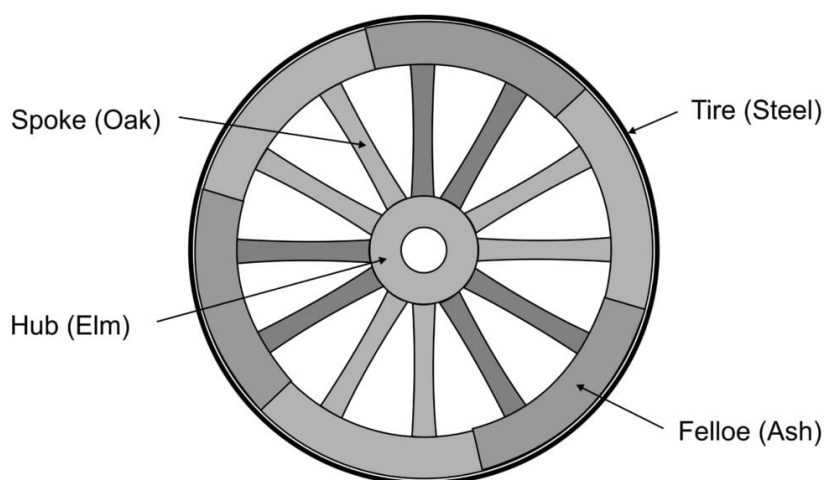


Modern Wheels

The wheel has been around since about 4000 BCE (Bulliet, 2016). The first wheels used for transportation may have derived from potters' wheels used for moulding cups and bowls. Some early wheels were made of stone, but these were soon replaced by wood which was lighter and faster. Around 3000 BCE spokes were invented, and for several thousand years fast-moving chariots with spoked wheels often decided ancient battles.

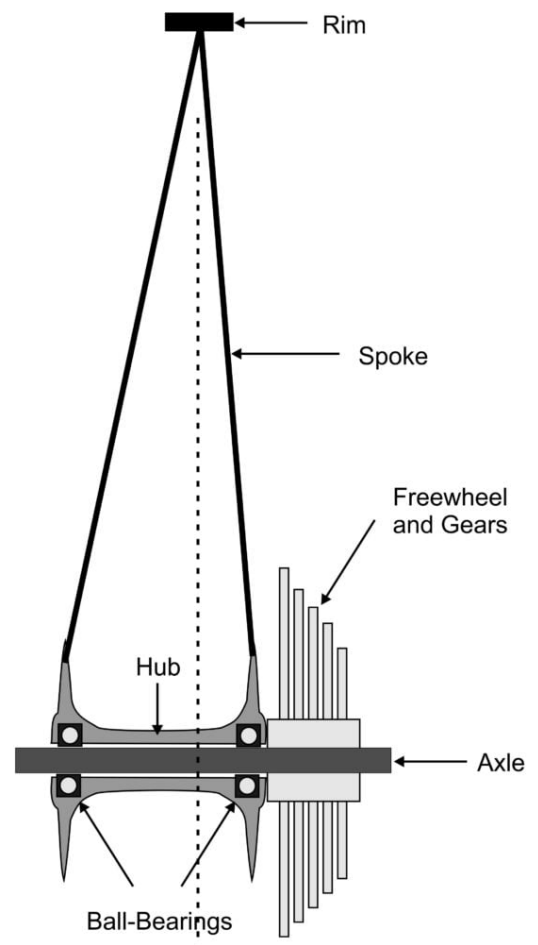
By the middle of the nineteenth century wooden wheels for carts and carriages had become fully developed (see figure). The rim was made by bending ash to form curved felloes. These were attached to the hub by strong oak spokes, and held in place by a steel tire.



In the last two hundred years the wheel has changed dramatically. Some changes have made the wheels more efficient (working well) and some made them more attractive (looking lovely). The forces driving the changes are thus similar to those that occur during evolution with its survival of the fittest and its sexual selection. However, wheel innovation is controlled by human design rather than random mutation, and the changes have occurred much more rapidly. And, as in evolution, some innovations do not survive: hubcaps and whitewall tires have become extinct.

