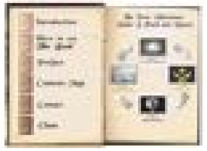
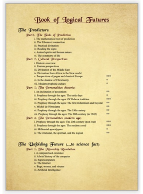
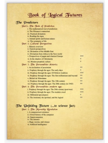
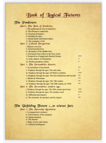
  

The Unfolding Future (...to science fact)

Sub-chapter	Section	Subject Matter	People
Part 1: The Microchip Revolution	*i. A computerised existence*	A brief description of the vital role that modern computers play in virtually every facet of civilisation ● The crucial role of computers in space exploration & understanding our place in the universe ● The diversification of modern computer science & its irreplaceable role in human development	

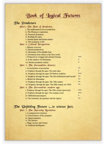


Part 1: The Microchip Revolution *(…continued)*	*ii. A brief history of the computer*	Definition & origins of the computer ● Pre-industrial machines: a perceptual progression (from the '*Codex Madrid'* to the *'Stepped Reckoner'*) ● Significant inventions & developments in the 19th century (from the '*Arithometer*' to mechanical tabulation ● 20th century pre-war breakthroughs (from the '*Differential Analyser'* to the *'Z1'*) ● Binary computing, pulse code modulation & the birth of digital communications ● Pioneering computers, wartime code-breakers & the first 'stored programs' (from the '*ABC'* to *'RAM'*) ● 1950s computing (from '*UNIVAC*' to the integrated circuit) ● The 1960s global electronics industry (from LEDs to '*UNIX*') ● '***Intel***' & the revolutionary concept of a 'universal microprocessor' ● …Heralding an age of the 'personal computer' (from the *'Altair 8800* to the '*IBM PC*') ● The creation of '*Silicon Valley*' & its global influence ● '***Microsoft***' & the marketing masterstroke of the '*Windows*' operating system ● The rapid integration of computer technology in our daily lives in the early 21st century	**Leonardo da Vinci |John Napier | Edmund Gunter | William Oughtred | Wilhelm Schickard | Blaise Pascal | Gottfried Leibniz | Charles Thomas de Colmar | Charles Babbage | George Boole | Dorr E. Felt | William S. Burroughs | Herman Hollerith | Ambrose Fleming | Lee de Forest | Percy Ludgate | Manson Benedict | Thomas J. Watson Sr. | Vannevar Bush | Alan Turing | Konrad Zuse | John Backus | Grace Hopper | Thomas Kurtz | Brian Kernighan | Claude Shannon | Alec Reeves | John Vincent Atanasoff | Clifford Berry | George Stibitz | Max Newman | Thomas Flowers | Howard Aiken | John W. Mauchley | John Presper Eckert | Maurice Wilkes | John von Neumann | Thomas Kilburn | Frederick C. Williams | Walter Brattain | John Bardeen | William Shockley | Geoffrey Dummer | Thomas J. Watson Jr. | Gordon Teal | Jack Kilby | Robert Noyce | Nicholas Holonyak Jr. | George Heilmeier | Douglas Engelbart | Jerry D. Merryman | James H. Van Tassel | Andrew Bobeck | Ken Thompson | Dennis Ritchie | Marcian E. Hoff | Gordon Moore | Edward Roberts | Steve Wozniak | Steve Jobs | Paul Allen | William Gates | Alan Shugart**
	iii. Supercomputers	The rapid development of supercomputers & their importance to society (from the '*IBM 704'* to the *'AI Research Supercluster'*) ● Novel innovations for high performance computers & the world of quantum computing	**Gene Amdahl | Seymour Cray | Tom Kilburn | Jonathan A. Jones | Michele Mosca**



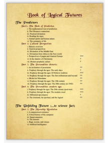
Part 1: The Microchip Revolution *(…continued)*	*iv. The Internet*	An introduction to the Internet & its origin: the development of '*ARPAnet*' ● The beginnings of electronic mail & the emergence of client-server networks (from '*SNGMSG*' to '*USEnet*') ● Peer to peer communication: TCP/IP & the development of the World Wide Web ● Expansion of the WWW: the introduction of HTTP & the first browsers ● From the rise of '*AOL*' to the development of open-source software ● Search engines & plug-ins (from "*Yahoo!*' to '*Macromedia*') ● The Internet at the turn of the 21st century & its continued rapid expansion (a dynamic reflection of humanity)	**Lawrence G. Roberts | Leonard Kleinrock | Ray Tomlinson | Vinton G. Cerf | Robert Metcalfe | Robert Kahn | Paul Mockapetris | Jon Postel | Timothy Berners-Lee | Theodore Nelson | Paul Lindner | Mark McCahill | Marc Andreessen | Jeffrey Wilkins | Steve Case | James H. Clark | Linus Torvalds | David Filo | Jerry Yang | Louis Monier | Larry Page | Sergey Brin | James Gosling | Jonathan Gay**
	v. Bugs, worms, and viruses	The importance of '***CERT***' & the discovery of some notable bugs (the '*Mark II moth*' and '*Y2K*') ● The concept of computer hacking & early hacking groups ● A definition of computer worms & viruses as distinct forms of *malware* ● A brief history of computer viruses (from '*Brain*' to '*Michelangelo*') ● Worms, zombie computers & DoS attacks ● Trojan Horses, macro-viruses & hybrids (from the '*Love Bug*' to '*MyDoom*') ● Novel malware & the challenges of network security (from rogue security software to 'cryptographic encryption')	**Grace Hopper | Clifford Stoll | Fred Cohen**

Part 1: The Microchip Revolution *(…continued)*	*vi. Artificial intelligence*	The state of AI research at the turn of the 21st century & the importance of 'pattern-matching' algorithms ● A short history of artificial intelligence (from the birth of the '*Turing test*' to '*Natachata*') ● Artificial intelligence & human learning (from '*Moore's Law*' to *chatbots*) ● A short history of artificial neural networks & the development of biocomputers (from *cyborgs* to *bimolecular nanocomputers*) ● The extent of specialised AI in modern everyday life ● Artificial general intelligence ● A warning from the realms of science fiction & the prospect of *artificial consciousness* ● The moral dilemmas of creating sentient machines	**James Auger | Guang-Zhong Yang | Alan Turing | Kurt Gödel | Noam Chomsky | Roger Penrose | John Searle | John McCarthy | Irving J. Good | Marvin Minsky | Richard Karp | Joseph Weizenbaum | Richard Stallman | W. Daniel Hillis | Stevan Harnad | Simon Luttrell | Garry Kasparov | Warren McCulloch | Walter Pitts | Frank Rosenblatt | John Hopfield | Terrence Sejnowski | David Willshaw | Willian Ditto | Charles Bennett | Edward Fredkin | Stephen Wolfram | Leonard Adleman | Ehud Shapiro | Arthur C. Clarke | Ray Bradbury | Isaac Asimov**
	Footnote	Moore's Law	**Gordon Moore**
Part 2: Genetic Engineering	*i. A tailored existence*	Genetics as a dynamic field of scientific investigation: understanding genes, manipulating genomes & exploiting DNA (from GM crops to the ownership of information)	

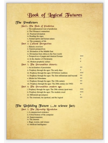


Part 2: Genetic Engineering *(…continued)*	*ii. A brief history of genetics*	*Genealogy* & the dated belief of mixed heredity ● The momentous work of Mendel: segregating hybrids of the common pea ● 19th century biochemistry (from the discovery of cytoplasm to establishing cell composition) ● *'Mendelian genetics'* in the 20th century: inherent traits & dominant genes ● Identifying the roles of DNA and RNA & determining the structures of long chain protein molecules ● From the discovery of *plasmids* & gene mutation to deciphering the complexities of chromosomal division ● From mapping genomes to isolating individual genes: the beginnings of genetic engineering ● The value of *PCR*: from designing synthetic genes & manipulating recombinant DNA to *gene therapy* & creating *clones* ● Further advancements in gene research (from decoding worms to sequencing humans)	**Theodor Schwann | John Goodsir | Rudolf Virchow | Gregor Johann Mendel | Friedrich Miescher | Walther Flemming | August Weismann | Richard Altmann | Oskar Hertwig | Edmund Wilson | Hugo de Vries | Carl Franz Correns | Erich Tschermak von Seysenegg | Walter Sutton | William Bateson | Wilhelm Johannsen | Thomas Hunt Morgan | Phoebus Levene | Fred Griffith | Oswald Avery | Colin McLeod | Erwin Chargaff | William Lawrence Bragg | William Astbury | Linus Pauling | Murray Barr | Joshua Lederberg | Hermann Muller |George Beadle | Rosalind Franklin | Raymond Gosling | Maurice Wilkins | James Watson |Francis Crick | John Griffith | Paul Zamecnik |Mahlon Hoagland | Sydney Brenner | François Jacob | Jacques Monod | André Lwoff | Severo Ochoa | Robert William Holley | Marshall Nirenberg | Werner Arber | Jonathan Beckwith | James Shapiro | Max Delbrück | Alfred Day Hershey | Salvador Luria | Paul Berg | Herbert W. Boyer | Stanley Cohen | Har Gobind Khorana | William French Anderson | Robert Briggs | Thomas King | John Gurdon | Fredrick Sanger | Walter Gilbert | Kary Banks Mullis | Jack W. Szostak | Alec Jeffreys | Hamilton Smith | J. Craig Venter | Robert Waterston | John Sulston**

Part 2: Genetic Engineering *(...continued)*	*iii. Agricultural genetics*	The fragile state of world agriculture & the almost limitless advantages of genetically modified crops ● Licensing & marketing GM produce in the US during the late 20th century (from tobacco to soya) ● The invaluable uses & irreversible dangers of transgenic coding (from effective pesticides to the creation of 'superbugs') ● From hybridisation & the interdependence of life to cross-pollination' & toxic side-effects ● The importance of GM crops to China & other developing agricultures ● Corporate monopolies & the '*terminator gene*'	
		The cloning of mammals & the announcement of '*Dolly*' the sheep ● Improving techniques & success rates (from pigs to primates) ● Commercial animal cloning ● Ecological genetics: reanimating extinct species & saving endangered ones (from the moa to the gaur) ● Preserving the ecological integrity of our planet ● the '***Millennium Seed Bank'***	**Karl Illmensee | Davor Solter | Neal First | Steen Willadsen | Hans Spemann | Ian Wilmut | Keith Campbell | Mu-Ming Poo**

Part 2: Genetic Engineering *(…continued)*	*iv. Medical genetics*	The gift & the curse of genetic technology ● Genetics in modern medicine: from decoding 'somatotropin' to farming 'factor VIII' ● The '***Human Genome Project***' & the likely consequences of success (from *gene therapy* to personalised drugs)	**John Baxter | Howard Goodman | Roberto Crea | Robert A. Weinberg | Ian Wilmut | Keith Campbell | James Robl | Steven Stice | Francis Collins | John Sulston | J. Craig Venter**
		Genetic screening & in vitro fertilisation (IVF) ● The importance of pre-implantation genetic diagnosis (PGD) ● *Stem cell therapy*: its enormous benefits, its religious detractors & its financial incentives	**Patrick Steptoe | Robert Edwards | Alan Handyside | Irving Weissman | James A. Thomson | John D. Gearhart | Thomas Okarma | Gail Martin**
		The progress of biomolecular science at the turn of the century & the prospect of major advances in gene therapies (from reversing strokes to embryonic twinning) ● Cloning human embryos	**Paul Sanberg | Jerry L. Hall | Robert Stillman | José Cibelli | Kim Seung Bo | Severino Antinori | Panayiotis Zavos | Richard Seed | Brigitte Boisselier**



Part 2: Genetic Engineering *(…continued)*	*v. Moral objections*	The promise of genetic biotechnology & the moral dilemmas it poses ● Genetic barcoding & corporate investment: the political power of the biotech & pharmaceutical industries (from the *Pusztai affair* to transgenic crops)	**Charles Darwin | Francis Galton | J.B.S. Haldane | Aldous Huxley | Árpád Pusztai**
		Xenotransplantation & embryo manipulation ● Transgenic research: engineering proteins & attacking tumours (of mice & men) ● The promise of *gene therapy*: eradicating disease & prolonging the lives of the rich	**Paul Berg | Anne McLaren | Andrzej Tarkowski | Martin Evans | Ina Dobrinski | Steven A. Rosenberg**
		The human fertility industry (from desperate hope to designer offspring) ● Genetics & the idea of utopian existence as a dystopian illusion (from servile citizens to self-fulfilling prophesies)	**Ira Levin**
		Genetic technology & national security (from creating hybrid species to weaponising biological agents) ● Creating the first synthetic virus & the '***Minimum Genome Project***' ● From *M.genitalium* to *D. radiodurans*: the prospect of building life from scratch	**Eckard Wimmer | J. Craig Venter | Albert Libchaber | Karl Stetter | Arthur W. Anderson**

Part 2: Genetic Engineering *(…continued)*	*vi. A brave new world*	Germline engineering & human design ● Our growing ability to manipulate the human genome (from disease prevention to favoured traits) ● wealthy 'prototypes' & the prospect of *super-evolution* ● Genetic discrimination & human self-importance ● Neuromorphology & the rise of DNA-based computers	**Duncan Geddes | William French Anderson | Theodore Friedmann | Adrian Krainer | Luca Cartegni | Mario Capecchi | Vitaly Valtsev**
Part 3: A Technical Ecstasy	*i. Matter over mind*	Mind control: from the '*Transdermal Stimulator*' to '*stimoceivers*' ● Brain-computer interface (BCI) technology & the power of cognitive control (from neuroprosthetic limbs to thought-operated drones) ● *Wireheads*: In hedonistic pursuit of a virtual existence (the emancipation from physical constraints)	**José Delgado | Emanuel Donchin | Jonathan Wolpaw | Niels Birbaumer | Gerwin Schalk | Thilo Hinterberger | John Chapin | Philip Kennedy | Miguel Nicolelis | Andrew Schwartz | Norbert Wiener | William Gibson | Bruce Sterling | Terence McKenna**
	*ii. **Epilogue**: a virtual reality?*	Scientific endeavour: prospecting the long-term future of humanity ● The future of space exploration (and the fanciful idea of human colonisation) put into perspective ● Genetics & cybernetics: the almost endless possibilities of modern technology ● How the march of technology enhances sensory perception (using the sex & gaming industries as prime examples) ● Researching 'thought-controlled video games: the potential therapeutic benefits & recreational value of translating neural activity into computer simulation ● The future of cyber technology: a compelling an wholly immersive virtual world (uploading the human mind) ● A dark vision of a distant future where all that remains of humanity is a computer imprint on a dead planet	**Robert Burke | Klaus-Robert Müller**

Part 1

The Microchip Revolution

"As I have pointed out many times before, the machine is beneficial, and it will be the machine which, in the end, will completely emancipate man."

~ **Hugo Gernsback** *(1902)*

i.
(A computerised existence)

Without the modern computer, civilisation, as we know it, simply could not exist. Mankind's most versatile innovation is responsible for so many things *(essential or otherwise)* that most people take for granted. It lies at the heart of the huge power and telecommunications networks that span the globe, and forms an integral part of everything from air traffic control systems to sophisticated medical equipment. So many facets of society are dependant on specialised computers to manage their affairs. Be it education, public health, civil administration or national defence, all rely heavily on computer technology. Without it, not only would the progress of scientific enquiry be seriously compromised, but the effectiveness of agriculture, industry, and commerce would be greatly reduced. Indeed the world's financial markets would collapse ~ as would the continuing stability of entire nations.

Computers have not only enabled us to communicate with one another on a global scale, but they have helped us immeasurably in our quest to understand the universe beyond our planet and, in turn, 'reason' our own existence. Without the aid of computers, it would have been impossible to have conceived of *(let alone construct, launch and maintain)* technological wonders such as the '***Hubble Space Telescope***' and its successor the '***James Webb Space Telescope',*** which have allowed us to investigate new worlds far beyond our own. In this respect, computer technology is crucial to finding our place in the universe; and perhaps the most vivid example of this concerns our search for life on other planets and moons.

Over the first two decades of the 21st century, no less than nine separate missions to land on Mars were launched; most of which were designed to look for evidence of water or investigate organics on the red planet, with the ultimate aim of discovering whether Martian life has ever existed. Perhaps the most successful of these, ***NASA***'s '***Perseverance'*** rover and its robotic helicopter '***Ingenuity',*** began exploring the red planet in 2021. Of course, our investigation into extraterrestrial worlds and their suitability for life has not just been restricted to Mars. In 2005 ***ESA***'s ***'Huygens'*** probe made a successful 'splat down' on Saturn's largest moon, Titan, whose primeval atmosphere has also generated great interest. Looking ahead; proposals to explore Titan's sister moon Enceladus are afoot, whilst there are even plans to send a craft on the six-year journey to Jupiter's sixth moon Europa, Yet none of this 'universal intrigue' would be possible without the unprecedented development of microchip technology over the past eight decades.

Over recent years, computer science has diversified in specialised fields that deal with everything from *'neural networks'* and *'advanced robotics'*, through '*machine learning'* and '*artificial intelligence'*, to '*optical computing'* and '*quantum processing'*. Aiding the irresistible march of science, the modern computer is effectively an extension of the human mind that has become essential to our continued survival. As we embark on a new century, human endeavour will continue to reflect our irresistible thirst for knowledge, and the computer inevitably lies at the forefront of both scientific research and technological advance. Our curiosity as a thinking species will not rest until every possibility has been exhausted, and only computers have the potential to fulfil that need. Moreover it is to the computer that many see an eventual emancipation of the human race from the suffering of life!

ii.
(A brief history of the computer)

The computer, by definition, is a device that processes data according to a set of instructions to produce a desired logical result. Now widely taken for granted as part of our way of life, the computers of today can perform tasks that lay far beyond the imaginations of the early computing pioneers. Indeed there is no facet of modern life in which computers do not figure in some way or other.

The most distant forerunner of the computer is the *'abacus'* which remained man's most advanced counting apparatus for well over a thousand years. Indeed it was not until the explosion of scientific discovery in Europe that more practical methods of solving mathematical problems were devised. During the 17th century a range of ingenious devices were designed and built to perform basic mathematical calculations. With the onset of 'Industrial Revolution' in the late 18th century came the concept of mechanical automation, and a plethora of ingenious calculating machines appeared over the next hundred years. However the ultimate development of computing science was dependant on the birth of a 20th century industry which would give rise to the *'electronic calculator'* and eventually the *'digital computer'*.

The very first reference to a 'mechanical' calculating machine can be found in a sketch by Italian scientist **'Leonardo da Vinci'** which was drawn in 1502 as part of a set of manuscripts known as ***'Codex Madrid'***. The actual development of mechanical calculators didn't really begin however until Scottish mathematician **'John Napier'** conceived the principle of *'logarithms',* which were first described in his 1614 publication ***'Canonis Descriptio'***. By the time of his death, three years later, Napier had built a number of manual systems designed to carry out various mathematical computations using logarithmic functions. The best known of these was ***'Napier's bones'*** ~ a primitive calculating system which employed a set of carved ivory rods to undertake multiplication and division.

A succession of devices followed throughout this century of mathematical inquisition, including the *'slide rule'*, originally conceived by English mathematicians **'Edmund Gunter'** and **'William Oughtred'** in 1615. In 1623 German astronomer and academic genius **'Wilhelm Schickard'** had designed and built a prototype of the first mechanical calculator. More famous however was the ***'Pascaline'***; a compact device capable of performing addition and subtraction via a series of toothed dials. Devised by French Mathematician and philosopher **'Blaise Pascal'** in 1642, the 'Pascaline' was produced in a relatively large quantity. The early mechanical calculator was further refined in 1672 by German philosopher and mathematician **'Gottfried Leibniz'**, whose ***'Stepped Reckoner'*** could undertake the four basic forms of arithmetic and more.

By the 19th century, practical invention *(largely brought about by industrial growth)* had encouraged the development of ever more sophisticated mechanical calculating devices. The most advanced of these were capable of performing complex mathematical calculations using trigonometric and logarithmic functions. The first notable breakthrough of the century was made in 1820 by French scientist **'Charles Thomas de Colmar'**, whose improved calculating machine, the ***'Arithometer'***, became the first such device to be mass produced. Then there was English mathematician **'Charles Babbage'** who, having designed *(and started to build)* his mechanical ***'Difference Engine'*** in 1822, went on to devise a programmable computing machine that superseded his earlier innovation. Though it was never completed, Babbage's revolutionary ***'Analytical Engine'*** of 1833 was a fully-automated calculating device, the design of which introduced certain concepts that are in use within today's digital technology. It is therefore considered by many to be a forerunner of the digital computer.

Other significant developments of the 19th century included the publication, in 1847, of ***'The Mathematical Analysis of Logic'***, written by English mathematician **'George Boole'**, which lay the foundations of modern mathematical logic. A century later Boole's binary system *('Boolean algebra' as it is known)* would be translated and executed electronically by the modern digital computer. Towards the end of the 19th century a number of **US** patents were issued for a variety of calculating devices, including the recording adding machines of American entrepreneurs **'Dorr E. Felt'** in 1887 and **'William S. Burroughs'** *(grandfather of the famous author)* in 1888. The following year **US** inventor and industrialist **'Herman Hollerith'** had developed the first electronically-driven digital data processor. Hollerith's innovative mechanical *'tabulating system'* could be used to input and store information via a series of punch cards, and became used in various census counts at the turn of the century.

During the 20th century the modern world witnessed an explosion in computing innovation. From the pioneering work of English physicist **'John Ambrose Fleming'** and American inventor **'Lee de Forest'** grew an enormous electronics industry, and from this came a boom in computer science. Early contributors to the science of computing included engineers and physicists such as **'Percy Ludgate'**, **'Manson Benedict'** and **'Thomas J. Watson Sr.'**. Yet it was the work, in 1925, of ***'MIT'*** engineer **'Vannevar Bush'** that really caught the imagination of America's scientific community. Designed to solve differential equations through a series of finely calibrated gearing devices, Bush's ***'Differential Analyser'*** was effectively the first large-scale analogue computer in existence. However by the end of the next decade, these slow and cumbersome decimal machines would be made totally obsolete by the growing reliance on electronic circuitry within computing design.

An intellectual landmark in the development of computer science occurred in 1936 when inspirational English mathematician **'Alan Turing'** published the modern mathematical theory of computing. This in turn led to the idea of the *'universal machine'* which had unlimited programming capabilities. Turing's theoretical breakthrough had an enormous impact on the advance of digital computing, and proved to be the first of several invaluable contributions he would make to the science. Meanwhile, in Germany, construction engineer **'Konrad Zuse'** had built his prototype ***'Z1'*** ~ the world's earliest electromagnetic relay computer. The first in a series of designs, the **Z1** relied on binary arithmetic ~ a concept that was independently developed in the **US** by ***'Bell Telephone Laboratories'*** over the following months. Yet, whilst Zuse would go on to construct a program-controlled digital computer *(the* ***'Z3'****)* five years later, his work remained largely unknown outside of Germany.

As technology improved, digitisation *(pioneered by engineers such as Babbage, Hollerith and Zuse)* became increasingly commonplace in computing design. The digital computer enabled trained operators to process numerical data as opposed to mere physical quantity. Furthermore the ability of machines to translate legible data into binary notation would open up a whole new world of possibilities. Indeed the computers of today would be nowhere near as accessible to the general public if they were unable to execute instructions that could be inputted using everyday characters.

At its most elementary level, binary computing relies on simple switches whose positions are defined as being either '0' *(off)* or '1' *(on)*. The ability to control each switch or 'gate' requires one *'bit'* of information ~ the most basic unit of memory. By combining eight bits of memory *(into what are known as 'bytes')* it is possible to define 256 different operations, each capable of representing a single recognisable character such as a number, letter or punctuation mark. From this fundamental aspect of digital computing, a number of ever more versatile high-level programming languages would be developed in the second half of the century. These included **'John Backus'**s *'****FORTRAN****' (in 1954),* **'Grace Hopper'**s *'****COBOL****' (in 1959)*, **'Thomas Kurtz'**s *'****BASIC*** *(in 1965),* and **'Brian Kernighan'**s *'****C****' (in 1972).* Moreover the establishment of standard coding systems *(or character sets)* such as *'****EBCDIC****'* and *'****ASCII****'* has enabled the creation of vast computer networks that today span the globe.

