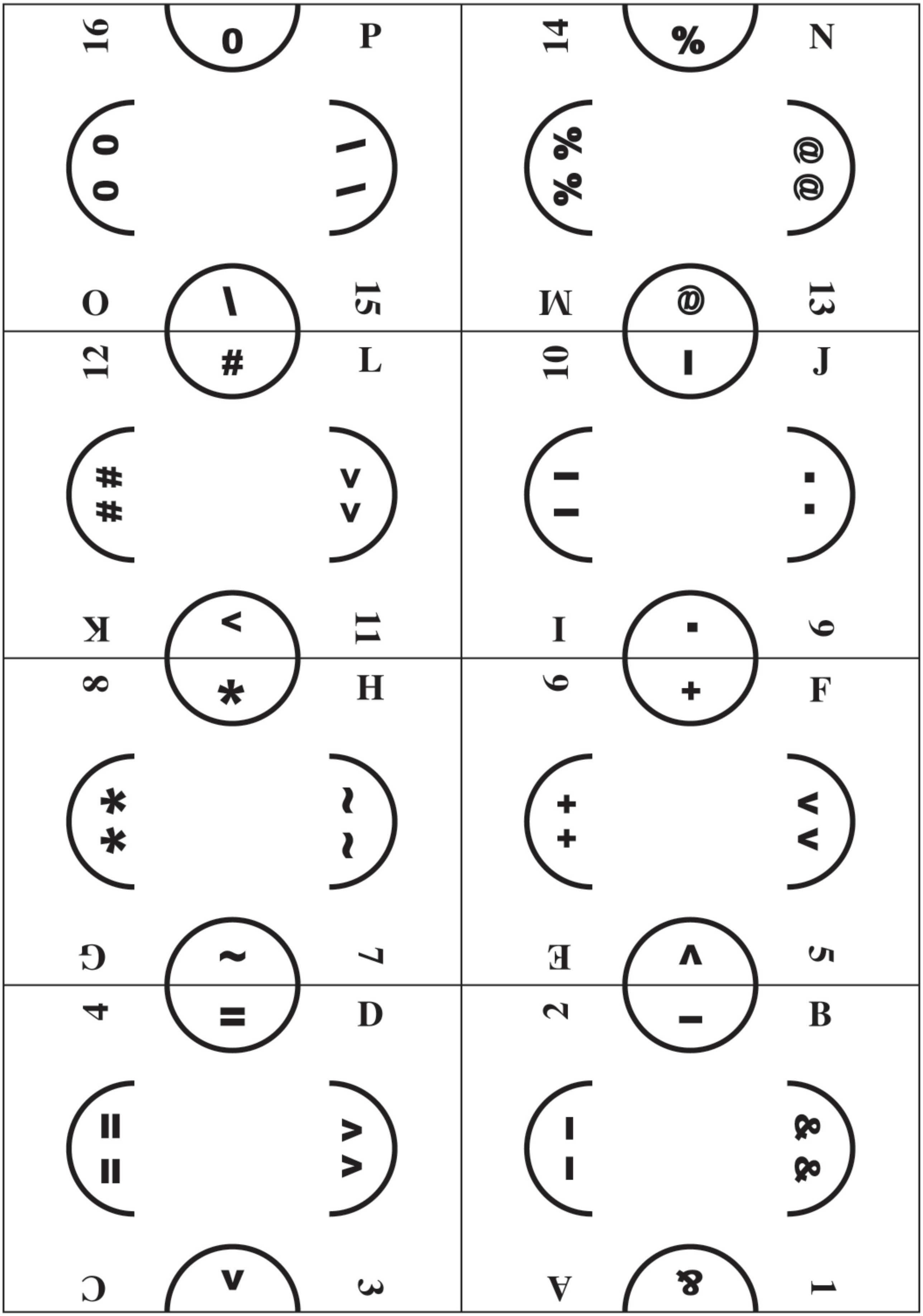
16 P O 15
14 N M 13
12 L K 11
10 J I 9
8 H G 7
6 F E 5
4 D C 3
2 B A 1