My Dear Darwin,

[sound of paper being screwed up]

Dear Sir,

[sound of paper being screwed up]

Dear Darwin,

After being exposed to your work for many years (indeed, all my adult life) I now feel compelled to write this letter to you. I have heard of your prodigious letter-writing to colleagues all over the world and since we live at locations quite inconvenient to each other, I fear we will never meet. Nevertheless, there are a series of strange co-incidences that lead me to feel close to you, metaphorically if not physically. One such co-incidence is the fact that my research laboratory at University College London lies just a few paces from your one-time home in London, on Gower Street. Forgive us, but we have since converted the building into a large lecture hall which we named "The Darwin Lecture Theatre" after you.

Another such co-incidence is a mutual acquaintance – Charles Babbage. I believe you have corresponded with Babbage and benefited from his 1837 book "The Ninth Bridgewater Treatise" in which he quoted Herschel's letter. One passage from this letter which caught your attention referred to the introduction of new species as "the mystery of mysteries" and that we should search for "intermediate causes" to explain these introductions. I know that you were so affected by this passage that you refer directly to it in the opening paragraph of "The Origin of Species." You said that your discoveries during your voyage aboard H.M.S. Beagle,

"…seemed … to throw some light on the origin of species – that mystery of mysteries, as it has been called by one of our greatest philosophers."

How fascinating to see how you were able to develop these ideas, and how Babbage – despite clearly also influenced by the same notions – remained embroiled in Natural

Theology. But while Babbage may not have understood evolution, his ideas relating to mechanical devices should be considered visionary, I believe. As you may have heard, Babbage spent many a fortune in his attempts to construct what he terms a Difference Engine. This remarkable machine (which I think will never be completed, for its costs seem tremendous) has some surprising properties that form the focus of my own scientific research.

But now I find myself almost at a loss for words. Our worlds are so far apart, it would seem. You may regard the rest of this letter as some flight of fancy dreamed up from the mind of Jules Verne, or one of the "Anticipations" of his successor, H. G. Wells. All I can tell you is that my words will be the truth, as bizarre and unlikely as you may find them.

In my laboratory we use machines that automatically perform high-speed mathematical calculations. We call these machines *computers* – and they behave in much the way that Babbage attempted in his mechanical designs for the Analytic Engine (which he intended to supersede his Difference Engine). But our computers are not mechanical. We make them calculate by passing electricity through carefully shaped, microscopic pieces of silicon. By this method we have computers that calculate anything you wish at unthinkably fast speeds. And while Babbage's Analytic Engine would fill a large hall with its convoluted mechanisms and steam power, we have electronic computers so small that they fit in your hand as snugly as a pack of cards.

As you might imagine, these computers are extremely useful devices and are now becoming employed for almost every conceivable task – handling our money, routing our telephone calls, analysing scientific data, controlling our factories. But now I return to the main reason why I feel so compelled to correspond with you. We also use computers for evolution.

I imagine you scoffing as you read this. How can a machine evolve? Even a very clever machine cannot breed with another, nor can it have children, nor could the "baby computers" grow and develop into adults. But now I must ask you to think in a new way. I suggest to you that living organisms are built from *information*. The reason why a living creature can develop from a single cell to a complex adult organism is because of the information contained in that single cell (and in every one of its

developing cells). I suggest to you that your process of evolution composes that information, fine-tuning the instructions held within the cells of life over countless generations. My parents mixed their information together and passed a new shuffled set of instructions to me. Sometimes mistakes are made and a child may have its own unique fragment of information – for example, I gained an extra tooth compared to my parents. Natural selection takes place, meaning that those organisms with better information (which has made them more successful) are able to pass on their information to their children. So I will pass on my information to my children if I survive long enough and they may gain my extra tooth as well. Those with worse information embedded inside their cells are less successful and less able to pass on their information. And so life evolves.

We like to call this information "genes" (fragments of a specific kind of molecule). But I am not concerned with the names or chemistry. What is important to a computer scientist like me is the information. Why? Because we can represent all information as numbers, and we have electronic computers that are designed to do nothing but process numbers at high speed.