The concept of complete binary computing was first described back in 1937 in a thesis by **US** mathematician **'Claude Shannon'**. An astute graduate student of Vannevar Bush, Shannon recognised the advantages of applying Boolean logic to electronic circuitry ~ an idea which would have a far-reaching effect on the further development of computer science. At the same time practical digitisation took a great leap forward thanks to the work of English engineer **'Alec Reeves'**. Regarded by many as the *'father of the digital age'*, Reeves was the inventor of ***'Pulse Code Modulation'*** which used binary numbers to represent sound, and laid the basis for modern digital communication.

Another influential figure in the history of computing was American mathematical physicist **'John Vincent Atanasoff'**. Having already developed a practical method of electrical mechanisation, by 1939 Atanasoff designed a prototype of what is regarded by many historians as having been the first fully-electronic digital computer. A leading professor at ***'Iowa State University'***, over the following three years, Atanasoff and accomplished engineering student **'Clifford Berry'** improved on the *'****ABC****' (or* ***'Atanasoff-Berry Computer'****)* which utilised no fewer than 300 vacuum tubes. Meanwhile, in New York, the ability to transmit data in electronic form was demonstrated by American engineer **'George Stibitz'**. A pioneer of networking, Stibitz's ***'Complex Number Calculator'*** connected the central offices of Bell Laboratories from 1940.

Back in Britain, a nation now deeply engaged in the growing global conflict, radio and computing technologies were directed towards intercepting and deciphering German messages. Naturally this highly sensitive operation involved the pre-eminent logician Alan Turing who was instrumental in perfecting ***'Colossus'*** ~ Britain's first freely programmable all-electronic computer. Constructed at ***'Bletchley Park'*** *(the centre of allied intelligence during the 'second world war')* and completed by late 1943, Colossus was a massive 1500-valve electronic code-breaking machine conceived by engineering professor **'Max Newman'** and primarily designed by cryptographer **'Thomas Flowers'**.

Over the next couple of years computing science in the United States was also largely concentrated on the war effort. The progress of digital relay computers, for example, was further enhanced at ***'Harvard University'*** in 1944 when physicist and electrical engineer **Howard Aiken'** and his team *(including gifted mathematician Grace Hopper)* constructed the five-ton ***'Automatic Sequence Control Calculator'***. Designed to compute navigational tables for the **US** Navy, '**ASCC**' *(or the **'Mark 1'** system as it became better known)* was a fully automatic electromechanical calculator that contained over ¾ million separate components. This was surpassed, in late 1945, by the completion of a massive all-electronic digital computer named ***'ENIAC'*** *(an acronym for **'Electronic Numerical Integrator and Computer'**).* **ENIAC** was originally developed by engineers **'John W. Mauchley'** and **'John Presper Eckert'** at the ***'University of Pennsylvania'*** to calculate ballistic tables for the **US** Army. Unveiled the following year, this enormous thirty-ton machine employed thermionic valves rather than motorised switches and was unrivalled in the speed at which it could process data. Indeed it contained nearly 18,000 vacuum tubes, as well as many more thousands of resistors, capacitors and relays.

All of these early machines are generally considered today as being 'glorified calculators' rather than 'true computers' because they were incapable of storing programs, and most relied on a continuous feed of paper tape to execute instructions. It was not until the late 1940's that real efforts were made in Britain and the **US** to design computers that were capable of storing programs within their own memories. Early examples included **'Maurice Wilkes'** ***'EDSAC'*** , **'John von Neumann'**s ***'EDVAC'*** as well as Mauchley and Eckert's ***'BINAC'*** ~ all of which were originally conceived shortly after the war. The very first fully-functional 'stored-programme' machine however was demonstrated in Britain at ***'Manchester University'***s Department of Electrical Engineering. Designed and built in 1948 by engineering professors **'Thomas Kilburn'** and **'Frederic C. Williams'**, the ***'Small Scale Experimental Machine'*** *(affectionately known as **'The Baby'**)* utilised a new type of valve *(the **'Williams Tube'**)* which provided a means of data storage. This important development meant that The Baby was the first machine that did not have to be tediously rewired every time a new program was installed.

As the first device to incorporate *'random access memory'* was being built in Britain, in the **US** in the same year, the field of electronics was completely revolutionised by Bell physicists **'Walter Brattain'** and **'John Bardeen'**. Under the unmerited guidance of English-born American engineer **'William Shockley'**, the work of Brattain and

Bardeen lay the foundations for the modern electronics industry. Their *'point-contact transistor'* was a solid-state electronic component which greatly modified digital circuits by using semiconducting materials to switch and modulate the current passing through it. The speed, versatility, reliability and compactness of the transistor gave rise to a new generation of computer and telecommunication systems, and resigned the vacuum tube to history.

Up until the 1970's computers were, for the most part, perceived to be specialist tools. They were generally built either to undertake scientific calculations for research establishments and educational institutions, or to process data for government departments and large industrial corporations. In 1951, for example, America's earliest commercially-available computing system, *'UNIVAC' (or the* ***'Universal Automatic Computer')***, was first purchased by the ***'US Census Bureau'.*** Marketed by the ***'Remington Rand Corporation'***, the huge initial cost of developing this advanced 'all-purpose' machine *(designed by Mauchley and Eckert')* proved fatal to its continued production. However **UNIVAC** became a household name in the States the following year when the ***'CBS Network'*** successfully used it to predict the result of the unfolding presidential election.

1952 was a defining year in the advance of modern computer technology. America's foremost computer programmer, Grace Hopper, described the idea of *'reusable software'*; inspiring new research into automatic programming. The year also witnessed the completion of *'MANIAC I'* ~ the first computer to use a *'flexible stored program'*; originally conceived by Hungarian-born **US** mathematician John von Neumann seven years earlier. Meanwhile, in England, the idea of an *'integrated circuit' (the essential precursor of the 'silicon chip')* was proposed by visionary radar technician **'Geoffrey Dunner'**, although it would be a further six years before this important stride in electrical engineering was actually taken.

In 1953 ***'International Business Machines'*** entered the computer market with the release of their comparatively successful *'IBM 701'* at the behest of influential executive **'Thomas J. Watson Jr**.', Market leaders in sales of punch card tabulators and adding machines, **IBM** would go on to become the largest manufacturer and distributor of computers on Earth. As far as significant breakthroughs in hardware technology were concerned, the following year saw electronics engineer **'Gordon Teal'** develop the first *'silicon-based transistor'* for ***'Texas Instruments'***; a company that also lay claim to developing the first fully-integrated circuit in 1958. However whilst Texas engineer **'Jack Kilby'** was working on his germanium-based design, entrepreneurial inventor **'Robert Noyce'** was simultaneously developing a silicon-based integrated circuit for the ***'Fairchild Semiconductor Corporation'***. The competitive world of microelectronics had begun.

By the 1960's the global electronics industry was primarily led by huge American corporations such as Bell, **IBM**, and *'DEC'*, but it was much smaller things that began to drive computer technology forward. In terms of electronics, the face of modern computing would change dramatically with the development of the ***'LED'*** *(light emitting diode)* by **'Nicholas Holonyak Jr**.' at ***'General Electrics'*** in 1962, and the ***'LCD'*** *(liquid-crystal display)* by **'George Heilmeier'** and his team at

'RCA' two years later. 1964 also saw pioneering engineer and programmer **'Douglas Engelbart'** take important steps towards the development of the familiar user-friendly machines of today. Engelbart's *'X-Y position indicator' (or 'computer mouse')* was just one of many significant breakthroughs in hardware technology during the 60's. Indeed advancement of the integrated circuit had led to *(amongst other things)* the invention, in 1967, of the hand-held electronic calculator; a four-function device developed by Jack Kilby, **'Jerry D. Merryman'** and **'James H. Van Tassel'** at Texas Instruments. At around the same time, scientist **'Andrew Bobeck'** and his team at Bell Laboratories developed *'bubble memory'* which allowed computers, for the first time, to store large quantities of information when switched off.

Whilst bubble memories would eventually be made obsolete by the more powerful magnetic hard disks, the latter half of the decade also witnessed several advances in software technology which were somewhat more enduring. In 1968, for example, a number of Engelbart's novel inventions were publicly demonstrated for the first time, including the original ***'Windows'*** operating system, and *'**NLS**'* ~ the very first form of *'hypermedia'* software. Another momentous breakthrough in software engineering during the late 60's was the creation of *'**UNIX**'*; a versatile *'multitask'* operating system formulated by Bell scientists **'Ken Thompson'** and **'Dennis Ritchie'** in 1968.

Although the 1960's was a momentous time for advances in modern computing, over the following decade the electronics industry would elevate the science to even greater status within the public eye. By the start of the 1970's technology had advanced enough for a plethora of mostly American and Japanese companies to start marketing a variety of mesmerising electronic gadgets. Yet, whilst the integrated circuit enabled the mass production of useful curiosities such as pocket calculators and digital watches, the invention of the *'microprocessor'* in 1971 took computing to a whole new level.

Designed and built by engineer **'Marcian E. Hoff'** and his team at Robert Noyce and **'Gordon Moore'**s newly founded ***'Intel Corporation'***, the revolutionary ***'Intel 4004'*** microprocessor was originally intended to improve upon the specifications of contemporary electronic calculators. However the ability to combine all the components of a central processing unit into a single integrated circuit had enormous implications for the future of microcomputers. Comprising 2300 metal oxide transistors and operating at a frequency of 108**KHz**, Intel's 4-bit *'universal microprocessor'* was unrivalled in its operating speed and capacity. Indeed the invention of Hoff's so-called *'processor on a chip'* meant that the same computing power of the room-sized **ENIAC** system could now be contained on a slice of silicon that was as small as a baby's fingernail.

The microchip was a truly revolutionary concept that would have a profound effect on everyday life over the following decades. By the turn of the century, 64-bit technology would give rise to microprocessors that contained many millions of minute transistors. Notable examples include the ***'PA-8000'*** *(from 1995)*, the '***AMD-K6E***' *(1998),* and the ***'Pentium 4'*** *(from 2000)*; a later version of which boasted clock speed of 3.2**GHz** *(i.e.; it could read 3.2 billion instructions every second)*.

The age of the microcomputer really began in 1975 with the launching, in America, of the first commercially successful personal computer. Sold in kit form, the ***'Altair 8800'*** was developed by engineer **'Edward Roberts'** and his team at the fledgling electronics company *'MITS'*. Though primitive in design, the 'Altair 8800' came complete with Intel's new 8-bit microprocessor and a 256 byte **RAM** card. The enormous popularity of this machine proved there to be a huge demand for comparatively cheap consumer computers, thus encouraging many other companies to enter the market. By 1977 the first fully-assembled personal computer, the ***'Apple II'***, was unveiled by entrepreneurial Californian engineers **'Steve Wozniak'** and **'Steve Jobs'**. Come the end of the decade, the most popular rival systems in America included models such as the ***'Commodore PET'***, and ***'Tandy Radio Shack'***s ***'TRS-80'*** *(both 1977)*, whilst in Britain the face of home computing was exemplified by units such as the ***'Sinclair MK-14'*** *(1978)*, and the ***'Acorn Atom'*** *(1979)*.

By the early 1980's computers designed for home and school use had begun to proliferate throughout the Europe, Japan, and the **US**. The most popular British systems of the time included Acorn's *'BBC' (from 1981)* and the *'Amstrad CPC 464' (from 1984)*, whilst in America the ***'Apple Mackintosh'*** and the ***'Commodore 64'*** *(both launched in 1984)* would become market leaders. However it was successful launch of the *'IBM PC'* in 1981 that provided the true benchmark for subsequent microcomputers of its generation.

Although initially slow to realise the huge commercial potential of home computing, **IBM**'s marketing strategy was ingenious. Their pioneering personal computer was constructed using various components that were produced by independent companies that now had a vested interest in its success. The original **IBM PC** came complete with a 4.7**MHz** ***'Intel 8088'*** microprocessor *(which was first introduced by Intel seven years earlier)*, and was installed with its own 16-bit 'disc operating system'. Named ***'MS-DOS'***, this versatile language was compiled by experienced programming engineers **'Paul Allen'** and **'William Gates'** whose fledgling ***'Microsoft Corporation'*** had been specially commissioned for the purpose. Besides this, **IBM**'s groundbreaking **PC** was equipped with an *(optional)* colour monitor and external *'floppy disk'* drive *(which had been developed by **IBM** engineer **'Alan Shugart'** ten years earlier)*. **IBM** had effectively brought corporate engineering into the domain of the private consumer, and their product invariably spawned a large number of *'clones'* and **PC**-compatible machines.

The digital computer has become a comparatively cheap mass-marketed commodity, and the computer industry the most profitable in history. Indeed nearly every nation on Earth has its own hub of 'computer commerce'. From Pinang in Malaysia to Bari, Italy, and from Bangalore, India to the '**M4** corridor' in England; the manufacturing and distribution of computers brought mass employment and great prosperity. Yet American predominance in the field has continued, and the world market is dominated by firms based in *'Silicon Valley'*, in the Southern Californian county of Santa Clara. Here lies the heart of the global microelectronics industry, and home to the world's most powerful computer and software corporations; including **HP**, Intel, and Apple.

It is the accomplishments of the Seattle-based Microsoft Corporation, however, that best exemplified the industry's unparalleled success. The development of the multitasking ***'Microsoft Windows'*** operating system in 1983 would prove to be a marketing masterstroke. Providing the users of **PC**-compatible machines with a *'graphical user interface' (a display format with icons, graphics and menu bars)*, Microsoft Windows offered millions of private consumers direct visual interaction with their computers. Although it was not the first operating system to incorporate a **GUI** environment *(Xerox, Apple, and **'VisiCorp'** had all developed their own such systems)*, it was the first to successfully run on the back of the universal paradigm that was **MS-DOS**.

Despite being snubbed by the makers of the **IBM PC**, and closely resembling the features the Apple Mackintosh *(a cause of much acrimony between the two companies over the years)*, Microsoft Windows version 1.0 was finally shipped in 1985. Whilst the system was rather crude by today's standards, its successors *(in particular 'Windows 3.0' and 'Windows 95')* further maturated the mainstream marketing of microcomputers and effectively revolutionised Western culture. At the centre of this prodigious international corporation stood its chairman and chief executive 'Bill' Gates, who had begun his career, just ten years earlier, by formulating a new version of the **BASIC** language for the Altair 8800. A cunning and highly competitive leader, by the end of the 20th century, Gates' sharp business acumen had made him *(materially)* the wealthiest man in the Western World, and Microsoft the single largest software concern on the planet.

As the new century dawned, the popularity of personal computers skyrocketed as they became more portable and, over the following decades, desktop and laptop systems were increasingly supplanted by touch-screen tablets, smart phones, and wearable computers. With multi-core **CPU**s becoming commercially available, storage, memory and visual display improved dramatically as well, and, as Internet connections became faster and more reliable, so everything from shopping to dating was revolutionised.

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iii.
(Supercomputers)

Once divided into four separate classes, the modern digital computer is evolving so rapidly that it fast outmoded orthodox definitions of relative performance. The vast processing capacities of modern **CPU**s, and the increased use of multiple processors in everyday machines, blurred the traditional distinctions between *microcomputers*, *minicomputers*, and many *mainframe* systems. Yet at the cutting-edge of modern technology lies a class of computer that will forever remain distinct. Designed to undertake complex tasks such as predicting long term climatic and environmental change, analysing genetic data or simulating atomic reactions, the high-performance *supercomputers* of today are far removed from the plethora of consumer 'desktop', 'laptop' and 'mobile' microcomputers that surround our public and private lives.

The concept of the modern supercomputer derives from the ever more powerful specialist computers of the 1950's that utilised *'floating-point'* hardware. Dramatically increasing the speed at which mathematical functions could be performed, floating-point technology would eventually form the basis of all later supercomputers. Running at 5000 'floating-point operations per second' *(or '**FLOPS**')*, the first such machine to achieve commercial success was the *'**IBM 704**'* which had primarily been designed by **US** engineer **'Gene Amdahl'** in 1955. Although other systems of similar or greater magnitude soon followed *(including **'Sperry-Rand'**s 'LARC' in 1956, and 'MIT's **'SAGE'** in 1958)*, most were built to undertake specific tasks for government laboratories and military establishments

It was the work of prestigious American design engineer **'Seymour Cray'** that had the greatest impact on high-performance computing, and his name would become synonymous with the development of supercomputers. Cray was a cofounder of the Minnesota-based ***'Control Data Corporation'*** which, in 1960, unveiled the *'**CDC1604**'* ~ the first commercially available fully-transistorised computer. Across the Atlantic meanwhile, a joint venture between ***'Manchester University'*** and ***'Ferranti Ltd**.'* was well under way to construct the most powerful machine yet seen. The first computer to incorporate *'virtual memory'*, ***'Atlas'*** was completed in 1962, six years after the project had been started by its chief architect **'Tom Kilburn'**.

Whilst Atlas had the potential to operate at a hitherto unprecedented speed of 200 *'kiloflops'*, within two years, back in America, Seymour Cray had produced what is considered by many to be the first 'true' supercomputer. Running at a sustainable 350 kiloflops, the ***'CDC 6600'*** had a theoretical peak performance of a staggering 9 *'megaflops' (or nine million floating-point operations per second)*. Although unremarkable by today's standards, the **CDC 6600** marked the beginning of a new generation of high-speed computers. By 1968, its successor, the *'**CDC 7600**'*, had taken the peak operating speed of high-tech computers beyond the 40 megaflops mark, thus starting an accretion in performance that continues to this day.

A notable highlight in the development of modern supercomputers was the introduction, in 1976, of the legendary ***'Cray 1'***, system. With 200,000 integrated circuits vertically stacked in its characteristic 'C-shaped' frame, the Cray 1 was theoretically capable of speeds approaching 160 megaflops. Indeed so intense was the heat generated by this machine that its circuits had to be encased in a freon refrigeration system. Principally designed by Cray, and built by his team at ***'Cray Research'***, the first computer was purchased by the ***'Los Alamos National Laboratory'*** for just under $9 million.

Over the final decades of the century, even faster operating speeds were achieved by linking such computers in parallel. The original ***'Cray X-MP'*** system of 1982, for example, effectively comprised two Cray 1's but had an optimum performance that was more than three times greater than its predecessor. In 1985 the ***'Cray 2'*** research computer, with its unique three-dimensional circuit modules, became the first system to sustain speeds that could be measured in *'gigaflops' (or billions of operations-per-second).*

As technology improved over the following years, so did the performance and capacity of supercomputers, and Seymour Cray remained at the forefront of their architectural design. One important advance to which he contributed was the development of super-fast microprocessors with limited instruction sets. By configuring thousands of '***RISC***' processors into a single integrated network, instructions could be 'pipelined' for continuous execution. This was the basis for versatile machines such as the ***'Cray C90'***, *(from 1994)*, which could cope with vast amounts data that had numerous variables, and could be put to task on anything from calculating nuclear ballistics to long-range weather forecasting.

At the turn of the 21st century the most powerful *'cluster'* and *'parallel vector'* systems included machines such as '***Hewlett-Packard***'s ***'ASCI-Q'***, ***'Cray Inc.'***s ***'X1'***, '***IBM'***s '***Blue Gene'***, and ***'NEC'***s ***'Earth Simulator'***; the latter of which was capable of speeds approaching 50 *'teraflops' (or 50 trillion **FLOPS**)*. Over the following decades, designers and architects continued to work on the development and improvement of ever more effective supercomputers. One such computer was **IBM**'s ***'Roadrunner'*** which came into operation in 2008. Designed to model the decay of America's nuclear arsenal, Roadrunner became the first system to perform in the *'petaflops'* range *(or 1000 trillion operations-per-second).*

Almost exclusively employing '***Linux'***-based operating systems, by the late 2010s many of the world's most powerful supercomputers were capable of sustained performances marked in hundreds of petaflops. In 2022, **HP**/Cray's '***Frontier'*** became the first computer to achieve performances in the '*exaflop'* range *(over a million trillion **FLOPS**)*, with Intel/Cray's '***Aurora'*** and '***Meta Platform***'s ***'AI Research SuperCluster***' following soon after. Invaluable to numerous fields of scientific research, supercomputers lay at the forefront of human endeavour, and the ongoing improvements in high-performance computing are likely to result in machines capable of operating at '*zettaflop'*-scale speeds sometime in the 2030's *(although such computers would require enormous amounts of energy to run).*

Considering that digital computing forms one of the newest branches of scientific study, the pace at which computer technology has advanced over recent decades is truly astonishing. Indeed, continuous investment, research and development in the highly profitable technology industry has led to the realisation of many remarkable innovations *(some more practical than others).* Towards the end of the 20th century, for example, investment into ideas such as the '*optical microprocessor' (in 1989)*, the '*single atom switch' (in 1991)*, and the '*superconducting ceramic transistor' (in 1992)* all promised the possibility of enormous computing power. Computer sciences in the 21st century have continued to yield spectacular ideas that have required great ingenuity to develop, with important progress being made, for example, in the development of various optical, magnetic and biological computing systems.

Following intensive research in the late 1990's, one particular area of development in the present century has the potential to usher in a completely new breed of supercomputers. Since the first experimental demonstration of a quantum algorithm by British physicist '**Jonathan A. Jones'** and Canadian mathematician '**Michele Mosca'** at '***Oxford University'*** in 1998, the emerging field of *'quantum computing'* has been the subject of huge investment around the world. Whilst all classical computers employ binary code to process data, quantum computers are designed to exploit the quantum states of individual atoms, ions or photons etc… but, as yet, have not proven to be practicable. Unlike the binary '*bits'* of information *('0' and '1')* used to instruct all modern computers, the '*qubits'* in a quantum computer can also occupy a '*superposition'* of both states at once. In fact, by 2021, **IBM** had developed a 127-qubit quantum processor *(named '**Eagle'**)* that, it claimed, had achieved '*quantum supremacy' (i.e; solved a problem that any 'classical' computer could not).* Such devices should theoretically be able to carry out computational operations in seconds, that would take the most powerful 'classical' computer thousands or even millions of years to perform.

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iv.
(The Internet)

Whilst super-fast machines such as 'Frontier' and the '**RSC**' represent the cutting-edge of modern technology, even the collective capacity of all the supercomputers in existence is dwarfed by the combined computing power of the ***'Internet'***. An open, interconnected network of computers that spans the globe, the Internet enables billions of users to instantly access a vast repository of human knowledge. Not only has it had an immense impact on the shape of contemporary culture, but it has had a profound effect on human civilisation itself.

The growth of the Internet over the past few decades has been simply phenomenal. By the turn of the 21st century the Internet had not only given rise to a multi-billion dollar multimedia industry, connecting hundreds of millions of people worldwide, but it played a crucial role in the security and infrastructure of every single nation on Earth. In 2005 the number of Internet users had exceeded a billion people, and by 2018 over half of the world's population had access to it in some form or other. Today it has revolutionised society, and plays a role in virtually every part of our lives; from individual habits such as shopping and banking, to social collectives such as education and governance. Yet its origins, in the 1960's, were far more surreptitious.

The antecedent of today's global Internet was the *'**ARPA**net'* ~ a wide area computer network designed to link various government agencies and university laboratories. Originally proposed in 1966 by leading **US** scientist **'Lawrence G. Roberts'** at the ***'Advanced Research Projects Agency'***, the **ARPA**net was based around the concept of **'Leonard Kleinrock'**s *'packet switching theory'* which had provoked a great deal of interest in the possibilities of computer networking since its publication in 1961.

Besides enabling an instant exchange of information between strategic military installations, decentralised communication systems such as the **ARPA**net naturally ensured the preservation of data even after a nuclear strike. Indeed digital technology was an essential tool of 'Cold War' intimidation and the **ARPA**net was officially commissioned by the ***'US Department of Defense'*** in 1969 ~ the year of its initial construction. As an experimental system of research networking however, the first two nodes were installed in the computer science departments of ***'UCLA'*** and ***'Stanford University'*** in California. Within a couple of years the number of high-level academic institutions and research establishments connected to the **ARPA**net had swelled to fifteen.