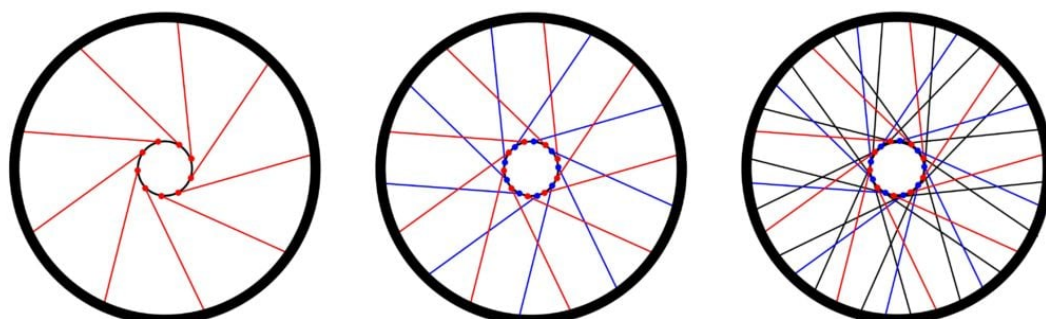
Bicycles

The new velocipedes (after 1820) and pedal-driven bicycles (after 1860) were powered by human beings rather than horses or oxen. This forced the development of lightweight wheels (Brandt, 1993; Herlihy, 2004). The first change was to make spokes of wire rather than wood. Initially these wires were arrayed radially from the hub to the rim. Spokes generally alternated between the two sides of the hub, giving the wheel a triangular cross-section, and thereby increasing the wheel resistance to compression (illustrated on the right). When a free-wheel system (invented in 1869 by William van Anden) was added to the rear wheel, the length of the spokes on the side of the free-wheel was shortened to maintain the wheel's balance. This was called "dishing" the wheel, i.e. making it more like a dish than a plate. Ball-bearings were first used to facilitate the rotation of the bicycle wheel around the fixed axle in 1869.



In 1874, John Kemp Starley invented a tangential approach to lacing the spokes of a wheel. The spokes were attached to the hub at an angle and crossed over each other on their way to the rim. This improved the ability of the wheel to resist the rotational forces (torque) involved when changing speed. Various levels of cross-over (from 1 to 4) are possible. Typical road bikes have 3-cross (3X) spokes. The spoke crosses another almost immediately upon leaving the hub, a second about an inch or so away from the hub, and a third about one

third of the way out toward the rim. The following figure shows the lacing pattern of a 3-cross wheel (Litt, 2010; Brown & Allen, 2011). The left shows half the set of spokes from one side of the hub; the middle shows all the spokes on that side of the hub; the right shows all the 36 spokes from both sides



of the hub.

The 3-cross spoke pattern is present in the famous Rover Safety Bicycle marketed by Starley in the 1880s:

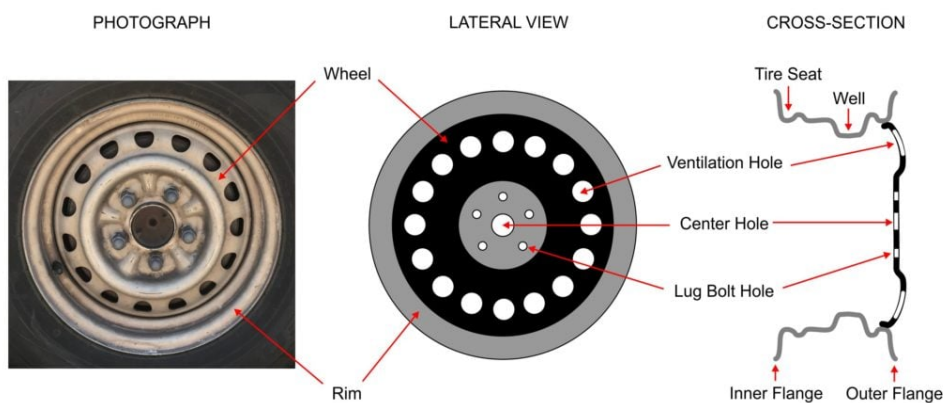


In 1889 John Boyd Dunlop made the first commercially successful pneumatic tires for bicycles. The idea had been patented some forty years before, but had not been followed into production.