Perhaps you see the path down which I am trying to lead you. If evolution of life is really evolution of information, and we have machines designed to process information, then can we have evolution of information in our machines?

The answer is a resounding yes. We can create information within the virtual universes of our computers. Populations of information. We can create an environment in which this information is judged. Each individual packet of information can be assigned a fitness score corresponding to how well it survives its virtual environment. Then the fitter individuals can mix their information and produce offspring that inherit their parents' information. Generation by generation, the individual packets of information can be evolved until they are able to survive their environments using weird and wonderful methods. Our computers can evolve information.

We like to call this process a genetic algorithm, but the name is not important. What is significant is that the same process of natural selection that you describe in the Origin of Species can happen in another universe. In the universe of numbers created in the mind of a machine. We can evolve information for specific purposes just as you might selectively breed your pigeons to achieve certain features. We can evolve better wings

for passenger vehicles or fans for combustion engines. We can evolve better ways to trade or handle our financial markets. We can evolve new ways to detect fraud, better schedules and timetimes. We can evolve art and music that is indistinguishable from that composed by the human mind. We can even evolve new designs for computers.

I know all this is true, because I have used my computer to evolve many such designs. I have evolved the electronic brains for bug robots (looking like giant mechanical lady birds). They were then able to navigate through mazes, learning the route like living organisms. I have evolved strategies for insurance fraud detection in collaboration with some of our major banks. Sometimes I would play music to the audiences of my seminars and then challenge them: "could you tell which song was composed by a human and which was evolved by my computer?" They could never tell them apart! Even some of my furniture at home was evolved by my computer. I think I am the only person in the world with an evolved coffee table.

The amazing thing is not that computers can enable evolution. What amazes us is how effectively computer-evolution solves every problem we throw at it. I have genetic algorithms evolving designs that are not just better than anything I could create – they are beyond my understanding. Like the designs of life, which are so convoluted that we struggle to unravel their mechanisms, designs evolved by computer can also be astonishingly diverse, complex and creative. On several occasions our computers have evolved designs that should not function, according to our current mathematical understandings… but they work even better than our human designs. So we now use computer-evolution as our tutors. We find that it is possible to create entire virtual universes with the same Laws of Physics as our own, and enable evolution of new autonomous virtual organisms, new species, predator, prey, flora and fauna. We use them to learn more about the process of evolution, about how and why complex life arises without guidance or direction from a higher being. We have swimming, running and slithering virtual organisms living and evolving inside our computers, and they are wonderful to watch!

But I know you are a practical scientist not a mathematician, so I feel I should mention our most recent research. Not all evolved designs remain in the virtual worlds of our computers. In our laboratories we now have machines called Three-Dimensional Printers. Imagine, if you will, gluing sheet upon sheet of paper until you have a solid block of wood. Now imagine that you cut each sheet of paper into a specific shape

before gluing them – you could create almost any three-dimensional form you wished by accumulating it layer by layer in this way. Our Three-Dimensional Printers work like this, except that they do it all automatically and they can print in almost any material – including metal. What this means is that any form we might evolve in the mind of a computer can now be directly printed into reality. We're still developing these ideas, but the first physical evolved robots (mechanical automata) have been created. One day we hope to evolve real physical artificial life, that can assemble itself, repair itself and breed. We are not looking for godhood, no – we are trying to make technology that is as adaptive and friendly to us as the animals and crops we have artificially bred to complement the human world. We'd like living, evolving technology that will wish to work with us, instead of inanimate tools that prefer to break or fail under pressure and care nothing for the repercussions of their stupidity. We'd like technology with a desire (built into it by evolution) to help us and take care of us. When that happens evolution will once again be as fundamental to human existence as it was for the previous millions of years as it shaped us.

Like you, my friend, I have devoted much of my scientific career to studying evolution. Perhaps we are worlds apart in more than one sense, but I hope you can see that although our methods and tools are very different, we share a similar fascination with the process of evolution and its results. To end, let me share with you a habit of mine. In each of my books I like to write the following:

"and finally I would like to thank the cruel and indifferent, yet astonishingly creative process of evolution for providing the inspiration for all of my work. Long may it continue to do so."

Yours sincerely,

Peter J. Bentley.