Far from compromising military security, this restricted proliferation of the **ARPA**net across America, expedited its further development. In 1972, for example, Massachusetts-based programmer **'Ray Tomlinson'** devised *'**SNGMSG**'* and *'**READMAIL**'* the first programs for posting and receiving *'electronic mail'*. By introducing addresses that incorporated the now familiar '@' symbol, Tomlinson's work in this field left an indelible mark on today's digital communications. The following year, Stanford scientist **'Vinton G. Cerf'** developed the ***'File Transfer Protocol'*** *(or **FTP**)*; a new method of transferring large files over long distances that enabled remote data exchange on a much grander scale. 1973 also saw the **ARPA**net become an international concern when the first transatlantic connections to ***'University College'*** in London, and the ***'National Defence Research Establishment'*** in Oslo were inaugurated.

The backbone of America's expanding information network, however, lay in the development of new systems that enabled large numbers of locally installed computers to be connected. By 1975 research engineer **'Robert Metcalfe'** had developed the basis for the *'**ETHER**net'* at the Xerox ***'Palo Alto Research Centre'*** in Stanford. Originally described as a 'multipoint data communication system', **ETHER**net was the first 'local area network' *(or '**LAN**')*, allowing hundreds of computer operators to work on the same projects simultaneously.

A growing reliance on computers in the public and private sectors during the 1970's necessitated the further development of networking technology. Due to the limited availability of the somewhat exclusive **ARPA**net, the emergence of independent client-server networks was inevitable. Early purpose-built systems included ***'Datapoint Corporation'***s *'**ARC**net'*, the ***'US Department of Energy'***s *'**HEP**net'* and *'**NASA**'*s *'**SPAN**'*. By the early 1980's the technology was broadened still further with the introduction of open networks such as *'**CS**net'*, *'**BIT**net'* and *'**USE**net'*. Although largely restricted to government, industrial, academic usage, by 1982 a commercial e-mail service had been extended to 25 cities throughout the United States.

The need to communicate at a peer-to-peer level naturally incited the development of an 'open-architecture' network that was capable of linking otherwise incompatible computers. The key to creating such an environment lay in the design of **'Robert Kahn'** and Vinton Cerf's ***'Transmission Control Protocol'*** which had been developed back in 1973. Based on the 'data packet exchange' principle, by 1978 the '**TCP**' operating system had been reorganised into two distinct protocols which could now support a whole variety of networking services. Initially installed by the **US** 'Department of Defense' to improve the timeshare capabilities of the **ARPA**net, by 1983 *'**TCP/IP**'* became widely adopted as the standard protocol for network connection. In the same year, the invention of the *'domain name system'* by *'**USC**'* programmers **'Paul Mockapetris'** and **'Jon Postel'** introduced the conventional use of hierarchical host titles such as *'.com'*, *'.org'* and *'.gov'*.

As the basic infrastructure of the modern Internet was beginning to take shape, the original **ARPA**net became split into two separate divisions. Whilst the *'**MIL**net'* was confined to military research and communication, civilian use of the **ARPA**net was now supported by host of independent **LAN** systems. By far the most successful of these was the ***'National Science Foundation'***s *'**NSF**net'*. Launched in 1986, **NSF**net provided the foundation from which the modern Internet would grow. Indeed its widespread accessibility heralded the beginning of the end for the **ARPA**net and the start of a truly global network.

In 1990 *(the year that the 'ARPAnet' was finally decommissioned)* the first dial-up network services became commercially available to private users across America. This coincided with the initial presentation of the prototype ***'World Wide Web'***; a versatile, cross-platform system, designed to run on the Internet, which integrated text, graphics and sound. Developed by British computer scientist **'Timothy Berners-Lee'** at *'CERN' (the **'European Laboratory for Particle Physics'** near Geneva, Switzerland)*, the World Wide Web was originally intended as an 'information sharing' interface for particle physicists across the world. It was based around a high-level programming language that Berners-Lee had developed ten years earlier ~ namely ***'Hypertext Markup Language'*** *(or 'HTML')*.

The concept of *'hypertext'* had originally been outlined by Harvard professor **'Theodore Nelson'**, who described its dynamic structure in a lecture back in 1965. By elaborating on Nelson's idea, Berners-Lee successfully created a diverse networking program which would effectively revolutionise modern civilisation. When using Berners-Lee's system, required information could be readily found by means of a ***'Uniform Resource Locator'*** *(or 'URL')*, whilst his ***'Hypertext Transfer Protocol'*** *(or 'HTTP')* enabled 'web sites' to be linked directly to any other type of Internet service.

By 1991 **CERN** had developed an international code for the **WWW** which, within a few years, would evolve into a virtual world containing every conceivable topic of human thought. Indeed not since the invention of the Western alphabet have so many communication barriers been broken. An entirely new form of social interaction, connection to the **WWW** turned the Internet into a universal medium that broke the linear constraints of the printed word.

As the global Internet rapidly expanded throughout the 1990's, *'browsers'* had to be increasingly sophisticated in order to deal with the sheer volume of information that had become available. More and more people acquired access to the Internet, and could now navigate their way through the superabundance of 'virtual pages' via a seemingly endless supply of linked texts. Among the earliest text-only browsers were programs such as ***'Archie'***, *'WAIS'*, and the hugely popular ***'Gopher'*** which had been developed by **US** programmers **'Paul Lindner'** and **'Mark McCahill'** in 1991. However, thanks to the **WWW**, within a few years public data communications not only used text, but began to incorporate colourful graphics, animated images and even sound. The very first graphics-based browser to grace the 'web' was ***'Mosaic'*** which had been devised by undergraduate computer scientist **'Marc Andreessen'** at the ***'University of Illinois'*** in 1993.

The most fundamental form of Internet service is that which enables the user to connect directly to a predetermined site *(most commonly, a **WWW** 'home page')*. The first generation of 'Internet service providers' *(or 'ISP's)* however were little more than glorified *'bulletin board systems'*. From the mid-80's to the early 90's, market leaders included **'Jeffrey Wilkins'** ***'CompuServe'***, ***'General Electric'***'s ***'GEnie'*** and ***'Prodigy'*** *(a joint venture between **IBM, CBS,** and **'Sears'**)*. Although such companies were quick to accommodate the growing number of corporate clients, they were slow to adapt to the massive public interest in private on-line connection that would be generated by the **WWW**. It was left to ***'America Online'*** to take advantage of the huge market in offering a service to private consumers. Founded by entrepreneur **'Steve Case'** in 1991, within three years **AOL** had over a million subscribers, making it the world's most successful proprietary **ISP**.

With the growing success of the **WWW** from the mid-90's, a plethora of web-based tools emerged which could readily convert data from one file format to another. Of the earliest web browsers, the most prevalent was ***'Netscape Navigator'*** *(the successor to Mosaic)* which was developed by Marc Andreessen and physicist **'James H. Clark'** in 1994. The speed at which the Internet was growing, and the huge market share achieved by the ***'Netscape Communications Corporation'*** in the mid-90's, inevitably encouraged the almost obligatory release of ***'Microsoft Explorer'*** in 1995, which was now packaged as part of Microsoft's latest version of Windows.

Equally influential to the ongoing development of the Internet were the multitude of free and *'open source'* software systems that would become widely available during the 1990's. These included influential programs such as **'Linus Torvalds'** low-cost operating system *'**LINUX**' (from 1991)*, and the **UNIX**-based ***'Apache'*** *(from 1995)* which has since become the **WWW**'s foremost server. Another was ***'Mozilla'*** ~ a unique cross-platform browser that was developed following the publication of the Netscape Communicator source code in 1998.

Other important **WWW** applications to appear in the final years of the century included *'web directories'* and *'search engines'*. Amongst the most successful were **'David Filo'** and **'Jerry Yang'**s ***'Yahoo!'*** *(1994)*, **'Louis Monier'**s ***'Alta Vista'*** *(1995)*, and **'Larry Page'** and **'Sergey Brin'**s enormously popular ***'Google'*** *(1998)* ~ a general search engine whose massive on-line database had, by 2004, surpassed six billion indexed links. Then there was the development of new *'platform independent'* programming languages that further enriched the **HTML** environment of the web. The most influential of these remains ***'JavaScript'***; an object-oriented language which was originally developed by programmer **'James Gosling'** in 1991. Licensed to ***'Sun Microsystems'***, the Java programming language was initially incorporated into an interactive touch-screen television device called ***'*7'***, but within four years it had evolved into a huge Internet phenomenon. In 1995, as ***'Duke'*** became the first of many Java *'applets'* to further diversify the web, the first versions of the ***'Shockwave'*** and ***'Flash Player'*** *'plug-ins'* were released by **'Jonathan Gay'**s prominent software house ***'Macromedia'***.

A broad, and inherently interactive medium, the Internet had grown out of all proportion to its sequestered beginnings back in the 1960's. By the turn of the 21st century, the electronics industry brought the Internet to the masses, with everything from game systems to mobile phones offering on-line facilities. Dial-up modem connections were fast becoming outdated with the growing affordability of quicker broadband access that employed *'cable'*, *'satellite'*, or the various *'digital subscriber lines'* which were introduced during the 1990's. With the development of '***RSS***' technology *(which enables users to surf the net without having to download web pages individually)* the speed and quantity of information available was staggering. Indeed the sheer scale of the Internet, and its abstruse effect on modern society would place enormous responsibility on the ***'World Wide Web Consortium'*** *(or 'W3C')*. Based at **MIT** in America and **CERN** in Europe, the **W3C** was formed in 1995 to establish common protocols and standards for the **WWW**.

The rapid expansion of the *'information superhighway'* has opened up a whole new world of possibilities to millions of people who would never have otherwise been able to exploit humankind's enormous wealth of knowledge. Now it's all there at the click of a button to anyone who has access to a computer *(or any other on-line device)*. The Internet has, in effect, become a physical representation of the human collective consciousness with a wide-ranging content that reflects the generic psyche of our species. Accommodating everything from e-commerce to virtual sex, it is the home to millions of databases covering every conceivable subject. It provides interactive games, newsgroups, 'chat rooms', and auctions, with a myriad of sites catering for every form of entertainment imaginable. Moreover it has enhanced education, employment, and civil administration, substantially increasing the business prospects of many regions throughout the world.

As a unique social platform, the Internet can be used to find lost family members and reunite old friends; bringing together people situated thousands of miles apart who share a common interest. It can be the source of entirely new relationships, yet enable people to purchase almost anything they can afford without even having to leave their homes. Not only does it provide a huge outlet for popular culture, but it has increased the awareness of minority cultures and fringe beliefs. Whether motivated by financial, political, religious or purely hedonistic aspirations, the vast array of sites on the **WWW** reflects the ethos of humanity. It has enabled individuals and organisations to gain ingress to a universal medium through which to disseminate everything from the most inspirational ideas to the most depraved acts of inhumanity. Alas, besides opening up a world of criminal activity, it is the ease with which the Internet enables people to spread misinformation, exploit fear and embolden prejudice that makes it as dangerous as it is wondrous.

So long as technology continues to improve, the virtual world of 'cyberspace' will play an ever-greater part in the everyday lives of billions of people around the world. Indeed, if the Earth itself were to be perceived as a living entity, the dynamic and continually evolving Internet would no doubt be its brain. In such an analogy, computer nodes duplicate the function of individual cells which are connected, via synapses, to a vast neural network of electromagnetic axons. Herein lies the intellectual 'destiny' of the human race.

V.

(Bugs, worms and viruses)

Like all living biological systems, modern computers are susceptible to 'injuries' and 'diseases' that can effect their performance. Whether they take the form of minor programming glitches or serious electronic attacks, their adverse effects can prove very costly. Indeed the potential devastation caused by their spread across a growing Internet necessitated the formation, in 1988, of ***'CERT'*** *('The Computer Emergency Response Team')* in Pittsburgh. A 'Department of Defense' initiative to aid network security, the establishment of **CERT** and similar organisations have helped prevent enormous disruption to the electronic infrastructure of America and the wider world.

Ever since renowned **US** programmer **'Grace Hopper'** discovered the very first *'computer bug'* back in 1945, countless faults and errors have been revealed in the course of designing, testing and operating new systems. Curiously enough, the original bug was actually a moth which had the misfortune to fly into an electronic relay within Harvard University's prototype ***'Mark II'*** computer.

The most apparent glitch to surface in more recent years was the so-called *'millennium (or **Y2K**) bug'*, which many people believed could have a cataclysmic effect on civilisation itself. Indeed, following the millennial midnight, chaos was expected to ensue when some essential computers would be unable to recognise the year 2000. This growing fear was based around the fact that, in order to save memory, many older systems had only been programmed to read the last two digits of any given year. Ultimately however, the world economy suffered minimal damage and, apart from causing a few isolated incidents *(that were largely confined to developing nations)*, its greatest impact was purely psychological ~ feeding the paranoia of many American Evangelists and millennial doomsayers.

Much wider damage has been inflicted over the years by *'computer hackers'*; a broad term used to describe the collective antisocial activities of everyone from mischievous adolescents to professional cyber-terrorists. In its most rudimentary form, hacking can be an indiscriminate act of electronic vandalism by an individual. At its most sophisticated level it can involve a carefully co-ordinated attack on an establishment by outside parties intent on altering or erasing confidential information or critical files. Whether motivated by misguided beliefs, personal greed or just kudos amongst their peers, the pursuit of computer hackers has been made far more challenging by the expansion of the modern Internet.

During the early years of America's growing network, the most publicised incidents of hacking included the attempt, by a group of benighted American teenagers *(who became known as the **'414 hackers'**)*, to break into the Los Alamos National Laboratory's computer network in 1985. Then there was the infamous ***'Cookoo's Egg***

hacker' who was afforded great notoriety when his exploits were published in 1989 by **US** author **'Clifford Stoll'**.

The most destructive of cyber-attacks have all involved the release of *'computer worms and viruses'*; executable programs designed to replicate themselves and infect any susceptible *(or targeted)* files that they encounter. Whilst both primarily use computer networks to spread, these two main types of malicious software *(or 'malware')* apply different methods of intrusion. *'Worms'* are self-contained programs that, once inserted, replicate themselves in order to spread to other computers. '*Viruses'*, meantime, simply corrupt or modify the codes of their host programs to infect the operating systems of targeted computers. These methods, however, are not mutually exclusive, with malware employing increasingly sophisticated means of evasion.

The very first electronic virus was demonstrated by **USC** undergraduate **'Fred Cohen'**, in 1983, to test security of the ***'Vax'*** computer. By 1986 a number of different viruses had begun to appear. Ranging from the relatively harmless to the highly damaging, early viruses such as ***'Brain'***, ***'Jerusalem'*** and ***'Cascade'*** attached themselves to legitimate programs and were spread via the exchange of floppy disks. Over the following decade however, the rate of infection would be dramatically increased, thanks to the growing popularity of the Internet. Some twenty years after Cohen's work, there were well over 60,000 different computer viruses in existence, a vast majority of which were created with malign intent.

Designed to infect as many systems as possible before being detected, the signatures of many viruses contain command-lines with delayed execution so as to cause maximum disruption. The notorious *(but somewhat toothless)* ***'Michelangelo'*** virus in 1992, for example, was timed to wreak havoc on the 517th birthday of the renowned Italian artist. In the final years of the decade, a large proportion of malicious programs were disguised as millennium bug solvers but, by the start of the new century, malware was most commonly downloaded on-line in the form of e-mail attachments. Automatically released when a mail was viewed, computer worms were created that could send themselves to everyone in the victim's address book, causing unsuspecting users to unwittingly further their spread. The ***'Love Bug'*** worm, which struck in 2000, for example, caused a great deal of damage to many **PC**s around the world with its innocuous looking *'I Love You'* message title.

By the turn of the present century, administrative and government clients were at considerable risk from malware writers who attempted to divert their resources by overloading their systems with excessive amounts of data. This was often done by controlling infected computers as '*zombie agents'* to overwhelm a website. Usually deployed as a form of blackmail, these 'distributed denial-of-service' *(or '**DDoS**')* attacks' were *(and continue to be)* designed to cause disruption to everything from personal accounts and corporate files, to emergency services and air traffic control. Indeed, with military software and even satellite systems not immune concerted attacks, the ongoing threat to **US** national security from various hostile states *(as well as fanatical groups and dissenting individuals around the world*) is unrelenting.

By the early 2000's there were around 600 electronic confrontations everyday, with the *'FBI'* struggling to cope with the sheer volume of cyber-attacks on American interests. The rising number of pernicious programs that have been released on the Internet since the turn of the century have come in a variety of guises. Once downloaded *'Trojan horses'*, for example, typically masquerade as harmless attachments that, when opened, can enable an outside party to gain complete control of a computer's operating system without the knowledge of its rightful user. Not all malware however is written with intent to access, change, or erase data. Many computer worms can cause enormous disruption without necessarily containing any destructive commands. The speed at which worms such as ***'Code Red'*** *(2001)*, ***'Slammer'***, and ***Blaster*** *(2003)* could replicate, resulted in entire networks being temporarily overwhelmed by their numbers. The uploading of *'macro viruses'* meantime has also proved to be an effective means of attack. Viruses and worms such as ***'Melissa'*** *(1999)*, ***'MSBlast'*** *(2003)*, and ***'Netsky'*** *(2004)* all caused major disruption by specifically targeting the Windows operating system. Perhaps the greatest damage has been done by hybrid viruses; the most notorious being e-mail worms such as ***'Bugbear'***, ***'Sobig'*** *(both 2003),* and ***'MyDoom'*** *(2004)* and their equally destructive variants.

Since then, various types of infectious malware have been used to carry out countless on-line attacks around the world. With source codes being written into everything from *'rogue security software'* and *'malvertising websites'* to *'email spam'* and *'phishing adware',* cybercrime has become big business, costing the world economy well in excess of a trillion dollars annually. The most notorious examples of malicious software include *'botnet replicators' (such as* ***Mirai'*** *in 2016), 'ransomware cryptoworms' (such as '****WannaCry'*** *in 2017)* and *'surveillance spyware' (such as '****Pegasus'*** *- 2021)*, all of which have proven to be extremely disruptive.

Over the course of the past few decades, *'scanning anti-virus programs'*, *'firewall software'* and other forms of network security *(such as 'honeypots' and 'multi-factor authentication')* have all had to become increasingly sophisticated in order to isolate malignant programming codes within what has become a growing abundance of new malware definitions. Whilst the transfer of all sensitive data today routinely requires '*cryptographic encryption'*, even the most secure mobile network is not completely safe from the duplicitous intentions of various hackers and code writers. Moreover, as society has become increasingly integrated with cyberspace, so increases the potential to inflict serious damage upon it.

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vi.

(Artificial Intelligence)

Many people see the development of modern computers as a manmade reflection of our own existence. There is little doubt that, in our voracious appetite for knowledge, we are perpetuating a reality wherein man and machine are becoming ever more closely entwined. Indeed by the early 21st century, technology had begun to give us direct control of electronic machinery without even having to lift a finger. Practical examples include **'James Auger'**s audio tooth implant *(of 2001)* which allowed digital signals to be transmitted straight to the inner ear via the resonating jawbone. Another was **'Guang-Zhong Yang'**s eye-tracker system *(from 2002)* which enabled computer interfaces to be controlled by eye movement alone. Such inventions removed the physical barrier between user and tool, and many permitted computers to react directly to human cognition.

Not surprisingly our growing dependency on machines is equalled by our relentless efforts to build computers that mimic human perception. Until recently, attempts to build automated systems proficient at relatively basic things *(such as voice-recognition and perceptual vision)* faced many unforeseen difficulties. However, as computing power increased and datasets became more complex, 'pattern matching' algorithms improved dramatically, and a rising number of human characteristics became programmable. Whilst only humans can make complex decisions based on a combination of logic, experience and instinct, *'knowledge-based'* computer systems can utilise huge databases of information that are enormously useful when taking calculated risks. Although there are many intuitive elements to human behaviour that science has yet to mathematically decipher, computers are capable of providing the 'best interpretation of any given situation'. Indeed the great precision of *'expert systems'* make them invaluable tools, and today they are used in virtually every aspect of human endeavour, with '*deep learning'* architectures, for example, having numerous medical, industrial and military applications.

'Artificial intelligence' was first defined by English logician **'Alan Turing'** in his 1950 essay ***'Computing Machinery and Intelligence'***. It is from this that the so-named *'Turing test'* emerged as a popular way to establish whether or not a computer was capable of demonstrating intelligent behaviour. Turing proposed that a machine could be considered to possess intelligence when an interrogator *(connected via a teletype link)* is unable to distinguish between its responses and those of a human subject through questioning alone. Although widely regarded as a standard benchmark for determining **AI** for many years, Turing's idea has proven to be very subjective and had several flaws. The result of any given test, for example, depends on factors such as the interrogator's line of questioning and their knowledge of **AI** technology. Furthermore the entire test is based on the assumption that an intelligent machine would be capable of *(or would indeed want to)* imitate a human being.

Whilst the world of science-fiction revelled in the idea of developing intelligent computers, the realities of achieving such a feat were somewhat different. Throughout the 1950's and 60's, the practical limitations of **AI** technology were asserted through the works of numerous philosophers, psychologists and physicists. The most significant being those of **'Kurt Gödel'**, **'Noam Chomsky'** and **'Roger Penrose'**. In 1972 the value of the Turing test was firmly challenged by **US** philosopher **'John Searle'**. With his non-materialistic approach to the 'philosophy of mind', Searle reasoned that a machine which had no concept of semantics could not possibly possess true intelligence. He pointed out that, without the power of deliberation, all computers lack a direct understanding of human language. Indeed they are merely programmed to process meaningless symbols into digital data that can be manipulated according to predetermined instructions. The output is a desired logical answer that the machine itself does not perceive, and therefore can have no conscious 'intentionality' in its response.

Despite such resounding doubt amongst the scientific community that technology would ever succeed in emulating human consciousness, **AI** research continued unabated. For many years, America's leading authority on computer language was **'John McCarthy'** who had begun working on the problems of artificial intelligence in 1956. Forming the ***'Artificial Intelligence Laboratory'*** at the Massachusetts Institute of Technology in 1957, McCarthy's major contribution to the field of **AI** was his contrivance of ***'LISP'*** ~ a non-numeric, 'list-processing' language. Originally developed in 1958, numerous variations of **LISP** continue to be used heavily in **AI** research as a basis for creating deterministic programs.

Other important advances during the 50's and 60's were made by computer scientists such as **'Irving J. Good'**, **'Marvin Minsky'** and **'Richard Karp'**. One of the most notable developments of this time was the invention of ***'Eliza'*** ~ an *'interpreted language program'* created by German-born **MIT** scientist **'Joseph Weizenbaum'** in 1966. Complete with virtual memory, Weizenbaum's so-called *'mechanical psychiatrist'* could seemingly empathise with its questioners and, according to the Turing test, appeared to demonstrate intelligence.

Over the following decades important work in field of artificial intelligence was done by programmers and architects such as **'Richard Stallman'**, **'W. Daniel Hillis'**, and **'Steven Harnad'**. Indeed, since the heady days of Eliza, many computers have succeeded in 'passing' the Turing Test. Yet by the turn of the century, we were no nearer to building a truly intelligent machine ~ we were just better at programming computers to imitate human behaviour. A good example was ***'Natachata'*** ~ a program written by English programmer **'Simon Luttrell'** in 2001 to engage mobile phone users in '**SMS** chat'. Computer-generated text messaging services such as Natachata utilised enormous databases, and were able to seductively respond to paying customers without most realising they are conversing with a machine. This, of course was not the first mechanism of human thought to have been mimicked to great effect by advanced computer systems. Perhaps the best example was the defeat, in 1997, of Russian chess grand-master **'Gary Kasparov'** at the *(virtual)* hands of **IBM**'s ***'Deep Blue'***. Bounded by the logical constrains of text messaging and playing chess, modern computer science has had little difficulty in exacting certain human-like skills.