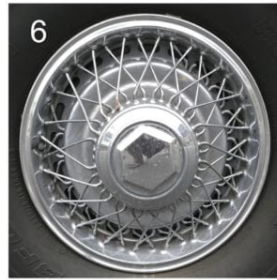
Automobiles

The first automobiles used bicycle wheels. As the automobile became heavier, the wheels had to become more robust. Although

wire wheels were still used in racing cars and motorcycles, the most common automobile wheels were made of two pieces: a drum (barrel or rim) upon which the tire was mounted, and a wheel disk that was welded (or bolted) to the drum (see right). The joining occurred on the outer edge of the wheel. The complete wheel was therefore deeply dished to allow space for the brakes, which initially worked by pushing against the inside of the drum. Nowadays, these have largely been replaced by disk-brakes which operate on a disk attached to the axle within the dished wheel. A major difference between automobile and bicycle wheels is that the automobile wheel is fixed to the axle.



Initially the automobile wheel-disk was made of solid steel, but holes were soon inserted (Reif, 2011; Duffy, 2014). These lightened the wheels without significant loss in strength, and provided ventilation to prevent the brakes from over-heating. Unfortunately, the wheel was visually unattractive. To overcome this, whitewall tires were invented, but this still left a dark and dirty inner wheel. One could paint the wheel, but a more common approach was to cover the wheel with a shiny cover made of aluminum or plastic. This hubcap or wheel-cover also protected the lug-bolts that held the wheel to the axle-hub. The following figure shows examples of the exposed wheel (1 – unpainted, 2 – painted), two simple hubcaps (3 – baby moon; 4 – full moon), a simple decorative hubcap (5), and finally a very complicated decorative hubcap (6) imitating wire spokes (note the steel wheel behind the wires).



When a tire needed changing the hubcap had to be removed to access the lug bolts. The hubcap was therefore spring-clipped to the wheel so that it could be easily popped off with a tire-iron. Unfortunately, potholes and bumps often had the same effect, and hubcaps became a common sight at the edge of the road (see right). Businesses sprang up to collect and resell lost hubcaps. One way to prevent this was to fix the hubcap more permanently to the wheel and to leave holes to access the lug bolts. Ultimately this led to there being two wheels: the sturdy steel wheel that supported the rim and the light wheel-cover that made the wheel look more appealing.



This redundancy can be prevented if the supporting wheel could

be made more visually attractive (Newton, 2007). Then it would provide both the strength and the shine. The advent of new magnesium and aluminum alloys and improved casting techniques led to wheels that no longer needed to be covered to look good. The following illustration shows an early aluminum wheel (Style 5) from BMW with a mesh pattern that pays homage to wire-spokes (1), a classic Mercedes star wheel (3) and an elegantly simple alloy wheel from Lexus (3):



Recently the rim, spokes and center disk are typically forged in one piece. The following illustration compares an old two-piece welded steel wheel to two new one-piece forged wheels from Bayern and from Konig:

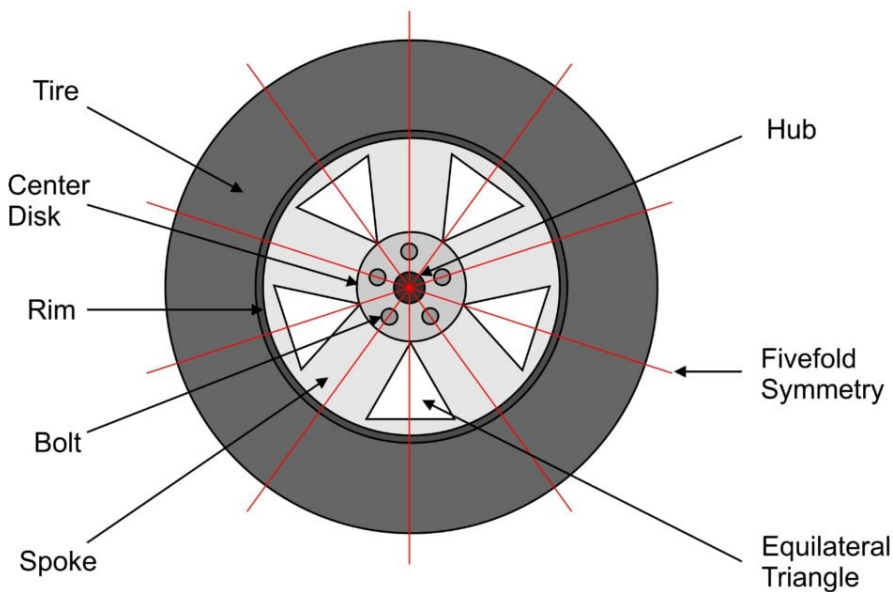


With the bright new wheel designs there is no longer need for whitewalls. Hubcaps are now restricted to the center hole of the wheel where they display the company logo. The most famous of these “center caps” is made by Rolls Royce to rotate in the opposite direction to the wheel, making the double-R legible at any speed.

Primes and Patterns

Most wheels on passenger cars are attached using 5 lug-bolts.

Smaller cars can use 4 or even 3 and larger cars and SUVs often use 6. Fivefold symmetry makes it difficult to generate resonance vibrations between different parts of the wheel since 5 is a prime number. The other advantage is that the openings between the spokes approximate an equilateral triangle, the strongest triangle design. Five-sided shapes (pentagons and pentacles) are aesthetically pleasing, perhaps because they have some symmetry but not too much.



Although the spoke design is generally based on 5, the spokes may be paired or tripled, and spoke patterns based on 3, 4, 6 or 7 are also possible (following illustration). The combination of 5 lug-bolts and 7 spokes seems to fulfil the idea of “prime” wheels.



With the new alloys and finishes, various patterns can be designed. Shiny surfaces can highlight the basic structure

(1). Rotationally asymmetrical wheels (2) look like they are meant to go in one direction. This leads to the problem that the wheels on the two sides of the car want to go in opposite directions. On the right, the wheel from the Lexus (3) shows a pattern that alludes to the tangential spokes initially developed for bicycle wheels.



Envoi

Wheels have developed to satisfy both function and fashion. They are an essential part of both the operation and attractiveness of the modern bicycle and automobile. Wheels define a vehicle's "street presence."

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Progress

Loss of Paradise

The ancients did not believe in progress (Bury, 1932; Pollard, 1968; Meek Lange, 2011). They had two main ideas of how the world changes over time. One was that an initial state of peace and plenty – the Garden of Eden of Genesis, the Golden Age of Hesiod, or the Arcadia of Virgil – had degenerated over time to our present world of strife and suffering.

The decline from our golden beginnings to the present age of iron might have been simply caused by the passage of time, but more often than not it was attributed to human foolishness. The Jews told the story of original sin and the Greeks recounted the myth of Pandora's box.

Lucas Cranach (1530) portrayed the Golden Age as a time when we could dance without fear of the lion and eat of the tree of knowledge without concern for the consequences. The word "paradise" means an area enclosed by a wall. Suffering and death remained outside the wall.