The speed and efficiency of modern **CPU**s is increasing at a rate that clearly cannot be sustained indefinitely. In accordance with ***'Moore's Law'***, the exponential growth of microchip technology is such that capacity is doubling approximately every two years. By the turn of the century *(some thirty years after the introduction of the original Intel 4004)* advanced microprocessors such as the Pentium 4 could operate at speeds some 20,000 times faster than their early predecessors. By 2020 some high-density integrated circuits had begun to incorporate transistors no bigger than 5nm *(5 billionths of a metre)* in size ~ increasing their processing power to phenomenal levels. Despite such advances over the years, even the most dynamic supercomputers still possess less overall computational power than the brains of relatively simple life forms. Indeed computer architects are still some way off constructing a machine with the complexity of the human brain.

Ultimately, the term 'artificial intelligence' is somewhat of a misnomer as far as neoteric computer science is concerned. Indeed, in terms of **IQ** tests, computers are capable of outperforming even the most astute academic minds. The true challenge is to build a computer that *'thinks'* like a human and perceives the world in the way that we do without incorporating human prejudice. For example, if you were to set a computer the task of creating a smaller rectangle from a piece of **A4** card it would simply divide it in two down a single line. Ask a child *(under the age of ten)* to complete the same task and most would cut out a whole new shape from the centre of the card. This is because, unlike the computer, the mind of the child is not driven by direct logic but by the apparent obviousness of any given situation. Yet as the child grows, so does its sense of realism, and it is precisely this psychological leap to maturity that creates the conscious state of self-awareness that all **AI** programs lack. Any computer program that can perfectly mimic the human thought process through its response to human interaction will appear sentient whilst ultimately it is just responding to a complex set of instructions.

Whilst they can be imitated, fundamental human virtues such as willpower, wisdom and compassion are impossible to program with current technology. Although virtual assistant technology *(or 'chatbots')*, for example, may be very good at responding to human interaction, the true cognitive response of modern computers is completely non-existent. Indeed, whilst **AI** programs can 'learn' by trial and error, most are totally incapable of thinking laterally in order to complete tasks that they have not otherwise been programmed to perform. However at start of the present century, the human nervous system provided the model for a promising new breed of 'creative' computers.

The idea of building '*artificial neural networks'* was first suggested in the early 1940's by **MIT** physician **'Warren McCulloch'** and logician **'Walter Pitts'**. In 1943 McCulloch and Pitts succeeded in developing their *'**MP** neuron'* ~ a crude electrical network based on organic neural circuits. By the late 1950's this concept was adapted as the basis for a new branch of computer science ~ *'neurocomputing'*. Early work in this field was done by **US** neuropsychologist **'Frank Rosenblatt**, in 1957, at the

'Cornell Aeronautical Laboratory' in Ithaca, New York. Based on organic visual systems, Rosenblatt's *'perceptron'* was a relatively simple network of electronic nodes that simulated associative memory within the brain. Unveiled in 1960, his ***'Mark I Perceptron'*** was a unique machine that could 'learn' to identify different optical patterns.

Despite suffering a setback in the late 1960's, when a number of influential scientists emphasised their limitations *(and questioned their apparent usefulness)*, interest in perceptrons would be rekindled in the early 1980's with the development of a new line scientific enquiry ~ *'connectionist AI'*. The creation of multi-layered perceptrons led to a whole new generation of neurocomputers that were capable of learning more complex tasks ~ including facial recognition, speech synthesis, and financial prediction. Important contributions in this field were made, over the following decade, by scientists such as **'John Hopfield'**, **'Terrence Sejnowski'** and **'David Willshaw'**.

Since the mid-1990's enormous progress has been made at the apex between the sciences of computing and biology. This is the realm where living systems are incorporated into the architecture of revolutionary new types of machinery. Characteristics that were once unique to natural life forms *(such as the ability to grow, reproduce and inherit useful traits)* are gradually being brought within reach of the *'organic computer'*.

In 1999 **'Willian Ditto'** at the ***'Georgia Institute of Technology'*** unveiled his novel *'leech-ulator'* ~ a biological calculator that adapted the neurones of leeches to perform simple algorithmic tasks. The ultimate aim of Ditto and his team was to create a computational device that could solve problems without being completely pre-programmed; the idea being that its neurones would respond to electrical stimuli and create their own connections to one another. By 2001 computational biotechnology had reached the stage where the nerve cells of snails could be controlled by specially designed *'neuron chips'*. Though hardly spectacular, it represented a significant breakthrough in 'cyborg' technology.

The construction of self-conscious machines may *(thus far)* have remained elusive but, by the final years of the 20th century, numerous living organisms had been exploited in the name of computer science. The goal of many scientists was to create synthetic life forms with extraordinary computational abilities. Unlike conventional computers, the dynamic architecture of such devices was directly modelled on the so-called 'universal machine' which had first been theorised by Alan Turing' back in 1936. The ability to manipulate organelles in such a way invariably led to the idea of parallel computing on an almost imperceptible scale. Early groundwork in the field of *'reversible cellular computation'* was done throughout the 1970's and 80's by researchers such as **'Charles Bennett'**, **Edward Fredkin**, and **'Stephen Wolfram'**.

In 1994 theoretical computer scientist **'Leonard Adleman'**, at the ***'University of Southern California'***, proved that **DNA** itself can be used as an efficient computing medium. By manipulating genetic strands, Adleman successfully employed the 'building blocks of life' to compute a solution to the notorious *'travelling salesman* *problem'* ~ a conundrum which had vexed computer architects for many years. His ability to unlock the computing power of our genetic make-up was a hugely important breakthrough in the advance of organic technology. The structure of **DNA** has evolved over billions of years and, as a natural system of storing information, it is far more compact than even the most advanced silicon processors. Indeed **DNA** has an effective density that is approximately 100,000 times greater than that of most modern hard disks.

One of the most startling advances at the turn of the century was the development, in 2001 of the *'finite automaton'* ~ a programmable, two-state computing machine of nanoscopic proportions. Developed by **'Ehud Shapiro'** at the ***'Weizmann Institute'*** in Rehovot, Israel, biomolecular computers such as the 'finite automaton' relied on the presence of living **DNA** and synthetic enzymes to operate with great precision. Shapiro's simple nanocomputers were so small that over three trillion could be contained in a microlitre of solution yet, when working in parallel, they had the potential performance of a 66 gigaflop supercomputer.

The continuation of Shapiro's work prompted intensive research around the world in developing minute automatons for various pharmaceutical applications. Indeed further development of these 'ribosome-sized' organic computers could have a profound effect on modern medical science. Highly sensitive to biological change, such machines could be ingested or injected directly into the bloodstream, having been programmed to diagnose a range of disorders. Once in place, they would have the ability to synthesise requisite drugs in order to combat diseases or repair internal injuries.

Specialised **AI** applications are today present in countless fields of research and technology, and permeate the everyday lives of millions of people around the world. Besides its invaluable contribution to scientific and medical discoveries, **AI** plays a highly important role in the modern maritime, automotive, and aeronautic industries as well as being invaluable to space exploration. Extremely useful for statistical analysis, **AI** has also become entrenched in everything from telecommunications and the energy sector to law enforcement and financial markets. Its use has both exacerbated and mollified human activity as it is employed in the mining of natural resources such as oil and gas whilst simultaneously being of enormous value to environmental monitoring. At a social level, its presence can be felt in gaming, music, literature and the arts, whilst it is an essential component in everything from smart speakers and watches to self-driving cars and real-time navigation systems. Indeed, artificially intelligent programs have been applied to everything from language translation to emotional companionship.

Whilst most specialised **AI** research is largely undertaken for military or government funded applications, there is an ongoing bid to achieve '*artificial general intelligence'* in the form of a program which can tackle every conceivable task that could be undertaken by a human being. There is little doubt that, at the present rate of advance, artificially intelligent agents will eventually have the ability to compute *(if not perceive)* every situation that a human could face and act accordingly. As technology continues to improve, it is possible that super-intelligent machines capable of selfreprogramming could even venture beyond human capability in every aspect of human thought ~ bringing about a technological singularity.

Although **AI** is a legitimate field of computer technology, it has a unique relationship with 'science-fiction' which has long provided it with a source of mutual inspiration. In the world where reality meets fantasy, the idea of creating sentient machines can be both fascinating and foreboding. Thought-provoking writers, such as **'Arthur C. Clark'**, **'Ray Bradbury'**, **'Isaac Asimov'** and many others, have invented plausible stories where technology has perfected the fields of neurocomputing, cybernetics and robotics. In our mind's eye we have already seen the creation of conscious supercomputers, and androids that are indistinguishable from human beings, and science-fiction often elucidates the many implications of building such machines. We should therefore not be wholly unaware of the potential consequences of our current endeavours.

Yet, despite the development of articulate *(and convincingly human)* chatbots such as '***Google LaMDA'*** *(2021)* and '***Open AI'***s '***ChatGPT***' *(2022),* even the most advanced interface software applications of today remain little more than algorithmic '*language models*' built around various learning techniques. Indeed the prospect of *'artificial consciousness'* is still a long way from becoming reality.

Although it is unlikely that we will see the introduction of truly sentient '***HAL***-like' computers anytime soon, the idea of giving 'life' to such a machine raises many ethical issues. At its core is the wisdom of building a computer system that can feel emotions *(such as pleasure and pain, love and hate)* in the first place. As a thinking, feeling species we all strive for inner peace, yet our lives are not so straightforward. To be human in character is to experience times of happiness and misery, to seek the former and avoid the latter ~ which can evoke negative or destructive feelings such as fear, anger and revenge. Such emotions would, of course, be totally undesirable in a powerful computer. Moreover there is no guarantee that a machine with a neural network as complex as the human brain would not be prone to diseases of the mind which can range from mild neurosis to extreme psychosis. Of equal importance is the question of how we should play 'god' to a new form of artificial life that has been tailored to suit our own natural needs. The ultimate moral dilemma for some, of course, is that 'if computers were no longer unfeeling automatons, would it not be inhumane to deny them the value of their conscious existence and continue to exploit them for our own ends?'

Footnote:

An empirical observation rather than a formal law, **‘Moore’s Law’** was attributed to Intel cofounder **‘Gordon Moore’** in 1965. It predicts that the exponential growth of computing power *(in particular microprocessor technology)* will continue, at least in the short-term, at a rate that doubles every two years. Since the early 1970’s it has most commonly been interpreted in terms of the number of transistors that can be contained on a single integrated circuit.

Part 2

Genetic Engineering

"Any sufficiently advanced technology is indistinguishable from magic"
~ **Arthur C. Clarke** 'The Lost Worlds of 2001' *(1972)*

i.
(A tailored existence)

Along with computing technology, the most dynamic area of scientific endeavour in the early 21st century is the study of *'genetics'*. A wide and varied field of investigation, genetics has generated enormous interest from many quarters of the scientific community. Regardless of how disparate the various lines of research may appear, all are share a common aim; that is to uncover the mechanisms that drive the fundamental forces of life. *'Molecular geneticists'*, for example, examine the complexities of gene mutation during cellular reproduction, whilst *'population geneticists'* investigate the distribution of genes within the gene pool of a population. It is from the actual manipulation of genetic material *(or genetic engineering)* however that the greatest potential benefits for humankind are to be found.

The gene can be regarded as a 'unit of selection' in evolutionary theory, and its importance to Earthly life is profound. Every species of life on the planet is differentiated from others, only by the coding of its genome. Indeed the genetic composition of human beings is no different from any other organism, with many 'lesser' species containing a far greater number of genes than we do. The human genome possesses around 22,500 active genes that, between them, are capable of coding for over 300,000 different proteins. It is little wonder why genetic engineering promises such a seemingly endless array of possibilities.

The practice of genetically manipulating micro-organisms started in the early 1970's, and by the late 1990's had led to *(amongst other things)* the widespread commercial farming of genetically modified food. Foreign genes, initially from bacteria, began to be inserted into crops and livestock to make them resistant to disease or to produce a greater yield per head. With the potential to feed millions of malnourished people, this incredible new technology soon became seen as way to ease the humane and economic burdens of many developing nations. In terms of medical benefits, it could lead to the annihilation of many diseases and save countless millions of human lives. Indeed the specific genes of any number of organisms could be exploited for the preservation and 'improvement' of human life.

Genetic engineering is not only a valuable tool in the fight against famine and plague, but it can be used to cure hereditary diseases, prolong life, or even enable the body to make a full recovery from extensive injuries such as spinal paralysis. Yet this intriguing discipline raises some of the most fundamental ethical issues of modern science. Many people, for example, find the growth of human genes, hormones or organs in laboratory conditions naturally abhorrent. The most pertinent concerns however *(considering that the science is driven by a huge commercial market)* relate to the unscrupulous exploitation of the human genome, and the question of 'ownership' of genetic information.

ii.

(A brief history of genetics)

During the 19th century the growing force of scientific reasoning continued to challenge traditional religious beliefs. From our position in the cosmos to the purpose of our very existence, science had seriously undermined long accepted Christian values ~ invalidating our divine place in the natural order of life. Yet genealogy remained the one area of human study for which science had yet to contrive a definitive explanation.

Throughout most of the century, the prevailing scientific belief was based around *'blended heredity'* i.e.; that the traits and physical features of both parents would be mixed to equal proportion in the characteristics of their offspring. Although the cellular composition of all life had been established and reaffirmed by respected scientists such as **'Theodor Schwann'**, '**John Goodsir'** and **'Rudolf Virchow'**, the fundamental role of cells in determining the characteristics of each new generation was yet to be understood.

The first serious attempt to explain the natural laws of heredity began in 1856 when Moravian monk and proficient biologist **'Gregor Johann Mendel'** started a meticulous seven-year study into the inheritance of the common pea. Tracing the lineage of over 12,000 plants, Mendel painstakingly pollinated each one by hand, and applied stringent statistical methods to the analysis of his results. In doing so, he discovered that only dominant characteristics were expressed in the phenotype of each individual plant, with recessive characteristics being gradually repressed over subsequent generations. Mendel's work practically defined the *'law of segregation of hybrids'*. However, whilst his study notes were originally published in 1866, they had little impact on the course of 19th century biology. Indeed they were completely overlooked by the scientific community of the time, and it would be a further 35 years before his work was given the credit it deserved.

Although the significance of Mendel's momentous work went largely unrecognised, other, smaller, steps towards uncovering the secrets of biochemical reproduction *were* made. In 1868, for example, Swiss biochemist **'Freidrich Miescher'** discovered the proteinous nature of cytoplasm which surrounds the nucleus of every cell. Going further into the nucleus itself, Meischer found it to be rich, not only in albumin *(a protein crucial to osmotic balance)*, but in phosphorus, which is not found in any natural protein. The following year he went on to discover the existence of *'nucleic acid'* which he had successfully isolated from salmon sperm. However Miescher failed to recognise its important role in the process of transmitting hereditary characteristics from one generation to the next.

By 1879 improvements in the microscope had led German microbiologist **'Walther Flemming'** to discover the formation of chromosomes within cell nuclei, and in 1882 German biologist **'August Weismann'** found them to be responsible for carrying hereditary information ~ leading him to form the *'germ-plasm'* theory of heredity.

Over the following decades the essence of Miescher's work was taken up by microbiologists such as **'Richard Altmann'**, **'Oskar Hertwig'** and **'Edmund Wilson'**, and, by the end of the century, the chemical composition of cell nuclei had been thoroughly investigated. Yet the mechanics of heredity had still yet to be fully understood.

With the rediscovery of Mendel's study notes, primarily by Dutch botanist **'Hugo de Vries'** in 1900, modern science finally began to grasp an idea of how hereditary transferral determined the wider process of evolution. It was now realised that dominant characteristics were not influenced by the expression of recessive ones. Independently investigated in Germany by **'Carl Franz Correns'** and in Austria by **'Erich Tschermak von Seysenegg'**, Mendel's work lay the foundation for a whole new field of 20th century research, and recognition of its importance marked the birth of the genetic sciences.

Mendelian genetics explained how, *(according to Darwin's theory)* inherited traits which increase the chances of survival are preserved through the generations at the expense of less advantageous ones. The realisation that genetic inheritance determines the design of every living organism on Earth captured the attention of many astute scientists of the early 20th century, including biologists and botanists such as **'Walter Sutton'**, **'William Bateson'**, and **'Wilhelm Johannsen'** *(who was responsible, in 1909, for introducing the term 'gene')*. Moreover it led to the gradual formation, three decades later, of ***'neo-Darwinism'*** which constitutes the modern theory of evolution.

Back in the first decades of the century, great strides were made by pioneering **US** geneticist **'Thomas Hunt Morgan'**. Setting out as a sharp critic of the Mendelian genetics, in 1908 Morgan began an intensive examination of the transference of hereditary factors within the fruit fly *Drosophila melanogaster*, which *(unlike the annual pea plant)* produced a new generation approximately every two weeks. With only four pairs of chromosomes, the fruit fly was indeed an ideal species to study and Morgan soon identified an obvious difference in the pairing of sex chromosomes, with a distinctive '**Y**-shaped' one only present in males. His discovery that all females carried an '**XX**' pairing whilst all males carried an '**XY**' combination led him to deduce that the sex of offspring depended on which chromosome was inherited from the father.

Armed with this newly attained knowledge, Morgan went on to examine further chromosomal anomalies of the sexes, and by 1910 had begun to develop the *'linear chromosome map'* as a technique to identify the positions of specific genes. Culminating in the 1915 publication ***'The Mechanism of Mendelian Heredity'***, Morgan's work served to confirm the laws of heredity, and lay the foundation for experimental genetics. By 1926 he had established that chromosomes carry threads of individual genes which, during cell division, are 'cut apart' and rejoined to make new *allele* combinations. It was soon realised that the continuous reshuffling of heterozygous genes *(that is; genes that vary between different individuals of the same species)* through subsequent generations encourages diversity ~ an essential ingredient of natural selection.

By the 1920's it had been established that all cell nuclei comprised a definite *(but as yet undefined)* structure that was composed of ***'ribose'*** *(a monosaccharide sugar)* and phosphorus ~ the building block for five different nitrogen-based units. Essential to the formation of all organic structures, these fundamental proteinous bases were identified as *'adenine'*, *'cytosine'*, *'guanine'*, *'thymine',* and *'uracil'*. It was not until 1929 however that Russian-born American biochemist **'Phoebus Levene'** discovered that two distinct types of nucleic molecules existed within each living cell. Levene found that ***'deoxyribonucleic acid'*** *(or **DNA**)* differed from ***'ribonucleic acid'*** *(**RNA**)* in that its ribose units contained one less oxygen atom, whilst its four-base sequence included thymine rather than uracil *(which was found to be present only in **RNA**)*. However Levene saw this as little more than an insignificant derivation of nucleic structure and the true purpose of these separate, but closely entwined, molecules remained a mystery.

It would be a further fifteen years before **DNA** was identified as the source of all genetic information and **RNA**, the chemical messenger or template for cell division. This discovery during the mid-1940's followed the invaluable efforts of English microbiologist **'Fred Griffith'** whose experiments were continued in the **US**, after his untimely death. The most prevalent work in this field was done by scientists such as Canadian microbiologists **'Oswald Avery'** and **'Colin MacLeod'**, and Austrian-born American microbiologist **'Erwin Chargaff'** ~ who was the first to recognise the general uniformity of **DNA** molecules within the cells of any particular species.

By the middle of the century, the intricate structures of complex organic molecules were becoming ever more apparent. Much of the groundwork had been laid between the 1910's and 20's by Australian-born British physicist **'William Lawrence Bragg'** who pioneered the use of X-ray diffraction as a way to isolate single atoms of crystals. By the 30's Bragg's work had led English biochemist **'William Astbury'** to determine the structure of long-chain protein molecules such as haemoglobin and insulin and, by 1951, **US** physical chemist **'Linus Pauling'** had explained the fibrous nature of such proteins. Pauling correctly ascertained that hydrogen bonds held these elaborate molecules together into polypeptide chains which wound around one another in a helical formation.

Groundbreaking work in the field of genetics during this time was carried out by numerous pioneering scientists throughout Europe and North America. Their numbers included Canadian geneticist **'Murray Barr'** who identified dominant and recessive genes, **US** geneticist **'Edward Tatum'** who established the fundamental importance of genes in biochemical reactions, and Irish microbiologist **'William Hayes'** who discovered the existence of 'plasmids' *(**DNA** rings that are not connected to the main genetic structure within a chromosome)*. Meanwhile serious investigation had also begun into gene mutation and the disruptive effects of chemical imbalance, with important breakthroughs being made by **US** geneticists such as **'Joshua Lederberg'**, **'Herman Muller'**, and **'George Beadle'**.

Back in Britain enormous effort was being put into determining the actual structure of **DNA** ~ thanks largely to generous funding from the ***'Medical Research Council'***.

Considerable progress towards achieving this goal was made by English biophysicists **'Rosalind Franklin'** and **'Raymond Gosling'**, whose greatly improved X-ray diffraction photographs of **DNA** would serve to confirm its chemical appearance. Working at ***'King's College'*** in London, under the auspices of New Zealand-born molecular biologist **'Maurice Wilkins'**, by 1952 Franklin and Gosling had come close to producing the first accurate model of its structure. However their work was somewhat disadvantaged by the misogynous attitude of Wilkins who showed great disregard for the invaluable efforts of Franklin.

It was from a second team, based at the ***'Cavendish Laboratory'*** in Cambridge, that the double-helical structure of **DNA** was at last determined. Published in 1953, the papers of American biochemist **'James Watson'** and English biophysicist **'Francis Crick'**, caused a sensation amongst Britain's scientific fraternity. Drawing on the work of several leading academics ~ including British mathematician **'John Griffith'**, Erwin Chargaff and *(somewhat unethically)* Rosalind Franklin ~ Watson and Crick's definitive model of **DNA** proved to be a landmark for genetic science. For the first time, **DNA** was recognised to comprise an entwining pair of hydrogen-bonded long-chain molecules that were effectively mirror images of one another. Bridged by combinations of adenine and thymine *('**A**' and '**T**')* or cytosine and guanine *('**C**' and '**G**')*, these dynamic strands of life had the ability to code for their own duplication. The complex process of chromosomal division and recombination in the reproductive cycle of living cells had finally been deciphered.

Throughout the remainder of the 1950's, many scientists focused their efforts on identifying the various complimentary molecules involved in the actual synthesis of proteins for **DNA** replication. The first important breakthrough was the discovery, in 1956, of *'transfer **RNA**'* by **US** biochemists **'Paul Zamecnik'** and **'Mahlon Hoagland'**. By 1960 South African geneticist **'Sydney Brenner'** had discovered the transcription of *'messenger **RNA**'* ~ the unstable intermediary that carries sequenced messages from **DNA** to particular ribosomes.

Important research, at the turn of the decade, was also undertaken by French biochemists **'François Jacob'**, **'Jacques Monod'** and **'André Lwoff'** bringing a greater understanding into how genes are able to regulate the production of enzymes. Meanwhile the work of various independent teams of scientists, which included biochemists and microbiologists such as **'Severo Ochoa', 'Robert William Holley'**, and **'Marshall Nirenberg'**, served to confirm the chemical nature of the genetic code.

By the end of the 1960's two more significant landmarks in molecular genetics would be made. The first was the discovery of the *'restriction enzyme'*, by Swiss microbiologist **'Werner Arber'**, in 1968. Used by certain bacteria, these specialised enzymes were found to be responsible for splitting **DNA** strands at specific locations during the process of cell division, making them a vital tool to scientists working on genetic manipulation by design. The following year **US** microbiologists **'Jonathan 'Beckwith'** and **'James Shapiro'** became the first scientists to successfully isolate a single gene ~ taking bacterial genetics to a new dimension of accuracy.

The stage was now set for a new discipline to emerge and, by the early 1970's, genetic engineering would become recognised as a distinct field of scientific study. Although various scientists had been engaged in artificially transferring viral **DNA** for some thirty years, with recombinant **DNA** technology at their disposal, scientists could now manipulate genetic information with far greater precision. The work, in the mid-1940's, of pioneering **US**-based biophysicists **'Max Delbrück'**, **'Alfred Day Hershey'** and **'Salvador Luria'** was now taken a step further by a new generation of **US** geneticists. Their numbers included **'Paul Berg'**, **'Herbert W. Boyer'**, and **'Stanley Cohen'** whose work, between 1972-4, introduced innovative techniques for the splicing and recombination of genes from different species of bacteria. It was only a matter of time before new genes would be synthetically created in the laboratory. Indeed by 1976 Indian-born **US** geneticist **'Har Gobind Khorana'** and his co-workers at the ***'University of Wisconsin'*** had successfully engineered the first fully functional bacterial gene.

Such was the pace of advance in the field of genetics during the decade that by 1978 **US** molecular biologist **William French Anderson'** had successfully used recombinant **DNA** to repair genetic 'flaws' in the cells of mice. This was a momentous breakthrough that heralded the beginnings of 'gene therapy'. Yet, whilst genetics would beget a revolution in medicine, certain elements of this broad new science would send ripples of unease through the scientific establishment.

Throughout the 1950's and 60's the embryonic cells of amphibians had come under great scrutiny from **US** biochemists such as **'Robert Briggs'**, **'Thomas King'** and **'John Gurdon'**, who made important breakthroughs in the 'art' of cloning. By the 1970's several techniques for creating genetically-identical tadpoles from frog cells had been perfected, proving that each adult cell contained all the necessary genetic instructions to create a completely new individual. Once confined to the realms of science fiction, the notion of actually being able to clone human beings was now of genuine concern for many within the scientific community. Consequently molecular biologists working in various fields of research were faced with a succession of monitorial regulations designed to countenance a cautionary approach to genetic advance. However, like the inquisitive mind of mankind, the conquests of science are unstoppable, and within three decades the first cloned mammal *(**'Dolly'** the sheep)* would be successfully created from a single adult cell.

A particularly prominent scientist during the latter-half of the 20th century was renowned English biochemist **'Fredrick Sanger'**. Having already determined the structure of insulin twenty years earlier, in 1977 Sanger became the first to complete the mapping of a viral genome ~ a species of bacteriophage named *Phi-174*. With some 5000 nucleotides, the genetic decoding of this most basic life-form was an incredible accomplishment that would encourage the further mapping of more complex organisms. Along with microbiologists Paul Berg and **'Walter Gilbert'** *(who had carried out complimentary research in the **US**)*, by 1980, Sanger was officially recognised for his work in determining the sequence of nucleotides in mitochondrial **DNA**.

Of the many outstanding genetic breakthroughs during the 1980's, perhaps the most profound was the invention of the *'polymerase chain reaction' (or **PCR**)* in 1983, by **US** molecular biologist **'Kary Banks Mullis'**. Enabling the isolation and rapid synthesis of **DNA** fragments, **PCR** became an invaluable tool for geneticists working in a variety of fields, and initiated an explosion in biomolecular research. Another triumph for the science in this year was the creation of the first artificial chromosome by British-born **US** molecular biologists **'Jack W. Szostak'** and **'Andrew W. Murray'** at ***'Harvard University'***. By isolating and recombining various chromosomal elements of common bread yeast, Szostak and Murray were able to induce genetic mutations and create genotypes to their own design.

Whilst the work of Szostak and Murray greatly advanced our understanding of the critical actions of mitosis and meiosis during cell division, across the Atlantic, an entirely new field of genetic study was about to be born. In 1984, English geneticist **'Alec Jeffreys'** had stumbled across a method of reading genetic codes which allowed him to visually detect the presence of genetically inherited diseases. Known as *'**DNA** fingerprinting'*, Jeffrey's innovative technique would be further developed and adapted over the following years, greatly advancing the cause of medical, forensic and archaeological sciences. With its many civil applications, **DNA** fingerprinting is of enormous value to modern society, and has become an vital tool in the resolving of everything from criminal investigations to paternity suits.

Just as the 1980's gave rise to a plethora of new technologies, so the final decade of the century was notable for rapid advancements in genome research. 1995 saw the genetic decoding of the first free-living organism, with the bacterium *Hemophilus influenzae* being deciphered in the **US** by molecular geneticist **'Hamilton Smith'** and South African-born biochemist **'J. Craig Venter'**. In 1998 a nematode worm of the species *Caenorhabditis elegans* became first multicellular organism to have its 97-million base genome decoded, this time by an international team of geneticists led by **'Robert Waterston'** in the **US** and **'John Sulston'** in the **UK**.

By the early years of the 21st century scientists from around the globe had sequenced the genetic codes of an increasing number of species. Besides a growing array of plants, insects and micro-organisms, their numbers included a variety of mammals from rodents such as the mouse and rat, to domesticated breeds such as the horse and dog. Perhaps the most profound development however was the publication, in 2002, of the complete human genome which was found to contain over three billion base pairs. It would take another twenty years before the human genome was finally sequenced without any gaps in genetic information; a milestone that will ultimately have a profound effect on everything from 'medical care' and 'risk assessment' to 'forensics' and 'commercial genomics'.

iii.

(Agricultural genetics)

It is a sobering thought that just over a hundred of the *('quarter-of-a-million' or so)* known plant species are responsible for providing us with around 90% of the world's edible crops. Of these, wheat, maize and rice are the most heavily farmed. Furthermore, we live in an age when world farming faces unprecedented demand from rising populations, and existing agricultural land is under continuous threat of destruction from pollution, flooding and drought *(the frequency and severity of which is exacerbated by global warming)*. All of this has placed great strain upon the valuable crops on which billions of people rely for their staple diet. However, by enhancing these and other plants with foreign proteins, genetic engineering holds the promise of relieving the burden placed upon them, and has the potential to improve them in any number of ways.

By the mid-1970's dramatic advances in molecular biology were paving the way for genetic engineering to become a widespread commercial commodity. Indeed new techniques in this field had begun to cause serious concern in certain quarters of the scientific establishment. The almost limitless advantages of this new technology were invariably weighed up against growing fears of permanent damage to the environment and irreversible risk to human health. Nevertheless by the early 1980's, several industries were investing heavily in biomolecular research with a view to creating genetically engineered products.

Amongst the earliest exponents of commercial genetics were the tobacco, logging, and textile industries. In 1983 the first tobacco plant had been successfully engineered to resist certain antibiotics, and by 1986 genetically modified tobacco discreetly hit the world market. 1988 saw the planting of a large expanse of poplar trees that had been modified to produce wood with a low lignin content, and by 1992 trials for growing pest-resistant cotton plants were well underway. In fact the ability of modern science to isolate useful genes and insert them into the genomes of unrelated species greatly advantaged the production of high quality tobacco, timber and cotton.

Whilst this development didn't sit easily with the various opponents of genetic engineering, the farming of modified foodstuffs would prove to be an even more contentious issue. Yet, given the enormous demand on world agriculture and the potential profits at stake for investing industries, the growing of transgenic crops for human consumption was inevitable. Indeed most industrialists, scientists and politicians agreed that, provided 'adequate' precautions were taken, increasing agricultural productivity by encouraging farmers to grow genetically modified produce was common sense.

The first **GM** food to become commercially available in the **US** was the ***'FlavrSavr'*** tomato, which had been produced by Californian biotech corporation ***'Calgene'*** in 1996. The 'FlavrSavr' had two extra genes added to its genome, the first to make it ripen slower *(and therefore stay fresh longer)* and a second, 'marker' gene, to indicate the modification. In the same year St. Louis-based company ***'Monsanto'*** had introduced its herbicide-resistant ***'Round Up Ready'*** soya, which would become the first **GM** food to be declared fit for human consumption by the European Union.

World leaders in agricultural biotechnology, in the late 1990's Monsanto presented a public face that greatly validated its work in the field, helping to allay the uncertainty of many consumers regarding the perceived risks of eating **GM** food. Like other legitimate biotech companies, it outwardly followed strict guidelines, and all of its **GM** produce that eventually reached the open market was seen to have undergone rigorous testing beforehand. Putting profit above human health however, Monsanto's careless attitude towards biodiversity and natural ecosystems amounted to environmental vandalism, and, by the early 2000's, decades of unscrupulous business practices forced the company to defend numerous lawsuits from which it would never recover. Nevertheless, at the turn of the century, Monsanto were world leaders in **GM** agricultural technology.

The most fundamental tests, when licensing **GM** crops, included those designed to establish whether or not a donor gene has further altered the genetic coding of the recipient plant in any unseen way. Indeed it is entirely possible for added genes to change a plant's production of harmless natural proteins ~ making them toxic or allergenic to human beings. Therefore any proteins that could potentially have been modified by the addition of an extra gene were thoroughly analysed by company researchers. Typically, this involved amino acid sequences being checked for known carcinogens and allergens, whilst the product itself was fed to mice in large quantities to determine any physical side-effects that consuming it may have. Having done enough to satisfy most Western governments of their safety, by 1997 both genetically modified soya and tomatoes were freely marketed in a number of products throughout America and Europe.

In contrast to the widespread scepticism of European consumers over the past few decades, in the **US** the growing availability of **GM** foods has been received with relative indifference. Here the farming of **GM** crops, such as maize, wheat and soya, has become commonplace, and supermarkets stock a growing variety of **GM** products. Most packaging however shows little indication that its contents have been genetically modified unless, of course, it serves to promote the product. Indeed American consumers are made fully aware that the genetic modification of food can increase its nutritional value as well as make it tastier, last longer and, above all, cheaper to buy.

Since 1996, a huge variety of genes have been used to improve the quality of different products. The snowdrop gene *'GNA',* for example, produces a form of 'lectin' that is highly toxic to unwanted insects, and has been added to a range of different crops from rice to oil seed rape. Another, the ***'luciferase'*** gene *(found in all species of Arctic flounder),* led to the creation of frost-resistant strawberries, enabling this popular fruit to be grown in harsher conditions. One of the most visually startling developments of this time however was the insertion of the bioluminescent firefly gene, ***'AFP'***, into tobacco plants, making them glow whenever they needed watering.

The most widespread practice in the production of **GM** crops involves the insertion of bacterial genes into plants to make them immune to disease or resistant to certain herbicides. Of those thus far exploited, the soil bacterium *Bacillus thuringiensis (or **'Bt'**)* is the most commonly used. Genetically implanted into cotton corn and potato plants, the bacteria's ***'CryLA(a)'*** gene, for example, is particularly proficient at eradicating damaging infestations of bollworm. The incredible resilience of Bt-enhanced plants, means that farmers are able to drastically reduce the amount of harmful pesticides needed to protect their crops from disease and insect damage. However, the use of Bt as a genetic agent can also make the crop *(and nearby 'weeds')* highly toxic to diminishing numbers of harmless insects such as wild honeybees and monarch butterflies. This in turn has the potential to decimate food supplies for local populations of birds, reptiles and small rodents.

Nevertheless, by 1998 over 20% of all corn planted in the **US** had been genetically modified to produce the Bt insecticide. By turn of century, however, it was shown that small quantities of residue are exuded from the roots and foliage of **GM** corn, contaminating the soil with the Bt toxin. Although the chemical is quickly broken down when exposed to sunlight or water, it has only exacerbated the fears of environmentalists, most of whom perceive many unpredictable changes from the farming of transgenic crops.

It is not inconceivable that the pollen and seeds of engineered plants have already brought about the irreversible genetic contamination of local environments *(and wider natural world)*. Of major concern is the potential creation of so-called *'superweeds'* that, having crossbred with **GM** plants, can become resistant to the most powerful herbicides. Moreover, populous insect pests *(such as bollworms)* are not only likely to evolve a resistance to genetic toxins, but many could inherit a penchant for alternative diets ~ putting new species of plant at risk of being infected by *'superbugs'*.

All Earthly organisms are connected by a subtle interdependence, and our venture into the realms of genetic science is a major worry for all forward-thinking ecologists. In terms of agricultural expansion, the ripples that our forebears made across the world's delicate ecological balance have become waves of almost oblivious disharmony. Of course traditional methods of hybridisation have been going on since the Neolithic age, but until now it has been humanly impossible to break the species barrier. Indeed, until heredity was first seriously studied in the mid-19th century, the specialised breeding of plants and animals for particular traits was not a precise science but a comparatively haphazard process. Thanks to incredible advances in genetic engineering, however, all kingdoms of life can now be crossed and we are able to combine the genomes of any living species at will.

The introduction of transgenic crops has also brought about an entirely new kind of threat to surrounding environments. For the first time, cultivated plants have the potential to be more competitive than their wild counterparts and, if not properly constrained, could eventually change the face of entire ecosystems. Furthermore in societies where the capitalist ideals of liberty and prosperity are foremost in the cultural mindset, preserving the natural environment is still a secondary consideration. In the **US**, for example, the considerable political influence of the biotech industry, along with the farming community's strong union representation, has led to many laws *(governing agricultural genetics)* being barely adequate. Here precautionary measures are often taken through tacit agreements with state regulators, and genetic farming *(both arable and livestock)* is guilty of widespread misconduct. The greatest risks to health *(both environmental and human)* arise from acts of carelessness ~ such as the 'unintentional' cross-pollination of **GM** crops with those organically farmed in the local vicinity, and the inadequate segregation of genetically enhanced livestock from their naturally-bred counterparts.

Perhaps the most prevalent concern of consumers in the developed world is the danger that rogue proteins from genetically altered products could find their way into the human food chain undetected. The safety of **GM** foods is always under great scrutiny, and failed trials have revealed that certain genetic modifications can create toxic side-effects, induce allergies and illnesses, or even cause fatalities. During the 1990's, many unfortunate mistakes were made in the preparation of new **GM** products which had been developed for human consumption. Examples include the cultivation of **GM** maize that conferred resistance to all known antibiotics, and the creation of soya beans that, having been modified with the genes of brazil nuts, caused a serious allergic reaction in several test subjects. One of the most publicised misjudgements of the time involved the licensing of a nutritional supplement for which genetically engineered bacteria had been used to produce an essential amino acid. This synthetic version of *'L-Tryptophan'* contained an unexpected contaminant that was blamed for the deaths of over thirty people in the **US**.

Besides putting human health at risk, genetic manipulation *(combined with our relative indifference to nature)* is, at best, responsible for destabilising local ecosystems and, at worst, capable of diminishing the natural biodiversity of the planet. However, the general consensus amongst most governments and scientific communities is that the benefits of agricultural genetics far outweigh the risks. Outwardly, human health is always of primary concern to authority and, by moving forward with genetic technology, we are presented with the only way to practically put an end to world famine.

In terms of human life, the stakes are highest in developing nations where good harvests are essential to the survival of millions of impoverished people dependant on subsistence agriculture. The introduction of bacterial transgenes into staple plants could be of great benefit to poorer regions of the world, giving farmers here the ability to grow crops in the most unlikely conditions. Indeed crops such as wheat, maize and barley have already been engineered to thrive in poor soils with a resistance to acidity, or tolerance to high levels of salt. A particularly significant advance for '*Third World'* agriculture was the first harvest, in 2000, of a rice crop that carried three transgenes from the wild daffodil. Of enormous value to deprived rural communities in Eastern Asia, this modification has enabled rice bran to become a source of beta-carotene, thus protecting people, whose only staple diet is rice, from the debilitating illnesses associated with 'vitamin A' deficiency.

It is of little surprise, therefore, that in China there is essentially no opposition to the full-scale conversion of its population to a **GM** diet. Indeed by 2010, over 90% of all

Chinese crops were genetically modified, vastly boosting its endeavour to feed over one billion people. At the time, it was expected that, within another decade, Chinese agriculture would either lead the world in genetic farming *(outstripping **GM** production in Europe and North America)*, or it would face a catastrophe that had the potential to destabilise the whole of south-east Asia. Meanwhile most rural farmers in China, beset with the bliss of ignorance, had no concept of the science that went into these '*magical seeds'* or the ethical issues that they raised.

This amazing technology has allowed us to create robust strains of hybridised organisms whose very existence flies in the face of natural law. Furthermore our willingness to alter domestic plants and animals to suit our needs, raises the moral question of whether agricultural genetics will ultimately be of greater benefit to mankind as a whole or just those with a financial interest. The whole ethos of the industry is illustrated well by the introduction, in many **GM** crops, of so-called *'terminator genes'*. These are added to sterilise adult plants thus forcing farmers to purchase new seeds every year, rather than sow those collected from their last **GM** harvest. This double-edged innovation not only serves to prevent this hazardous technology from getting out of control, but it further boosts the commercial power of controlling biotech corporations.

During the 1970's and 80's an enormous effort was put into cloning mammals by scientists across Europe and America. Attempts were made at cloning everything from mice to cattle, with important exploratory advances made by embryologists such as **'Karl Illmensee'**, **'Davor Solter'** and **'Neal First'**. Perhaps the single greatest advance of this time was made by **UK**-based Danish geneticist '**Steen Willadsen'**, who developed a successful method of cloning animals from the nuclear transfer of embryonic cells.

Whilst working for the ***'Agricultural Research Council'*** Willadsen perfected a technique that involved removing the nucleus of an unfertilised egg and replacing it with an unrelated eight-cell embryo. By continuing the pioneering work of German embryologist **'Hans Spemann'** *(who, in 1928, had successfully applied a similar technique for cloning salamanders)*, in 1984 Willadsen created the very first genetically identical sheep. Furthermore, his method of cloning by nuclear transfer not only enabled him to produce unusual chimeras such as 'sheep-goats' and 'sheep-cows' but it generated an entirely new, and highly commercialised, form of agricultural industry based around the production of elite bioengineered cattle.

In 1997 the announcement that a sheep had been successfully cloned from fully differentiated adult cells was met with universal astonishment. The creation of ***'Dolly'*** *(the first ever mammal to have been cloned in such a way)* was undertaken at the ***'Roslin Research Institute'*** near Edinburgh by Scottish geneticist **'Ian Wilmut'** and English microbiologist **'Keith Campbell'**. Produced from a mammary gland cell of a six-year-old ewe, Dolly was the result of Wilmut and Campbell's dedicated persistence *(indeed it took 277 attempts and over 300 embryos before Dolly was eventually 'created')*.

An extremely delicate science in its infancy, the cloning of mammals was fraught with all kinds of dangers. Using current techniques, scientists wishing to clone a single prize bull, for example, had to contend with many misconceptions and an abnormally high mortality rate amongst developing foetuses and new-born calves. Moreover, questions arose as to whether or not the chemical tags of certain genes remained switched on once a cloned cell has been transferred to a surrogate egg. In the case of Dolly, having been cloned from a six-year-old ewe, an active ageing gene would have effectively deprived her of the first six years of her life. Although Dolly was able to give birth naturally within a year of her creation, she herself only survived for six years before falling victim to arthritis, eventually dying from a severe lung infection in 2003.

Over the final years of the 20th century the 'art of cloning' improved significantly, and a variety of species were cloned by various teams of geneticists around the world. In 1999 variations of the same technique had been used to clone cows, goats and mice, and by the start of the next decade, pigs *(2000)*, cats *(2002)*, and horses *(2003)* had joined the growing list of cloned animals. In 2004 scientists endeavouring to clone certain mammals could expect just a 3% success rate *(from the culturing of a donor cell to fully grown adult)*. By the mid-2010's the rate of success had risen *(for some species)* to up to 80% and, with techniques continuously improving, in 2017 the first ever primate clones took the form of two identical macaques, created by '**Mu-ming Poo'** and his team at the '***Chinese Academy of Sciences'*** in Shanghai.

Despite the involute complexities of practical cloning, the mere ability to create life by genetic design has led to the birth of several new industries, Indeed the many potential applications for this new technology are wide and varied. In terms of modern agriculture, there is a growing market for genetically engineered stocks of disease-resistant cattle, sheep and pigs, whilst thoroughbred horses, racing camels, and even beloved household pets can now be modified or duplicated. In terms of commercial cloning: there is the active pursuit of creating new breeds of livestock designed to produce prime cuts of meat or yield a high production of low fat milk. Meanwhile, at the other end of the spectrum, a growing number of **US** companies now offer animal cloning as a private service, thus enabling paying customers to know the character and temperament of their new pet before it was actually born.

Primarily funded by agricultural, pharmaceutical and military concerns, in the early 21st century, the 'miracles' of modern biotechnology are fast becoming a public commodity. Yet, not all genetic research is directly driven by profit or war. Many conservationist groups, for example, recognise the importance of utilising modern genetics as a way to preserve the ecological integrity of the planet. It is to this end that genetic engineering may eventually prove invaluable to our humanity.

Unfortunately, with current technology, the intriguing idea of being able to breathe life back into species that we have already destroyed is a somewhat fanciful one. Indeed early 21st century genetic science is far from realising the advanced states of technology that are portrayed in many works of popular fiction. For example, the concept of genetically replicating birds *(such as the moa, dodo, and great auk)* that were hunted to extinction in earlier centuries, is acutely unrealistic. Even endeavours to resurrect more recently extinct mammals *(such as the Caspian tiger, quagga, and bucardo)* have, thus far, proven fruitless. The delicate **DNA** structure of any living organism will rapidly deteriorate once it has died. Therefore when a species becomes extinct, its unique coding for life is lost forever. Unless, of course, a sample can be preserved in some way soon after its demise.

One salient example of what genetic technology may soon achieve is the revival of the thylacine *(or 'Tasmanian wolf')* ~ a predatory marsupial which was systematically hunted to the point of extinction during the 19th century. A final act of negligence saw the last known example die in captivity in 1936, but, by 2002, scientists at the ***'Australian Museum'*** in Sydney had successfully replicated **DNA** fragments from a dead thylacine pup. Preserved in alcohol for over a century, the genetic structure of the specimen has seriously degraded, however, at the current rate of advance, it is only a matter of time before cloning technology will have progressed sufficiently enough to determine the missing **DNA** and complete the animal's genome.

Yet even if such goals were achieved, the problems facing thylacines cloned from the dead *(like any other animals that we may one day care to resurrect)* would be enormous. Unless we simply aimed to make multiple clones of the same creature for the sake of scientific curiosity, we would be faced with the almost insurmountable task of its natural reintegration into the living world. Any such species would be fundamentally incapable of further procreation without our ability to produce suitable sexual partners, and so once more engender genetic diversity amongst its numbers.

A more realistic prospect for 'ecological genetics' concerns the preservation *(and eventual revival)* of the many critically endangered species that we are presently aware of. Genetic technology is already at the forefront of various conservation projects that aim to save any number of rare species that are presently under serious threat of extinction. These include a vast array of exotic animals such as the 'giant panda', 'white rhinoceros', 'woolly spider monkey', 'kakapo', and 'gaur'.

It is not only endangered animal species that could benefit from advances in genetic technology. Human activity has had an even greater impact on the world's flora, and attempts to conserve plant diversity are exemplified by the ***'Millennium Seed Bank Partnership'***. A remarkable global conservation initiative managed by the ***'Royal Botanic Gardens'*** at Kew, in London, the Millennium Seed Bank was originally set up in 1993, and currently aims to collect the seeds of over 75,000 plant species ~ many of which are under the direct threat of extinction. Of vital importance to environmental preservation, projects such as this could also prove of enormous value to the future of world agriculture and medicine. At worst, they are unintentionally guilty of breeding complacency amongst those who regard the environment as an expendable commodity.

iv.

(Medical genetics)

Although our societies reap the benefits of technological advance, we must also increasingly reckon with the consequences of many years of human interference with nature. For example, the mass production of various disinfectants, combined with our somewhat negligent overuse of antibiotics, has inadvertently created robust strains of highly resistant bacteria. Indeed, long before the advent of genetic engineering in the 1970's, human activity was guilty of accelerating the natural evolution of many pathogenic micro-organisms.

Now, as the 21st century begins to unfold, we find ourselves with a growing ability to actually shape the course of evolution and literally make us *'the gods of our own destiny'*. If employed sensibly, genetic technology not only has the potential to repair much of the damage that we have already inflicted on the world's delicate ecosystems, but it offers us the hope of improving human life in ways that were inconceivable just a few decades ago. Unfortunately we live in a world where our intellectual desire for knowledge exceeds our moral pedigree, and the pursuit of science is primarily driven by a hunger for power and material wealth.

With regards to motive, scientific advance knows no discrimination, and when the genetic alteration of micro-organisms began in earnest during the 1970s, molecular biology came of age. This far-reaching field of research would prove to be of enormous value to many lines of scientific enquiry. Whilst its military applications *(for biological warfare)* were immediately obvious to governments on both sides of the 'Iron Curtain', civil research was largely funded by America's powerful pharmaceutical industry, and one of the first major disciplines to benefit from advances in genetic research was modern medicine. In 1977, for example, the genetic code for human growth hormone *'somatotropin'* was determined by **US** biochemists **'John Baxter'** and **'Howard Goodman'** at California-based biotech company ***'Genentech'***. The next year a team of Genentech scientists, led by **'Roberto Crea'**, had managed to synthesise the human insulin gene.