Our forefathers' second concept was that nothing ever really changes. The world may go through cycles of improvement and deterioration, but in the end everything stays about the same. The world is not perfect and never will be. The Jewish preacher Ecclesiastes (3rd Century BCE, 1:9, KJV) claimed that all is vanity:

The thing that hath been, it is that which shall be; and that which is done is that which shall be done: and there is no new thing under the sun.

The Roman Emperor Marcus Aurelius (180 CE, *Meditations* X:I, Staniforth translation) proposed that the soul

... can encompass the whole universe at will, both its own structure and the void surrounding it, and can reach out into eternity, embracing and comprehending the great cyclic renewals of creation, and thereby perceiving that future generations will have nothing new to witness, even as our forefathers beheld nothing more than we of today.

These two ideas of history were often combined. Our original paradise cannot be regained. The beings that began in Eden now find themselves condemned forever to brief lives characterized

more by suffering than by happiness, and leading inexorably to death.

Eastern religions adopted a similar view. They conceived of human life as a continual reincarnation into a world of suffering. The only escape was from the ongoing cycle of death and rebirth (*samsara*) was to remove oneself from the changing world (*maya*) by abdicating all desire and dedicating oneself to wisdom and charity.

City of God

Into the gloom that pervaded much of our ancient wisdom came the idea of salvation. Belief in the resurrection of Jesus Christ would allow the believer to escape to Heaven at the end of life. Failure to believe, however, would lead to Hell. In the 5th Century CE, Saint Augustine proposed that human beings can choose either to belong to the City of God or to remain in the Earthly City, the one founded by Cain (*City of God*, XV:1). People of the City of God progress “from earthly to heavenly things, and from the invisible to the invisible” (X:14).



The illustration at the right shows a terra cotta maquette from the Hermitage, a model for Bernini's 1650 statue of Augustine in St Peter's Cathedral. Bernini's sculpture was meant to be seen from many different perspectives. So perhaps we are not amiss in interpreting Augustine's work in ways not intended by the saint.

The idea of Christian salvation, like the benefits of many other religions, is basically mean-spirited and divisive. An elect will go to heaven; all others will not. Membership in the elite is not awarded on the basis of achievement but gifted by the grace of God. Indeed, Augustine believed that since God is omniscient, membership in the elect is pre-ordained.

Great Chain of Being

Augustine's thinking was embedded in the notion of a Great Chain of Being (Lovejoy, 1936) that he derived from Greek philosophers, most notably from the Neoplatonist Plotinus. God created the world. Within this world everything was arranged hierarchically from inanimate matter at the bottom through plants, animals, man, and angels, to God at the top. This concept was extensively worked out in medieval Scholasticism, but persisted long after, as evidenced by Alexander Pope's lines in his *Essay on Man* (1734, Epistle I:VIII):

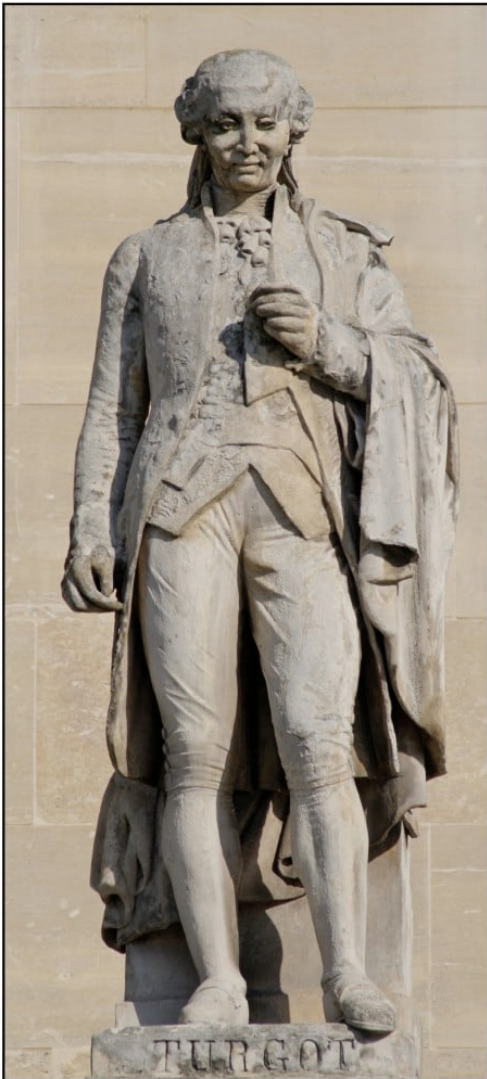
Vast chain of being, which from God began,
Natures ethereal, human, angel, man,
Beast, bird, fish, insect! what no eye can see,
No glass can reach! from infinite to thee,
From thee to nothing!