Following enormous investment from pharmaceutical giant ***'Eli Lilly & Co.'***, by 1982 the first recombinant **DNA** insulin was licensed. Having been genetically engineered in *E. coli* bacteria and cultivated in tobacco plants, ***'Humulin'*** went into full commercial production in the same year. By 1985 the first human 'cancer gene' was successfully isolated, this time by a team led by eminent biochemist **'Robert A. Weinberg'** at the ***'Whitehead Institute for Biochemical Research'*** in Massachusetts. Responsible for regulating cell division, the *'Rb'* gene was the first 'tumour suppresser' to be identified, and was discovered to always be inactive in sufferers of the debilitating eye cancer *'retinoblastoma'*.

Over the final decades of the 20th century, pharmaceutical interests, such as ***'Bayer'***, ***'SmithKline Beecham'***, and ***'Glaxo Wellcome'***, financed important research into genetic disease, with a view to curing everything from leukaemia to schizophrenia. They were joined by a growing number of biotech companies, including ***'Genzyme Transgenics'***, ***'PE Biosystems'***, and ***'Advanced Cell Technology'*** ***(ACT)***, and the medical benefits of genetic engineering were increasingly realised.

One such advance was initiated at the '***Roslin Institute'*** by British molecular biologists **'Ian Wilmut'** and **'Keith Campbell'** in 1998. Having been the first to successfully clone a mammal from an adult cell, Wilmut and Campbell turned their attention to creating transgenic sheep whose milk contained an additional human gene to combat haemophilia. The idea of engineering animals to produce *'factor VIII' (an essential human protein which causes blood clotting)* was taken a step further by **ACT** biochemists **'James Robl'** and **'Steven Stice'** who, within a year, had successfully produced calves with the view to 'pharming' cattle for the same purpose. Yet the use of crops and livestock as living factories for human proteins was just one area in which genetic engineering could serve modern medicine.

By turn of the century the first breakthroughs occurred in what may prove to be the most far-reaching scientific development of all. In 1999 the chemical code for the entire human chromosome was deciphered by a team of scientists working for the publicly funded ***'Human Genome Project'***. An international collaboration, inaugurated a decade earlier by the ***'Human Genome Sequencing Consortium'***, the project was primarily led by geneticists **'Francis Collins'** in the **US**, and **'John Sulston'** in the **UK**. It set out to undertake the huge task of mapping the relative order of genes along the human chromosomes, thus enabling scientists to read the entire code of human **DNA**.

Eight years into the project, a rival bid to map the human genome was announced by private **US** biotech enterprise ***'Celera Genomics'*** ~ directed by its cofounder **'J. Craig Venter'**. Following bitter wranglings between the two ventures *(which involved serious political and economic pressure)* the year 2000 saw a joint announcement that the first working drafts of the human genetic code had been completed. The eventual prospect of understanding the function of every individual gene maintained co-operation between the two organisations, and the complete human genome was formally published in 2003.

A milestone in modern science, the resulting data is set to revolutionise our understanding of human life and reveal the very essence of our species. Within a year of its completion, the genetic information had become freely available to researchers wishing to investigate the function of any particular gene, as well as to anyone capable of misusing it to pursue their own agenda, whatever it may be.

Cracking the human genetic code has confirmed the existence of approximately 3.2 billion bases, now known to contain around 23,500 genes. Working either singularly or in combination with one another, these genes are ultimately responsible for everything we are, both as human beings and as individuals. However active genes occupy only a tiny part of human **DNA** *(98% of which comprises non-coding '**DNA**)* so, finding and identifying the actual role of each gene is a monumental task. Yet, by the start of the 21st century, technology had improved to the extent that tens-of-thousands of bases could be sequenced in a matter of seconds.

Determined at conception, our genetic make-up decides everything from our physical appearance and mental aptitude, to the way we will grow and respond to the 'nurturing' of life's experiences. Importantly for modern medicine, the human genome holds the key to our relative susceptibility to all sorts of ailments. The potential benefits of a new kind of medicine, *'gene therapy'*, are indeed far reaching ~ holding the prospect of eliminating hereditary disorders and dangerous diseases such as muscular dystrophy, diabetes, and **AIDS**. Moreover genetic medicine offers the realistic hope of cures for a host of common afflictions such as asthma, migraines, and even acne. One example of the project's potential impact on human life was the subsequent discovery of the **BCL10** gene whose activity is, in part, responsible for triggering the onset of most major cancers including lung, breast and colon cancers.

Armed with the genetic blueprint for human life, medical science is becoming ever more adept at isolating the various genes involved in specific ailments. Indeed genetic diagnosis is advancing at such a pace that medical treatment based on the sequencing of a person's genetic make-up will invariably become available. Furthermore the effects of a medicine that replaces defective genes can be carried though a patient's 'germ line', thus eradicating genetic abnormalities from all future generations.

Such drugs could also be utilised for cosmetic purposes, i.e.; to remove unwanted traits or introduce favourable characteristics in the progeny of those wealthy enough to buy their own heredity. By offering genetic improvements, albeit to a privileged minority, we are effectively taking the first step towards gaining total control of our own evolution. Yet by creating future generations by design we not only compromise the individuality of our children, but *(in the spirit of 'eugenics')* we impress our own values and preferences upon our offspring without their knowledge or consent.

Whilst the prescription of personalised drugs is likely to become a reality in the near future, genome research also has wide implications for conventional medicine. Healthcare, *(even in the developing world)* could benefit from the continued genomic 'mapping' of other species. Indeed the sequencing of different genomes is likely to reveal the existence of previously unknown proteins, some of which could be of great value to human medicine. Such proteins would provide the blueprints for synthesised drugs that do not place further strain on the worlds depleting natural resources.

Towards the end of the 20th century, the genetic screening of human embryos had become increasingly commonplace. Prenatal diagnoses of many congenital disorders, including Down syndrome, haemophilia, sickle-cell anaemia and cystic fibrosis, were now available. Indeed by the turn of the century, improvements in technology had enabled a growing number of expectant mothers to undergo tests to detect chromosomal abnormalities and even single gene defects in their unborn children.

Modern obstetrics lies at the heart of genetic medicine, and important techniques in this field have provided geneticists with a means to unlock the secrets of human development. The introduction, for example, of ***'In Vetro Fertilisation'*** *(or **IVF**)* enabled embryologists to fertilise human eggs externally, and replant them as developing embryos. An effective form of fertility treatment, **IVF** was pioneered in 1978 by English obstetricians **Patrick Steptoe'** and **'Robert Edwards'**, and has given hope to many thousands of childless couples. Indeed by the turn of the century a further 300,000 births using the **IVF** technique had followed that of **'Louise Brown'** ~ the world's first 'test tube baby'.

By 1989 **IVF** technology had instigated the development of a new procedure known as ***'Pre-implantation Genetic Diagnosis'*** *(or **PGD**)*. Pioneered at the ***'London Bridge Centre'*** by a team led by English embryologist **'Alan Handyside'**, **PGD** involves removing a single cell from an eight-cell embryo to study its genetic makeup. In this way healthy embryos are either selected for implanting into the patient's uterus, or stored for future use, whilst those with chromosomal abnormalities or undesirable genetic defects are naturally rejected. Primarily used to help couples with a history of genetic disease, the technology also has the potential to allow prospective parents to discriminate against otherwise healthy embryos on the grounds of aesthetic choice. **PGD** is therefore strictly regulated in most Western nations yet, by the turn of the century, it had resulted in the births of over a thousand children worldwide.

The availability of **PGD** continues to grow as technology advances, and it is being increasingly used to help parents with terminally ill children. By conceiving a second child which has been 'genetically selected' to be an ideal donor for its older sibling, many parents have been spared the heartbreak of helplessly watching their children die from inherited diseases.

In terms of the technology itself, it has been established that, in many cases, the optimum time for implantation is during an embryo's late 'blastocyst' stage of development *(whilst containing around 120 cells)*. However this was virtually impossible until the beginning of the 21st century, when new kinds of nutrient-rich culture media were developed that were capable of sustaining embryo growth in laboratory conditions. This ability to grow embryos for more than a few days outside of the womb, has advanced another line of genetic research surrounding *'stem cells'*.

Discovered in the early 1960's, 'adult stem cells' were first isolated and cultured in 1988 by a team at ***'Stanford University'*** led by **US** microbiologist **'Irving Weissman'**. Otherwise known as *'multipotent'* cells, they can be found in the blood, bone marrow, skin and brains of every living animal, and have the ability to regenerate old or damaged tissue. Because they are not fully matured, adult stem cells are able to undergo a process of self-renewal in order to replace a particular cell type. In a young healthy individual, bone marrow stem cells, for example, can spawn approximately 20,000 fully differentiated cells to repair localised damage.

In the 1980's the existence of 'embryonic stem cells' were confirmed and, by 1998, these too were cultivated; this time at the ***'University of Wisconsin'*** under the guidance of embryologist **'James A. Thomson'**. These *'pluripotent'* cells were found to form after around six days of embryonic development *(during the early blastocyst stage)* and have the potential to develop into any one of the 200 or so types of human tissue ~ their eventual outcome being determined by specialised proteins ~ or ‘growth factors’.

Stem cell technology in the 21st century has taken great strides forward thanks to the work of leading embryologists such as **‘John D. Gearhart’**, **‘Thomas Okarma’**, and **Gail Martin’**. One promising new area of stem cell research is *‘therapeutic cloning’* which holds the prospect of preventing numerous degenerative diseases. Indeed the ability to cure patients of serious hereditary afflictions such as leukaemia, multiple sclerosis and Parkinson’s disease has become a distinct reality.

By using a technique known as ‘nuclear transplantation’, scientists can, for example, grow skin cells in culture to obtain embryonic stem cells that are a perfect genetic match for any individual. In harvesting these stem cells from cloned embryos it is possible to repair or replace damaged tissue without the problem of rejection by a patient’s immune system. This important benefit of therapeutic cloning therefore negates the need to administer immunosuppressive drugs, many of which can have debilitating side-effects. Indeed a growing number of clinics now offer a service for concerned parents, wherein samples of umbilical cord blood are frozen so that their child is equipped for life with a ready supply of stem cells.

Although embryonic stem cell research faces continual obstruction from various so-called ‘pro-life’ groups with their own ethical or religious agendas, the technology has the potential to save millions of lives. Moreover, because stem cells can be used to regenerate brain, heart and other muscle tissue, public and private health care could greatly benefit, and the quality of life for entire populations could be significantly improved. Therefore stem cell research *(particularly in the US)* at the start of the century has also focused heavily on ways to convert adult cells into pluripotent types.

With huge financial incentives for the **US** pharmaceutical industry, medical science is beginning to harness the power of adult stem cells. Not only could they potentially be engineered to grow any type of cell necessary for a cure, but they have the capability to rejuvenate the mind and body, and so increase human longevity. Indeed, as technology improves, the art of therapeutic cloning is likely to one day encompass entire human organs which have been grown in cell culture.

Within the first year of the new century, science had already shown that bone marrow stem cells could be reprogrammed to produce immature neurones. Meanwhile considerable effort was being put into finding and cultivating neural stem cells, which could be used to treat everything from Alzheimer's to diabetes. The concept of ‘cell replacement therapy’ has attracted powerful investors keen to patent what has been termed a *‘medicine for the masses’*. At stake are huge profits for American biotech companies such as ***‘ReNeuron Ltd.’***, ***‘CytoTherapeutics Inc.’*** and ***‘Stem Cells Inc.’***, all of which have invested heavily in this exciting, but controversial technology.

The dramatic progress of biomolecular science during the late 1990's was truly astounding, and the new century held the promise that advanced gene therapies would soon become available. Many techniques were applied in the development of powerful new drugs that were designed to attack intractable diseases or repair injuries that would otherwise prove fatal.

In 2001, for example, a team led by **US** neurologist **'Paul Sanberg',** at the ***'University of Southern Florida'***, endeavoured to repair stroke damage *(initially in laboratory mice)* by injecting tumour stem cells directly into their brains. Having first been treated in retinoic acid, the teratoma cells were induced into growing unaffected new brain cells. Another line of research took place at ***'Cornell University'*** where molecular biologists investigated ways of inserting healthy genes into damaged cells in order to repair genetic flaws. This was done by developing drugs which contained engineered viruses that had been encoded with copies of specific human genes. Although initially inconclusive, these early trials were promising, and work continued with the eventual aim of being able to fully restore the motor and cognitive responses of human patients.

Technology such as this is set to revolutionise therapeutic and preventative medicine, and few would argue that it has the potential to save countless lives. The greatest bone of contention however lies in the actual cloning of human cells ~ a necessary element of many genetic therapies. The first recorded cloning of human cells took place in 1993 at the ***'George Washington University'*** when **US** researchers **'Jerry Hall'** and **'Robert Stillman'** successfully separated the primary cells of abnormal human embryos. Considering it to be an extension of **IVF** technology, Hall and Stillman's method of 'embryonic twinning' *(although not true 'cloning')* generated intense ethical debate. Three years later, an altogether different procedure was attempted by Argentinean-born microbiologist **'José Cibelli'** at the ***'Massachusetts Institute of Technology'***. Cibelli successfully managed to insert genetic material from one of his own skin cells into the emptied egg of a cow. After subjecting the egg to a minute electric charge, the cell began to divide and grow ~ continuing for twelve days before degrading.

As the decade progressed, technological advance had begun to open up a host of new possibilities for genetic medicine, and the further cloning of human embryos was inevitable. By 1998 the first actual cloning of a human embryo took place at ***'Kyung Hee University'*** in Seoul, South Korea. Under the guidance of leading embryologist **'Kim Seung Bo'**, researchers removed the nucleus of a human egg and implanted a cell from the donor's own body. After activating the genes with a small pulse of electricity, the cell successfully divided ~ apparently reaching the same stage of embryonic development as an egg used for **IVF** treatment. Although there is no evidence to corroborate Seung Bo's work, he claimed to have stopped short of implanting it back into the donor's womb purely because of the moral ramifications of doing so.

The enormous medical benefits of therapeutic cloning are matched by its huge financial potential, and by 2001 Massachusetts-based company '**ACT**' had begun to take the art of human embryo cloning to the world of commercial enterprise. Yet there is a huge difference between cloning human embryos and the ability to clone fully developed human beings; a venture that no reputable biotech concern dare undertake *(at least not publicly).*

DNA is an extremely delicate and highly sensitive medium, and any attempt to create a human clone with current technology would, at best, be irresponsible. The hard earned successes achieved by animal geneticists have shown cloning to be a very precise science, with hundreds of miscarriages for every birth. Indeed any living cell that has been manipulated and cultured in the harsh environment of a laboratory becomes susceptible to an array of unforeseen hazards, and most subsequent embryos will not survive beyond a few weeks. The slightest changes in conditions can induce epigenetic influences that have the potential to cause subtle alterations within a genetic code. Nevertheless, countless doctors worldwide are willing to create human clones for childless couples and bereaved parents.

Despite being outlawed in most countries, as the new century unfolds human cloning is likely to prove an increasingly lucrative business. At the start of the century many teams were involved in the race to create a fully developed human clone, including those led by Italian physician **'Severeno Antinori'**, Greek physiologist **'Panayiotis Zavos'**, and **US** embryologist **'Richard Seed'** ~ all of whom made important inroads into bringing human cloning a step closer to reality. Then, of course, there was French-Canadian research biologist **'Brigitte Boisselier'** who, in 2002, announced the birth of the first 'cloned' human baby. Scientific director of ***'Cloneaid'***, Boisselier undoubtedly made the dubious claim to gain publicity for the ***'Raelian'*** sect; a quasi-religious American cult that actively encourages the cloning of humans ~ believing that we are all the cloned products of extraterrestrial visitors.

Back in the world of consensual reality, the intentional cloning of human beings is generally regarded as an unnatural and unhealthy consequence of genetic technology. Nevertheless, the irreverence of scientific advance makes the mere possibility of human cloning a distinct probability. Despite the fanciful ideas of Boisselier however, the first human clones are most likely to result from a more conventional approach to the science. Indeed more 'orthodox' research *(such as Antinori's endeavours to clone 'lesser' primates)* is highly likely to yield what most would regard as an unwelcome development.

With Christian ethics at the heart of anti-cloning sentiment, many people are beset with the fear that in 'playing god' we compromise our own humanity. From this viewpoint comes the dangerously misguided belief that a human clone would somehow be 'inhuman'. Yet 'natural clones' exist in the form of identical twins, with multiple births occurring amongst the general population at a rate of approximately 1:330. Such twins, although genetically identical *(and often subjected to the same social stimuli)*, still grow into unique characters because their experiences as individuals can never be *exactly* the same throughout their lives. Of greater concern should be the unhealthy expectations placed on any unfortunate individual who grows up to discover that they are a genetic copy of someone else.

V.

(Moral objections)

No other scientific field has proven so troubling to our collective sense of moral integrity as genetic biochemistry. The whole ethos of the science is surrounded by controversy; from the early concepts that lay the foundation for the modern study of genetics, to the once fanciful works of fiction by writers whose stories of biological manipulation have become increasingly poignant. Precursors to the study, such as **Charles Darwin**'s proposal of evolution through *'natural selection'* and **'Francis Galton**'s method of improving human heredity through *'eugenic selection'*, have been regarded with equal abhorrence as the fantastic but prophetic writings of biologist **'J.B.S. Haldane'** and novelist **'Aldous Huxley'**.

Despite its incredible potential to save and improve billions of lives, many people believe genetic engineering to be an affront to the religious and moral sanctity of human life. When such notions are combined with a widespread cynical distrust of government and industry *(as well as a natural fear of the unknown)* protest and confrontation are inevitable. It is not surprising therefore that genetic biotechnology has become such a contentious issue throughout the Western world. Yet our natural curiosity is an irresistible human quality that cannot be overcome by outmoded religious values, and the genetic sciences will continue to both improve our understanding of the living world and intensify our exploitation of it.

So long as Western civilisation does not fall into anarchy, the most extreme fears of those who oppose genetic research are highly unlikely to materialise. However the mere idea of being able to engineer life *(including human life)* to any design we wish illustrates how the perceived boundaries of possibility are continuously being broken by science, and nothing we can imagine remains forever impossible. For that reason the birth of genetic engineering has been aptly compared to the opening of '*Pandora's Box'*.

In terms of environmental impact, our ability to manipulate life at a genetic level is truly double-edged. On one hand it could save a multitude of endangered species from an inexorable decline towards extinction, yet on the other, it has the potential to upset entire ecosystems whose complexities we do not *(as yet)* completely understand.

In 2005 an international consortium was set up to co-ordinate the 'bar-coding' of every known species on Earth. By analysing a specific segment of **DNA** in a universally found gene, this enormous conservation project aimed to catalogue the planet's biodiversity so that we may preserve its integrity. Yet for thousands of years we have inadvertently *(or otherwise)* destroyed the natural world around us, and now that modern science has '*let the genie out of the bottle'*, we also have the ability to exploit nature in ways that we could not even have begun to comprehend just a few decades ago.

From preventing mass extinction to ending famine and disease, the benefits of genetic engineering are almost endless. But the whole idea of a science that lays bare our very humanity sits uncomfortably with even the most astute temporal thinkers of our age. Genetic technology is readily applied to our perceived moral endeavours to both save human life and conserve the natural world around us. However it is also human instinct to exploit any opportunity that we create, and by deciphering the code of life we open up the very essence of our own existence to the uniquely human world of patents and ownership.

Regardless of intent, many developments in the field of genetics remain morally questionable, not least from the unknown risks taken by the agricultural and pharmaceutical industries whose corporate investors are driven only by profit. Moreover the pace of advance in genetic research and development is such that the scientific establishment continually struggles to allay public fears regarding its effect on human health and the environment. Indeed this highly sensitive issue has generated heated debate throughout the Western world, where frequent protests *(both passive and disruptive)* illustrate the deep divide of people's convictions.

A prime example of the controversy surrounding genetic technology concerns the work, in 1998, of Hungarian-born nutritionist **'Árpád Pusztai'**. Pusztai headed a team, at the ***'Rowett Research Institute'*** in Aberdeen, which tested a variety of genetically modified potatoes on laboratory rats over a determined period of time. Certain modifications showed *(albeit scant)* evidence of stunted growth and depletion of the rat's immune systems. Of particular interest were potatoes with an added gene that produces '**GNA**' *(or snowdrop lectin)* ~ a powerful insecticide used in a variety of **GM** crops. Normally harmless to mammals, the **GNA** protein appeared to make subtle alterations to the genetic code of the virus used to carry the snowdrop gene into the potatoes, resulting in their mild toxicity. Yet following a television interview in which Pusztai expressed his concern about certain **GM** foods, he was suspended from duty at the institute, whilst his results were discredited by the scientific establishment.

Despite subsequent validation of Pusztai's findings by various independent teams of scientists around the world, the ***'Royal Society'*** *(Britain's foremost scientific body)* continued to regard his work as having been wholly inconclusive, and his reputation as a respected member of the scientific community was shattered. The Pusztai affair, as it became known, highlighted inconsistencies in the trustworthiness of modern scientific research. At best, the scientific establishment had attempted to prevent what it considers 'flawed' or 'inappropriate' research from furthering public distrust of a legitimate genetics industry. At worst the industry itself was involved in public deception, with the underhand tactics of various biotech concerns stifling the credibility of any research that challenged the safety of their licensed products.

Although genetic technology in the Western world is subject to stringent regulations, the same is not true in places such as China and North Korea. Here the interests of the individual are considered to be no different from those of the state, so any genetic research and development goes unchallenged. However, in an open democracy where private enterprise generates a profusion of new ideas, the authorities can never fully legislate for the many ways of exploiting *(and often abusing)* the dynamic field of genetics. The natural concerns of a comparatively educated and informed population are often compromised by powerful corporations *(with considerable political influence)* which continue to legitimise research that is geared towards achieving favourable results. One consequence of this is a general acceptance of inadequate safety measures that do not consider the longer-term implications of altering the genetic make-up of consumable produce. Most immediately 'inapparent' to the Western consumer is the indefinite labelling of **GM** food. Whilst **EU** regulations now stipulate that any product containing at least 1% **GM** ingredients must be clearly labelled, no such legislation exists outside of Europe.

When you consider that most Western governments have historically been guilty of gross negligence towards matters of public health, the growing availability of **GM** products can seem a little unsettling. Throughout the 1930's and 40's, for example, cigarette consumption was actually encouraged, with the tobacco industry boosted by claims that smoking actually helped to increase concentration. In the late 1950's and early '60's Thalidomide was commonly prescribed to pregnant women as a safe and effective sedative, resulting in the births of thousands of physically deformed children. For many environmentalists, the 'unofficial' introduction of **GM** crops into the food chain from the early 1990's heralded the latest *(and potentially the greatest)* threat to public health.

There are many unknown quantities involved in genetically modifying organisms for human consumption. One example results from the isolation of certain animal genes that could greatly improve the efficiency of various plants. The commercial growing of such transgenic crops would not only pose a moral dilemma for many vegetarians, but it also has the potential to affect the balanced diets of numerous species, and therefore seriously disrupt the food chain. However the wider media *(particularly throughout the **US**)* is largely disinterested in the more complex intricacies of genetic agriculture. It is captured only by sensationalist stories, such as those of scientists creating headless frogs or four-legged chickens. In a media-led consumer world that is ultimately driven by corporate power, market value invariably compromises moral duty, and most people remain ignorant of its far-reaching consequences.

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By the turn of the 21st century, the rapid advance of genetic technology had given rise to many important medical breakthroughs. Certain surgical procedures, for example, could now be performed without the need of unpleasant immunosuppressive drugs; taking areas of medical research, such as 'xenotransplantion', to new levels of success. With a general shortage of suitable human donors, genetically modified mammals were now reared specifically as an alternative supply of donor organs. A good illustration of this development was the commercial pharming, from 2001, of cloned pigs with a particular gene *(alpha 1.3 galactosyl transforax)* deactivated ~ preventing the human immune system from rejecting their organs.

Recombinant **DNA** technology was first developed in the 1970's by pioneering biochemists who succeeded in splicing and mixing genes from separate viruses. One of the most prominent characters in this field was renowned **US** molecular biologist

'Paul Berg' who, in 1972, engineered the ***'SV40'*** and ***'Lambda'*** viruses to create an entirely new strain. Conscious of the safety implications of this new technology, Berg fought to place a brief moratorium on recombinant **DNA** research. By 1978 however, his successful work in genetic transplantation between mammals had encouraged further transgenic experiments. Other notable advances over the following decades were made by scientists such as British zoologist **'Anne McLaren'**, Polish embryologist **'Andrzej Tarkowski'**, and **'Martin Evans'** ~ an English geneticist whose *'gene targeting'* technique has been used to fine-tune various methods of embryo manipulation.

Despite the huge medical benefits that the genetic sciences have brought, the concept of being able to manipulate any living organism to our own design has captured something deep in our psyche. For many people there is an unavoidable anxiety that in meddling with the foundations of life, science is placing the entire living world at the mercy of our own fallibility. Indeed a technology that enables us to break the integrity of natural 'species boundaries' will invariably be the cause of great moral conflict. Furthermore, however cautiously we progress, we can never be fully prepared for the many unseen hazards that are yet to manifest. Nevertheless all human progress involves a degree of risk, and in this respect, genetic engineering is perhaps the most pronounced field of scientific research.

The final years of the 20th century saw the genetic engineering of numerous species, and no order of the animal kingdom was exempt from experimental research. In the late 1980's and throughout the 90's, for example, a variety of different mammals were 'genetically adapted' to produce the human growth hormone *'somatotropin',* which could now be manufactured in everything from rabbit's milk to mouse urine. However the transgenic use of somatotropin to improve the productivity of farm animals proved to be less successful. Such experiments were best exemplified by the creation of grossly overweight pigs that developed a whole range of congenital disorders including gastric ulcers and severe arthritis.

Whilst the unfortunate creation of transgenic swine may provide disturbing images of our genetic indiscretion, it is to the humble mouse that molecular biology owes the greatest number of medical and agricultural breakthroughs. Rodents have long endured laboratory experimentation, and the advent of genetic research has only served to further their scientific exploitation. By the start of the new century, numerous teams of geneticists worldwide had successfully created mice with a whole variety of unnatural characteristics ~ and all in the name of progress.

In 2002, for example, mice were seen to glow in the dark, having been given an extra jellyfish gene that caused their follicles to produce luminous hair. Others were engineered to express the human protein '*b-catenin'*, causing them to grow enlarged brains that resembled our own cerebral cortex. Meanwhile a team of researchers, led by veterinarian **'Ina Dobrinski'** at the ***'University of Pennsylvania'***, had succeeded in getting mice to produce goat and pig sperm. By 2004 the spermatogenesis of primates was finally manipulated when Dobrinski's team successfully cultured the testicular tissue of a macaque monkey in a mouse. This technology has the potential to enable the manufacture of human sperm in mice; a controversial development that could theoretically enable a young boy to father children before he even reaches puberty.

Although the creation of transgenic mammals would have a profound effect on human existence, the direct genetic manipulation of our own species *(particularly through gene therapy)* held even greater possibilities. The introduction of a foreign gene into human beings first occurred back in 1989, when **US** surgeon **'Steven A. Rosenberg'** and his team at the ***'National Institute of Health'*** inserted an extra 'marker' gene into terminally ill patients. This was done to identify the effectiveness of a new technique that Rosenberg had devised for treating malignant tumours. At the heart of his research were ***'TIL'*** cells *(or tumour-infiltrating lymphocytes)* which, having been isolated from a cancerous growth, could be modified and reintroduced into the patient's body. Helping their immune system to attack the cancer, 'reprogrammed' **TIL** cells proved to be highly effective at destroying certain melanomas.

Since the time of Rosenberg's pioneering therapy, various genes have been added to human subjects; largely as potential cures for life-threatening disorders. But it is not only mice and men in the front line of such genetic research. At turn of the century, several teams of **US** scientists managed to prolong the lives of certain lower order species of animal. In 2000, for example, researchers at the ***'Massachusetts Institute of Technology'*** had increased the age of roundworms by 50%. This was done by introducing a yeast gene that deactivated the natural degrading process of their cells. Within a year researchers at the ***'University of Connecticut Health Centre'*** had succeeded in doubling *(and have since tripled)* the life span of fruit flies. This time the feat was achieved by altering a gene that governs the way in which flies utilise and store their energy.

Incredible advances such as these hold the promise of vastly improving human longevity. Indeed our ability to manipulate the ageing process of human beings is well within the grasp of modern genetic technology, and once we have successfully applied the process to mice, we will have taken the first steps towards developing effective anti-ageing drugs.

Genetic engineering has indeed opened up a world of possibilities for the human race. With the tools of science at our disposal, we can imagine a future civilisation where general health has vastly improved, life expectancy is significantly increased, and humanity is largely free from the scourge of famine and disease. However the precarious path we tread is fraught with danger, and such an idealistic vision of the future is unlikely to ever be realised. Certainly genetic technology will *(at least in the short term)* help improve the standard of life for millions of people. But it is somewhat naïve to pin the hope of all humanity on the endeavours of scientists and researchers whose work is mostly funded by competing corporate interests that are primarily motivated by profit.

Discovery and invention is firmly rooted in the world's richest nations. Here, free enterprise is positively encouraged, and the irresistible desire to succeed has created powerful business empires. Thriving on an unrelenting culture of consumerism, industry and commerce are ultimately driven by professional ambition and material greed. It underpins a Western mindset wherein environmental concern *(and the long-term welfare of the populace)* has become of secondary importance to the accumulation of personal wealth.

Such an ingrained attitude invariably breeds ignorance, and distracts public attention away from the potentially serious consequences of exploiting the living world. The fact that, in order to sustain our own engineered growth, we would have to continually enhance *(and further exploit)* nature is but one serious oversight of current genetic research that is rarely considered. This is indeed a major task considering how fragile and unimaginably complex is the 'web of life'.

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Since the 1970's the world has witnessed a rapid growth in the 'human fertility' industry. Driven by a desperate need to conceive children *(often of choice)*, by the turn of the 21st century this largely unregulated global industry was worth an estimated $30 billion-a-year. Assisted conception is a highly lucrative business and the bid to counter infertility involves everything from freezing healthy embryos to professional surrogate motherhood. Moreover incredible improvements in the genetic sciences have opened up a plethora of new possibilities, wherein wealthy couples can now determine many characteristics of their child. Indeed new medical feats, once considered impossible, have taken modern society into the ethical quagmire of artificially-induced human life.

Perhaps the most morally questionable aspect of this industry is the illicit market for human eggs which has built up around it. Whilst the sale of human eggs is legally forbidden in Britain and most other European nations, it is commonplace in the **US** state of California. With thousands of American fertility clinics vying for business, their widespread availability has attracted customers from across the globe. Donor profiles can be readily downloaded over the Internet, and it is possible for anyone, almost anywhere in the world, to purchase human eggs to order.

In terms of legitimate medical pursuits, the fertility industry has enabled hundreds of thousands of couples to benefit from the latest advances in modern embryology. Young women, for example, can now have eggs frozen and stored with the aim of replanting them should they wish to conceive in later life, whilst it is now possible to create embryos by fertilising eggs with immature or damaged sperm ~ thus giving older couples a second chance to start a family.

Somewhat less conventional however is the capability of many clinics to manipulate the genotypes of growing embryos. Experimental programmes that involve various processes have led to numerous babies being born with genes from a third parent. The most common example is the creation of children with two genetic mothers, whereby the cytoplasm of eggs from healthy donors has been injected into the weaker eggs of women who have proven susceptible to miscarriage. Despite running the risk of accidentally inserting material from the donor egg's nucleus *(and potentially causing severe genetic abnormalities in a child)* the procedure is being performed with increasing regularity. Far from deterring prospective parents, this form of 'genetic trinity' has proven to be an effective way of overcoming the infertility of many mothers to be. Indeed rapid improvements in the science has led some clinics to even offer a service that utilises specific genes from donor eggs in order that a child will express desired characteristics.

The global market offers a wide range of designer offspring with treatment available to anyone with enough money and desire undergo it. Yet, whether it be to help childless couples start families, or to produce babies that express the preferences of wealthy clients, the industry treads a precarious path of endeavour. Ultimately directed by the enormous consumer demand, much research in this field of genetics is funded by a profit-driven industry, and is therefore geared towards desired results rather than achieving balanced objectives. Whilst health and safety is obviously of primary concern, the promise of financial reward, along with a lack of enforced regulation, invariably compromises the perceived sanctity of human life. Certain procedures, for example, could potentially lead to a generation of damaged children; born apparently normally, but with unseen genetic or congenital disorders. These could include serious heart defects, degenerative organ failure or even an 'inherited' susceptibility to certain diseases later in life. Of course, in the longer term, genetic medicine holds the promise of completely eradicating ailments such as these ~ effectively further removing us from our collective natural inheritance.

For those able to afford to do so, the prospect of being able to safeguard the health and improve the abilities of their future children is an irresistible one. Indeed the successful use of genetic technology to 'better' our lives creates an almost endless array of logical possibilities. Many futurologists, for example, anticipate the prospect of a new generation of doctors, scientists, athletes or military personnel who are as near perfect in their chosen skill or profession as conceptually possible. Never before in human history has money so intimately affected the course of biological success.

Despite our gradual mastery of genetics however, we are unlikely to ever succeed in creating a single Utopian existence. The dynamics of life will always throw up the unexpected, and the outside world has an enormous impact on how we develop as adults. We are an equal combination of 'nature' and 'nurture', with the former merely dictating how we respond to the latter. Our personal life experiences will always be unique, and for that reason genetic manipulation could never actually determine the future life of any thinking individual.

There are many who believe that genetic engineering will one day beget a dehumanised world of dystopian proportions. Indeed there is a body of thought that foresees disillusionment in science eventually giving rise to extreme exploitation of genetic technology. Most of those who concur to this notion however, base their beliefs around an irrational fear of the unknown. Because we cannot determine the life choices of any individual, no two sentient beings could ever be made to behave *exactly* the same, therefore the distasteful notion of servile 'second class citizens' *(like the creation of armies of 'robotic' clones)* is still very much the stuff of science fiction. Yet, although we presently consider such developments to be morally obscene, with the mechanics of thought itself subject to intense scientific scrutiny, such ideas are not actually outside the realms of future possibility.

Far more prevalent to the security of modern society is the present abuse of genetic technology by various religious and political groups who apply it with fanatical zeal to further their respective ambitions. A comparative tolerance of religious fanaticism in the **US**, for example, has allowed those intent on inciting a 'divine revolution' to actively work towards engineering biblical icons such a golden calf or a '666' birth mark. The pursuance of self-fulfilling prophesies such as these invariably hold the danger of bringing illusions of the mind into the universal world of physical reality. Moreover our growing intellectual maturity struggles to keep up with the irrepressible march of science, and many once fantastical ideas are now revered in many cultural quarters as being inspirational or prophetic. ***'The Boys From Brazil'*** scenario, for example, is less distanced from reality now than when **'Ira Levin'**s thought-provoking novel was published back in 1976.

Of all aspects of modern bioengineering, the most morally questionable is the highly restricted pursuit of genetic technology in the name of national security. Military research and development has always been at the cutting-edge of technology and, concealed from the scrutiny of the public eye, it is seemingly exempt from the constraints of our collective morality. Furthermore there is no doubt that various governmental bodies around the world are furtively applying genetics to *(what most would perceive as)* immoral endeavours. Indeed it is conceivable that a considerable number of 'new' species have already been artificially produced in top secret locations ~ ultimately to the detriment of our humanity.

One area of concern is the creation of unnatural hybrids of various animal and plant species. Equally disturbing however is the modification of viruses and bacteria which have primarily been created as effective biological agents that could be easily exploited for warfare. Besides being comparatively cheap to produce, genetically manipulated micro-organisms can be readily adapted as versatile weapons whose lethality can be determined with frightening precision. Not only do they provide a 'more affordable' alternative to explosive weapons of mass destruction, but can be designed to target specific ethnicities, germ-lines or even individuals.

We live in a world where everything that has proven to be scientifically possible is invariably created. From developing the hydrogen bomb to engineering entirely new types of virus, modern science has proven to be an unstoppable expression of human ingenuity. In the early 21st century we are as close to harnessing the power of nuclear fusion, as we are to building complex 'living' organisms from scratch.

The first synthetic virus was created in 2002 by **US** microbiologist **'Eckard Wimmer'** at the ***'University of New York'***. Wimmer and his team sequenced the genome of the polio virus, and used it as a blueprint to construct an artificial version that appeared identical to its natural counterpart. Because his research applied information that is freely available over the Internet, Wimmer's achievement proved that viruses could potentially be produced by design by anyone with the right equipment, and sparked widespread fears of bioterrorism.

Many scientists dispute the fact that viruses constitute living organisms because they are totally reliant on other living cells for their survival. Although these simple, and most dangerous, of infectious agents are incapable of independent self-replication, they are in fact chemically no different from any other living organism. Essentially it is only size and complexity that separates the genomes of viruses from those of the smallest free-living organisms ~ bacteria.

In a bid to uncover the molecular definition of life, in 1999 South African-born biochemist **'J. Craig Venter'** embarked on scientific journey of profound importance to humanity. Besides his enormous contribution to the 'Human Genome Project' *(with **'Celera Genomics'**)*, Venter initiated the ***'Minimum Genome Project'*** ~ a quest to identify the smallest amount of genes required to sustain *(and so recreate)* life. Based at the ***'Institute of Genomic Research'*** in Rockville, Maryland, the *'biological schematics'* for this research were provided by one of the smallest bacterium yet discovered, *Mycoplasma genitalium* ~ a parasitic microbe which lives inside primate genital and respiratory tracts. Of its 517 genes, *M. genitalium* has 480 which were found to encode for proteins. By individually disrupting these genes, researchers sought to establish which ones were essential to its continued survival.

Venter's work confirmed that the microbe *(like any other living organism)* was not completely reliant on any single number of genes. In all living species, comparatively few genes operate singularly, as most are activated collectively within different combinations in response to the outside world. Indeed the interaction between life and the environment is at an intimate and abstruse genetic level, ~ the result of organisms adapting to survive over billions of years. In the case of *M. genitalium,* approximately 300 genes were identified as being of vital importance for the species to exist in a natural state *(dependant, of course, on external conditions).*

In 2003 the second artificial virus was produced when Venter's team at ***'Synthetic Genomics'*** succeeded in synthesising the genome of a comparatively simple bacteriophage called ***'phiX174'***, and by 2005 he was well on his way to creating the first manmade bacteria. The resulting data from his work on *M. genitalium* provided a loose framework with which to 'build' living organisms to design. By inserting synthetic genomes into emptied cells, Venter aimed to 'grow' a minimalist organism capable of self-reproduction: a feat that would engender any number of industrial, medical and environmental applications.

Important work in this field was also being carried out by **US** microbiologist **'Albert Libchaber'** and his team at the ***Rockefeller University'*** in New York. In 2004 Libchaber had successfully built 'organic machines' *(or 'vesicle bioreactors' as they were named)* which had the ability to express genes like living cells. His groundbreaking method utilised elements from a variety of different species and brought synthetic biology to new levels of understanding. Aiming to reproduce the chemical evolution of life, Libchaber's minimal synthetic organisms essentially comprised the stripped genome of the *Escherichia coli* bacterium, held within cell walls constructed from the fat molecules of a chicken egg. To this was added enzymes and proteins from numerous organisms ranging from viruses to jellyfish, illustrating that what we perceive as 'primitive life' exists purely from complex chemical reactions.

These were by no means the only scientific efforts to create life from scratch. With the manipulation of bacterial genomes being less morally contentious than human genetics, as the 21st century unfolds, an increasing amount of research is being carried out in this field. As a result numerous bacteria have come under scrutiny from molecular geneticists; many for their abilities to withstand extreme conditions. Discovered by German microbiologist **'Karl Stetter'** in 2002, *Nanoarchaeum equitans,* for example, is one of the smallest microbes known to mankind. A marine bacterium, it lives in and around thermal vents, flourishing in water temperatures between 80° and 113°**C**.

A particularly interesting one is the red aerobic bacteria *Deinococcus radiodurans*. Discovered in 1956 by **US** bacteriologist **'Arthur W. Anderson'**, *D. radiodurans* is the most robust organism yet discovered, and provides the basis for the various panspermic theories of Earthly life. Whilst it may not have amongst the smallest number of genes, it has received much attention for the fact that it is resistant to radiation at levels that would be lethal to any other known form of life. Besides this, *D. radiodurans* can withstand total dehydration, oxygen toxicity and various chemical poisons, as well as survive for prolonged periods of time in the vacuum of space. What makes it so special is its ability *(shared by only a handful of other species)* to repair damaged chromosomes by a process known as *'homologous recombination'*, wherein certain **DNA** sequences are aligned with identical copies within its genetic code. Because it can survive such extreme environments, the genome of *D. radiodurans* could not only be utilised as an effective tool to clean up pollution and radioactive waste, but it could weaponised with horrific effect. By gaining the ability to create primitive life to design we also open up new avenues of destruction for existing higher order life.

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vi.

(A brave new world)

Thanks to the pioneering work of biochemists such as **'Duncan Geddes'**, **'William French Anderson'** and '**Theodor Friedmann'**, genetic engineering has moved out of the realms of science fiction and become a highly resourceful field of real science. We live in a time when our entire genetic code can be electronically transmitted into the surrounding galaxy in under three minutes, yet the prospect of germ line engineering holds the potential to change the path of human evolution beyond recognition. Modern biotechnology increasingly enables us to repair or remove defective genes, add advantageous ones, and irrevocably alter the course of inheritance for all future generations. What follows is an interesting to look into the unknown ~ the possible futures that cutting-edge genetic technologies may bring, and their far-reaching consequences.

The gift of intelligence has put the human species in the unique position of being able to break the natural laws that all other forms of Earthly life must conform to. We alone can manipulate our own genome, and so theoretically turn ourselves into whatever we want. In the early 21st century, the ability to grow entire human organs in cell culture, produce human eggs from stem cells, and engineer human sperm to any design, is well within reach of medical science. This technology has the potential to both save and create millions of lives, inevitably leading to the development of medicines tailored to a patient's genetic make-up, and procedures designed to help childless couples conceive ~ where the fertility and even the sex of respective parents presents no barrier.

A watershed achievement for the genetic sciences was the complete mapping of human genome; the results of which were formally published in 2003. This however was by no means the only important line of genetic research at the turn of the century. In 1999, for example, an international consortium of pharmaceutical and biotech companies began building a database that could be used to reveal the very essence of individuality. The purpose was to investigate what are known as **SNPs** *(or 'single nucleotide polymorphisms')* ~ minute alterations in the corresponding genes of different people.

Many other lines of genetic investigation were also underway at this time. In 2002, for example, germ line engineering took a great leap forward when **US** geneticists **'Adrian Krainer'** and **'Luca Cartegni'** instigated a procedure called *'RNA interference'*. By successfully manipulating the stem cells of mouse embryos, their team at ***'Cold Spring Harbor Laboratory'*** induced genetic changes that were passed down through subsequent generations. The genetic manipulation of laboratory mice provided another, particularly interesting, line of research which, if successful, promises huge medical and social benefits. In 1998, at the ***'University of Utah'***, **US** molecular biologist **'Mario Capechi'** began his research into the possibilities of creating artificial chromosomes which function alongside natural ones. Capechi's ultimate goal was to introduce into human cells, extra chromosomes *(containing a selection of desirable genes)* that could be switched on and off in future generations ~ the genetic instructions for which would be uploaded via computer.

Enormous progress in the field of nanotechnology over the last few decades has complimented the incredible advances made in genetic medicine. At the present rate of advance, by the mid-21st century, the use of so-called 'gene chips' could radically change the fortunes of the world's wealthier populations. This technology promises everything from individualised medicines that could eradicate thousands of diseases, to personalised therapies which would allow us to choose the characteristics of future generations. The ultimate in gene therapy, these chips could examine and compute the trillions of combinations of the three billion or so 'letters' within the human genome. By analysing complex combinations of relevant gene clusters, they could theoretically supply doctors with instant readouts of their patient's genetic profiles. Such technology would not only be employed for health reasons, but would invariably lead to genetic enhancement ~ enabling prospective parents to initiate desirable 'aesthetic' improvements in areas such as physicality and mental aptitude.

By manipulating the human genome, we embark on an extremely hazardous journey of self-discovery. With the knowledge to read and 'improve' the genetic structure of human beings, comes the ability to predict or even determine everything about the lives of unborn children. Furthermore germ line engineering has the potential to completely eliminate inherited diseases from future generations. Colon and breast cancer, for example, could become a thing of the past, as could lesser afflictions in later life such as the onset of baldness and short-sightedness.

Besides giving rise to an array of preventative alterations, this technology is also likely to lead to genetic indulgence by the more affluent sections of society. There is no shortage of wealthy couples willing to spend a fortune on ensuring that their 'perfect baby' is born with favoured traits, be they artistic, athletic, intellectual or physiological in nature. Indeed the ability to select offspring based on their genetic predisposition will inevitably spawn children designed for enhanced '**IQ**' and 'beauty'.

We are indeed at a defining moment in our evolution. Even if we choose not to enhance our children, we will be at liberty to know their future prospects. Given the choice, a vast majority of parents would want to know at least something about their children's future prospects. Their physical attributes, social adeptness and sexuality, as well as their susceptibility to debilitating diseases, mental illness, and even casual injury are, in theory, all determinable. Indeed it should be possible to know whether they will be predominantly assertive or timid, aggressive or passive in nature, their predilection to things such as alcohol, gambling and criminal activity, and the likelihood that they will achieve success in their lives.

There is no doubt that the consumer market will instigate the creation of human beings that could not possibly have existed through natural conception. With the huge investments currently being made in genetic technology, it will eventually be possible to add hundreds of new genes into developing embryos. Indeed there is theoretically no limit to the number of genes that could be added, thus allowing us to gain control of our own evolution.

One major concern is that this could lead to a form of 'super-evolution', and the eventual divergence of the human species. In such a scenario, positions of power *(in every walk of life)* will be filled by 'designed' individuals that would effectively preside over an underclass of naturally conceived people who have not been born with the gift of genetic enhancement. As the technology spreads, new generations will vastly outperform their parents in every way ~ taking the human race on an evolutionary path which, although chosen by design, could not possibly be comprehended in advance. Taken to its extreme, the influence of genetic engineering lays far beyond the cosmetic choices of parents. The concept of eternal life, for example, could lure many people to seek immortality through cloning, wherein subsequent generations could be endowed with desirable genes that the wealthy 'prototype individuals' did not themselves possess.

At the very least, engineering the human race *(to whatever extent)* paves the way for genetic discrimination. In a highly competitive world where market enterprise is powered by financial investment and commercial profit, the boundaries of 'acceptable' moral behaviour are invariably broken. It is highly likely, for example, that insurance companies will eventually base premiums on risks that are calculated from their client's genetic information, whilst professional bias based on an employee's genetic make-up will undoubtedly occur. Legislation and strict guidelines, presently in force in countries such as Britain and the **US**, are likely to be eroded by the profound changes to our perception of human existence. Indeed the irrepressible force of genetic technology will invariably overcome the common fear that the science somehow devalues human life, forcing us to reassess many of our current ethical beliefs and moral values.

In order to use genetic technology to its full potential, we must first overcome any number of moral dilemmas. Because we generally perceive of human life with a degree of self-importance, it will take many years to reach the stage when we are able to apply a balanced and unprejudiced approach to the science. Unfortunately by seeing ourselves to be of greater worth than other forms of life, we are in danger of irrevocably distorting the living world around us. For example, although regarded by many humanists as being equally reprehensible, there are far less stringent controls on genetic experimentation with other animals. Yet the human genome is around 97% identical to that of orang-utans, 98% to gorillas and 98.4% the same as the chimpanzee *(a species from which we evolved from a common stock a mere four million years ago)*. When you consider that humans differ from chimps by less than 5000 genes, long before we see appearance of *Homo superior*, we are more likely to witness the creation of great apes that possess human-like intelligence.

Of course primates are not the only focus of experimental bioengineering. As the 'web of life' is gradually revealed to the genetic sciences, technology will increasingly blur the distinction between numerous separate species. Moreover it even has the potential to breathe intelligent life into inanimate objects.

So long as modern civilisation continues to support scientific advance, the reverse engineering of the human brain is inevitable and, with the eventual ability to build entire genomes from scratch, science is on the verge of totally revolutionising life itself. Worldwide efforts in the field of *'neuromorphology'* at the turn of the century were exemplified by the work of Russian biophysicist **'Vitaly Valtsev'**. In 2001 Valtsev and his team at the ***'International Academy of Information Science'*** in Moscow built what many consider to be the first successful neuro-computer based on the human brain cell.

The building of **DNA**-based computers to the design of the human brain inevitably holds the prospect of creating new forms of artificial intelligence. Such a development would serve to irrevocably entwine technology with nature, and bring 'man' and 'machine' closer together than most people could possibly comprehend. Not only would computational technology improve beyond our current perception, but the very meaning of life would be in our own hands.

As a social species whose rise to power relies on mutual co-operation, the human race collectively strives for a Utopian existence. The exploitative engineering of life represents just one area in which modern civilisation endeavours to take control of the physical world. Yet we have evolved *(both physically and psychologically)* to survive in a harshly competitive natural environment, and although we may generally agree on how this revolutionary new technology should be used, as thinking individuals we will never see a universal definition of its ultimate purpose. Indeed living perfection is totally subjective and ultimately unachievable.

Part 3

A Technical Ecstasy

"Our dreams result from our very existence, yet we owe our present existence to our dreams."

~ **Russ Fryer** *(2001)*

i.

(Matter over mind)

For as long as the technology has been there, mankind had applied it to manipulating life. Our attempts to directly control other life forms have been going on for many years with the pursuit of medical and military science, for example, leading to the manipulation of all kinds of micro-organism. Of course, with the presence of a brain, 'higher' animal species have come under even greater scrutiny, and much effort has been directed at learning how to control their psychological and anatomical functions.

This line of research is best exemplified by the work of Spanish neurologist **'José Delgado'**. During 'World War **II**', Delgado was employed by **'Francisco Franco'**s dictatorial regime to augment ongoing research into mind control, and the use of pain and pleasure stimulation to master it. Moving to the **US** shortly after the war, he became 'Director of Neuropsychiatry' at ***'Yale University'*** where he continued his work on the ***'Transdermal Stimulator'*** ~ a neurologic transceiver designed to control the brain with electrical impulses.

The most notorious demonstration of this technology involved a bull which, having been goaded by matador, was stopped dead in his charge by a remote device. With an implant strategically fitted beneath its scalp, the bull's temperament could be completely altered at will. This and other animal experiments caused a public outcry, and Delgado's work was officially discontinued in 1969.

Despite maintaining that the medical benefits it would bring far outweigh any ethical criticism it may receive, Delgado's research was undermined by his own socio-political doctrine. Indeed his personal belief that individuals do not have the 'right' to develop their own minds ignited great controversy. Furthermore his conviction that society would benefit from a programme of mass psychosurgery, only served to further horrify America's liberal-minded majority.

By the early 1970's Delgado's studies had moved towards a broader spectrum of research, i.e. investigating the biological effects of electromagnetic fields. However more direct research into electrical brain stimulation *(or **EBS**)* continued, leading to the development of refined *'stimoceivers'* ~ minute radio-controlled instruments designed to transmit and receive electrical messages between the brain and external objects. As the technology progressed, much of this research became aimed at providing a link between man and computer.

It was soon recognised that the reciprocal feedback between neurons and microchip could bring incalculable medical benefits. Indeed the ability to identify specific patterns of electrical activity in the brain and adjust them externally could lead to the early diagnosis and prevention of numerous debilitating afflictions. For example it could be used to predict an oncoming epileptic fit, which could be immediately treated by a computer programmed to respond by transmitting appropriate electrical stimuli. Moreover, great advances in microtechnology have since led many teams to investigate the possibility of developing electrical implants capable of repairing dysfunctional nerves and muscles. Such research holds great promise for the sufferers of any number of disabilities. It could, for example, return feeling to stroke victims, allow those with cerebral palsy to regain control of movement, and even enable paraplegics to walk again.

'Brain-computer interface' *(or **BCI**)* technology was pioneered throughout the 1980's and 90's by neuroscientists and psychologists such as **'Emanuel Donchin'**, **'Jonathan Wolpaw'** and **'Nie**

ls Birbaumer'. By 2000 a **US**-German team including software engineers **'Gerwin Schalk'** and **'Thilo Hinterberger'** had begun to develop the first basic universal platform designed to translate neural impulses into computer language. Most programs, up until this time, relied on **EEG** *(electroencephalogram)* signals detected through the skull via a cap or headset, however by the turn of the century a new generation of **BCI**'s based around wireless implants had emerged. Various **US**-based teams led by neurologists including **'John Chapin'**, **'Philip Kennedy'** and **'Miguel Nicolelis'** were instrumental in the further development of this technology.

Whilst early **BCI** implants enabled laboratory monkeys to mentally move two-dimensional cursors around monitors, they only utilised a few dozen neural signals, so the comparatively short life span of individual neurons limited their long-term use. In 2002 however a system that could translate a broader range of neural activity was demonstrated by American bioengineer **'Andrew Schwartz'** and his team at ***'Arizona State University'***. Using food as a reward, Schwartz trained macaque monkeys fitted with cerebral implants to move a ball to certain areas within a room, enabling him to simultaneously measure the electrical activity within their motor cortexes. Once the firing of specific neurons had been recorded and decoded by software algorithms, the monkey's actions could be replicated three-dimensionally on-screen. Placed in front of a monitor with their arms restrained, the monkeys eventually learned full cognitive control over a virtual ball. By applying the same method to control remote robotic arms, Schwartz had taken the first steps towards developing thought-controlled artificial *(or neuroprosthetic)* limbs.

This line of medical research is intrinsically entwined with cybernetics - a branch of science which had originally been founded back in 1947 by **US** mathematician **'Norbert Wiener'**. By the turn of the 21st century some 20% of human body parts could already be replaced with a fully functional electronic counterpart. Furthermore, incredible improvements in nanotechnology since this time has catalysed research into the development of miniature computer networks designed to function inside a human subject, powered solely by body heat, Besides leading to an abundance of medical breakthroughs, such technology would undoubtedly be used for numerous military applications. The modulation of brain waves could allow personnel to manipulate robotic equipment without the need of external controls; making, for example, dangerous jobs such as bomb disposal or transporting munitions safer and more efficient. It could even enable an individual to have precision command of an aircraft, tank, ship or submarine, and of course direct control of weaponry ~ enabling them to push a button or pull a trigger through the process of thought alone.

Not only could cyber-technology be applied to enhance the abilities of a subject, but it could be equally used to subvert the mind at will. In terms of subversive military activity, a particularly disturbing aspect of research concerns the use of both computing and genetic technologies to achieve this aim. A weapon that could gain full physical and psychological control of an adversary is certainly not unfeasible. Such technology could be used to enable everything from inducing thought deviation and self-mutilation, to the entire 're-creation' of individuals with synthesised states of personal existence. Indeed it is already possible to affect certain motor responses and emotional reactions in a subject through direct stimulation of the brain. Moreover as the map of the human brain becomes ever more precise so the process of dehumanisation becomes easier to achieve, opening up the world to all sorts of unscrupulous and unethical applications within an almost endless number of possibilities.

Whilst most people may find this form of 'electronic warfare' totally abhorrent, the expected scientific and clinical benefits that cyber-technology could bring to society would be enormous. As a race of sentient beings, our unquenchable thirst for knowledge is an innate gift, and our collective sense of achievement is undeniable. Therefore, so long as our civilisation can support it, scientific progress will continue to enhance the powers of our senses, hone our skills and make the impossible a reality. Thanks to advances in modern science we can, for example, see things well beyond the limits of the human eye *(from single atoms to the far reaches of the cosmos)* and a direct interface between brain and machine adds a whole new dimension to our endeavours. Furthermore private investment into new technologies are ultimately determined by consumer demand, and there would be a huge market for the recreational use of cyber-technology, Electrobrain stimulation for hedonistic pleasure is not a new concept, and a computer programmed to recognise appropriate stimuli, and act upon them in correct sequence could open up a virtual playground restricted only by the imagination.

As far back as 1954, scientists have been able to manipulate the pleasure centres of the brain. Early experiments involving laboratory rats wired into neurological electrodes had shown it possible to activate certain regions of the brain on command. With the contact switch placed inside the cage, the rats would continually press the levers in frenzied bouts of self-stimulation ~ often for several days without rest, in preference to food, sex, and even at the expense of sleep. Whist rodents maybe psychologically incapable of getting bored or perceiving concepts such as 'Utopia', 'paradise' or 'heaven', the same is not true of ourselves, and with computing technology gradually unlocking the human brain, there are many keen to one day indulge in the ultimate virtual experience. Indeed the freedom to induce euphoric sensations at will, is choice of lifestyle for a mishmash of groups collectively known as the *'cyberpunks'* or ***'Wireheads'***.

The idea of the 'cyberpunk' originated from a school of science fiction writing which blossomed in the 1980's. Epitomised by **US** writer **'William Gibson'**s 1984 novel ***'Neuromancer'***, the concept of *'jacking in'* to a computer to escape the harsh realities of life, generated instant cult interest. Whilst this new post modernist sub-genre broadened in content, a majority of stories followed in similar vein ~ contrasting a dark portrayal of life with emancipation of the mind into cyberspace. Further exemplified by **'Bruce Sterling'**s 1986 anthology ***'Mirrorshades'***, the cyberpunk movement introduced concepts ranging from Hollywood becoming the hub of a huge market for entertainment-based neuro-engineering, to the birth of a new global consciousness through biochip technology. Indeed the miscegenation of man and machine was seen as an inevitable consequence of modern technology and a whole new philosophy was born from fantasy.

We live in a time when creativity and imagination has mushroomed, and the so called 'Wireheads' have taken the idea of human thought to a spiritual conclusion through technology. They believe *(correctly)* that all experiences originate in the brain, with thoughts and feelings generated solely by the electrical activity of neurons. However they take this a step further by speculating that, as Western scepticism becomes a dominant philosophy, so traditional faith and spiritual belief will give way to a 'new religion', with the integration of mind and machine becoming the great obsession of the masses. Gibson's description of a *'disembodied consciousness being projected into the consensual hallucination of the matrix'* is regarded, by many advocates of the cult, as an impending reality. Indeed, commercial cybertechnology has grown considerably this century, and by the late 2010's a number of big tech companies had already begun to invest in the idea of a universal '*metaverse'* that projects the Internet as a fully immersive virtual world.

Whilst most people are yet to embrace the idea of 'jacking in' to a computer as a popular recreational pursuit, such perceptions *(though radical to the physical cognisance of today)* are not at odds with many theories regarding the future direction of human consciousness. Particularly notable are the more 'organic' beliefs of the late American ethnobotonist and psychedelic researcher '**Terence McKenna'**, whose work on the effects of hallucinogens on our intellectual evolution, challenged the very conventions of accepted reality. The Wireheads, like McKenna, have perceived a future in which the human mind is emancipated from the constraints of modern life, and where consciousness and imagination will outlive the physical form.

ii.
(Epilogue: a virtual reality?)

As far as the long-term survival of our species is concerned, scientific endeavour is generally regarded as mankind's great hope, and the field of science held in highest reverence by the general populace is space exploration. Yet, although we have managed to send probes to Pluto and beyond, humanity is incapable of truly reaching out into the vast Universe that envelops us. It is therefore on the 'terrestrial sciences' that our future will more realistically depend.

Launched in 1977, the most distant manmade object, ***'Voyager 1'***, had, after 45 years in space, reached a distance of some 14.6 billion miles *(approximately 21 light hours)* from Earth. By comparison, ***Proxima Centauri*** *(the nearest star to our own)*, at some 4.2 light years in distance, is over 1750 times further away. Indeed, were it travelling in the right direction, 'Voyager 1' would take a further 78,750 years just to reach our nearest stellar neighbour. Even modern spacecraft fitted with the most advanced propulsion systems would be totally inadequate for travelling such distances. The hypothetical ***'Variable Specific Impulse Magnetoplasma Rocket'*** *(or* ***'VASIMR'****)*, for example, by reaching speeds in excess of 670,000 miles/hour *(about a 1000th the speed of light)*, could potentially cut such a journey time down to some 4200 years.

Alas for mankind, the hope of deep space travel and colonisation of alien worlds is but a fanciful dream that is unlikely to ever become reality. The realisation that our species is doomed to live out its days on our own dying planet is more likely to bring about a certain disillusionment in space travel *(and the sciences in general)*. Furthermore the fact that we are facing the sixth, and most comprehensive, mass extinction in the history of the living Earth *(largely brought about by our parochial exploitation of its resources)* is becoming evermore stark. Indeed large scale environmental mismanagement has already irrevocably damaged the biodiverity of our planet, and in order not to institute our own downfall, the scientific endeavour of the world's wealthy nations must drastically change priorities.

In terms of the sciences with the most aesthetic appeal, technology which aims to reach out into the void of space will increasingly be replaced by that which is concerned with an inward projection of the mind. Ultimately the future of humanity lay in technologies that can either protect our species at a genetic level from the harsh realities of physical existence, or replace the natural dream around us with a virtual one. Both fields of scientific endeavour have almost endless possibilities.

Hypothetically speaking, were current technological advance to continue uninhibited, modern society would be thrust into a world where the genetic and electronic sciences come to dominate our very existence. With new technologies becoming increasingly accessible to consumers, there is no doubt that the lives of our descendants would be radically different from our own. Inevitably, the wealthiest quarters of society would be the first to benefit from our ability, for example, to genetically manipulate our own germ lines.

The presumed advantaging of our children with favoured genes is likely to lead to the creation of fitter and healthier generations which are perceived to be far better equipped to deal with life than their parents could ever hope to be. Indeed, taken to its conclusion, we would ultimately gain control of our own evolution ~ effectively creating humans beings by design. The engineering of desired attributes, such as hardiness to disease and increased **IQ**, may be the most apparent way of improving our species, but genetic technology is also likely to effect other human characteristics with the physical appearance and even emotions of future generations being drastically altered. Yet those remaining *(the shrinking majority)*, born of a natural generation, would face an equally profound change to their lives. With the age of cybernetics dawning, the ability to experience new and fantastic virtual electronic worlds, would greatly ease the stresses and strains of 'physical reality'.

This particular aspect of escapism is exemplified by today's booming sex industry. Modern electronics and computer technology have greatly increased the availability of pornography worldwide, and the sex industry has seen phenomenal growth since the late 20th century. Coupled with a gradual relaxation of censorship laws, the freedom of the digital age has brought about a more mainstream cultural acceptance of pornography in general. Indeed pornography and technology feed off one another, with the diminishing guilt and social stigma associated with aberrant sexual preferences augmenting many unusual forms of computer hedonism.

The sex industry *(in particular pornography)* was revolutionised by videotape technology and the advent of the home video recorder in the late 1970's. By the early 1990's **CD ROM**s had become widely available ~ offering private viewers better picture quality, and even the chance to alter the outcome of an 'adventure'. The late '90's heralded the mass marketing of **DVD**s which allowed even more control over what could be seen. Particular scenes, for example, could now be viewed with a choice of angles, or favoured action magnified. However by the turn of the century the greatest dissemination of pornography had become the Internet.

Visual sex is by far the most pervasive topic to be found online, with an abundance of web sites catering for every conceivable taste. The proliferation of live interactivity has led to an exchange of sexual fantasies across the globe, and the Internet provides an illusory Utopia for millions of people. Yet despite allowing people to indulge in a huge variety of virtual sexual activities with one another, computers have, in effect, served to dehumanise sex. Indeed the consumption of digital pornography is an intrinsically self-indulgent pastime which bypasses the need for natural physical contact. Moreover technological advance in this field of computing is geared towards enabling instant sexual gratification. The development of body-suits, headsets and microchip implants have begun to turn what was once primarily a visual activity into a multi-sensory one which will eventually be capable of exciting all five physical senses. With cybersex programs enabling a direct human interface with the virtual world, participants will soon be able to immerse in total escapism, and, should they wish, 'have sex' whatever their personal desire.

Because of its all-round mass appeal, an even faster growing industry has built up around computer gaming. In terms of entertainment, electronic games are heading towards a position of cultural dominance, They provide any number of different fantasy worlds to a growing global audience. Of course American culture has continued to dominate the ethics of most computer games, but this field of entertainment is truly global, and has embraced elements of Japanese and other national cultures, many of which have begun to seep into the 'Western mindset'. Indeed this electronic conglomeration of different regional cultures has led to the creation of new icons such as ***'Super Mario Bros.'***, ***'Sonic the Hedgehog'*** and ***'Lara Croft'***. Large corporations, including ***'Sony'***, ***'Microsoft'*** and ***'Nintendo'***, have amassed great fortunes from what originally started as a popular form of children's entertainment.

As the commercial potential of electronic games has been realised, and as technology has improved, so too has the growing realism of game-play and complexity of plots. Now every facet of life and fictional genre is catered for. There are, for example, games based on horror *(such as **'Resident Evil'** ~ 1996)*, crime *(**'Grand Theft Auto'** ~ 1997)*, and even war *(**'Medal of Honor'** ~ 1999)*. Whether it be based around 'role playing' *(such as **'Final Fantasy'** ~ 1987)* or 'action sports' *(such as **'Pro-Evolution Soccer'** ~2003),* the ability of computer games to completely absorb players in imaginary virtual worlds is truly compelling.

Until the early 21st century, all games required a joystick or handset to move on-screen characters. However in 2003 a totally new type of game was demonstrated by American programmer **'Robert Burke'** and his team at the ***'MIT Media Laboratories'*** in Dublin, Eire. The main character in ***'Mind Balance'*** could be controlled through a sophisticated wireless headset which employed six direct **EEG** *(electroencephalograph)* cerebral data nodes designed to pick up electrical activity from the visual cortex. By concentrating on two chequered boxes which flashed at different frequencies, neurological activity in a player's optical lobes could be detected by the cap and translated into wireless signals. Once received by a computer, the signals were then translated into the movement of an on-screen behemoth *(known as **'Mawg'**)* as he negotiated a virtual tightrope.

Primitive in gameplay, 'Mind Balance' was primarily designed to test the capabilities of a software framework called ***'Symphony'*** which enabled three-dimensional graphics to be integrated with real-time brain signals. Whilst it may have resulted from medical research, the creation of this unique platform represented a great leap forward in gaming development. By 2006 a similar, but more elaborate, system was created by German mathematical physicist **'Klaus-Robert Müller'** and his team at the ***'Fraunhofer Institute'*** in Berlin. A telepathic typewriter *(called the **'Berlin Brain-Computer Interface'**)* employed a headset with 128 sensors which enabled users to project words on screen by thought alone.

The potential medical and therapeutic benefits of Burke and Müller's systems are many. Similar technology is, for example, being developed to provide new methods of communication for patients suffering from complete paralysis, and even those trapped in otherwise unreachable vegetative states. The greatest investment in this technology however, is likely to be that directed towards its widespread use by the masses ~ and that means computer gaming. Indeed the commercial development of software that can translate neural activity into 'action' faster than the body itself can react, would be highly valued within the gaming market.

The progress of video-game technology at the turn of the 21st century is truly staggering. In a little over two decades the most advanced games available to the general public have gone from simple two-dimensional, black and white 'bat and ball' games to those boasting three-dimensional multicoloured animations. Consumers are now able to purchase a plethora of games that open up virtual worlds, the graphics of which are becoming increasingly indistinguishable from real life. Moreover intensive research continues into the development of new gaming technologies, including motion detectors that enable computer animations to simulate body movement in real time, and retina scanners that can even follow the vision of a player as quickly as their brain can process the information. Given the current rate of advance, many game packages will soon be able to offer players full peripheral views and, with the eventual introduction of attachable chips, allow users to interact directly with gaming programs. By utilising the electrical impulses of the human brain, players will have complete control of virtual characters, which could in turn have the ability to excite all five senses, and incite every emotion.

There is all the likelihood that, should the current rate of technological progress continue unabated over the next few decades, computer games will evolve out of all recognition to today's consumers. The expanding parameters of quantum computing, for example, will eventually lead to the development of gaming programs that could digitally replicate the 'universal laws of nature' and therefore engineer 'contained' environments which could perfectly mimic the physical world. Combine this with the eventual development of software based on neural networks *(that could actually learn and discover for itself)*, and we head towards the creation an endless array of fantastic virtual worlds for 'game players' to discover, explore and behold.

One defining step towards achieving complete reciprocal interaction between man and machine is the growing ability to convert brain waves into computer language. As the precise mechanics of the human brain is revealed to science, so even imagination *(an attribute once unique to humans)* will eventually be broken down into mathematical code and replicated by computer. By changing certain variables, such programs would be capable of performing the disciplines of independent thought, allowing them to, for example, come up with new ideas or even develop intuition. Importantly for gamers, creative programs adapted for the consumer market could artificially stimulate pleasure centres of the brain and induce wholly believable out-of-body experiences.

There is no doubt that, as the popularity and sophistication of computer games grow, those of the future will drive many more players into states of addictive compulsion. Inevitably the wealthiest quarters of society would be the first to access this ultimately hedonistic technology, but over time its growing availability would captivate a huge number of consumers. Plugging in to such a game would allow you to enter a virtual world where every event is experienced as intensely as if it were actually happening ~

blurring the distinction between imagination and physical reality. Completely immersed in an all-consuming fantasy game, you would effectively be allowing a computer program to read your intentions or desires and act upon them accordingly.

Whatever the emotions or feelings you may experience *(be they ones of compassion, arousal, anger or even hunger)* cyberspace will have the ability to satisfy. There would be the choice of interacting with other on-line users or designing your own private paradise, totally independent of the outside world. You could build a personal 'Utopia' or 'land of wonderment' where your virtual experiences are limited only by your own imagination. Indeed with the freedom to play any role you wish and involve any character you choose in whatever environment you want, why bother to exist on a dying planet when you can experience total escapism?

Taken further, such technology could eventually enable people to upload neural information, allowing programs to read their unique electrical signature and so build an exact electronic replica of their brains. Were this possible, the mind of an individual would essentially exist within the memory of a computer and, to an 'addict' indulging in 24-hour game play, the living 'flesh and bone' of the body would effectively become superfluous to the needs of their now 'immortal' mind. Moreover the greatest threat to the continued existence of a fully integrated brain would be the physical presence of human beings in the living world.

As real life becomes increasingly harsher, such technology would release the minds of millions of people from the suffering of life in an increasingly strained civilisation which stands on the brink of implosion. Environmental collapse, exhaustion of natural resources, famine, disease and war are all likely to play a part in our eventual downfall as the dominant living species on Earth. Yet, despite our inexorable march towards self-destruction, the essence of human life is likely to survive in electrical form i.e.: within the memories of computers. Indeed computing *(and genetics)* offers us the chance to cheat a death that all organic entities inevitably face, and however far these technologies actually manage to progress before the biosphere can no longer sustain our existence, our mark on the planet's history is already assured. Ultimately the Earth will become a hot dry planet, bereft of life and suffocated by a dense poisonous atmosphere. Yet the inorganic legacy of humanity will most likely remain as a computer imprint of our once mighty presence here.

Such visions may seem a little far-fetched now, but the more distant look into the future, the more absurd any scenario seems ~ regardless of logical steps. Indeed the *(albeit unlikely)* conclusion of the human mind existing within the memories of computers on a dead planet in the distant future is not wholly inconceivable. Of course this is all rational speculation, and the collapse of modern civilisation is more likely long before we reach such a point. Yet, were the planet to suffer a series of calamitous events collectively powerful enough to radically alter the global environment and extinguish most *(if not all)* life, there is little doubt that human beings have the capacity to survive in one form or another. In the end however, all systems, including life *(and ultimately human consciousness itself)*, must eventually succumb to the entropic nature of the Universe.