The hierarchy also characterized human society with the anointed King placed at the top, the lords and clergy below and the peasants at the very bottom. Society was not supposed to change: one knew one's place, and did not move between the levels.

Enlightenment

All this began to change with the emergence in the Europe of the 16th and 17th centuries of a new way of thinking that questioned the authority of the past. The very idea that we may not have understood the world correctly in the past implied that we might understand it better in the future.

This way of thinking led to the Enlightenment of the 18th Century. The new sciences had shown that we could understand more and more about the workings of the world, derive laws to predict what might happen, and harness energy to change the world which controlled us. Lives were becoming better.



The Enlightenment gave birth to our modern idea of progress.

In 1750 Anne-Robert-Jacques Turgot, Baron de l'Aulne (1727-1781) published an essay entitled *A Philosophical Review of the Successive Advances of the Human Mind*. He agreed with the ancients that

All things perish, and all things spring up again; and in these successive acts of generation through which plants and animals reproduce themselves time does no more than restore continually the counterpart of what it has caused to disappear.

This sounds much like Marcus Aurelius. However, Turgot also noted that human beings were different from the rest of the world, since they can accumulate and communicate knowledge:

The succession of mankind, on the other hand, affords from age to age an ever-changing spectacle. Reason, the passions, and liberty ceaselessly give rise to new events ... The arbitrary signs of speech and writing, by providing men with the means of securing the possession of their ideas and communicating them to others, have made of all the individual stores of knowledge a common treasure-house which one generation transmits to another, an inheritance which is always being enlarged by the discoveries of each age.

This allows the idea of progress, whereby

... the whole human race, through alternate periods of rest and unrest, of weal and woe, goes on advancing, although at a slow pace, towards greater perfection (all quotations from Turgot, 1750, p. 41).

Turgot became most famous for his work on economics, his *Reflections on the Formation and Distribution of Wealth* being one of the foundational works of economic liberalism. Nevertheless, it is to him in particular and to the Enlightenment in general that we must trace the origin of our idea of progress (Younkins, 2006; Meek Lange, 2011). The statue of Turgot by Pierre Travaux (1853)

illustrated above was appropriately photographed in the bright sunlight. Turgot was one of the giants of the Enlightenment.

Science advanced rapidly the 18th and 19th Centuries and by the beginning of the 20th Century it appeared that everything was within our reach. The study of thermodynamics had led to steam engines and automobiles, the study of electricity had given us artificial lighting and telephones, and the study of medicine had resulted in anesthetics and vaccines.

Society had become more humane. To some extent a belief in progress replaced our earlier belief in salvation.

Humanism is not science, but religion – the post-Christian faith that humans can make a world better than any in which they have so far lived ... Christians understood history as a story of sin and redemption. Humanism is the transformation of this Christian doctrine of salvation into a project of universal human emancipation. The idea of progress is a secular version of the Christian belief in providence. (Gray, 2003. xiii)

No one was more enthusiastic in their belief in Progress than the people of the United States. They considered it their manifest destiny to replace the simple life of the Native Americans with the railways and industry of European civilization. The 1853 painting of *Progress* by Asher Brown Durand of the Hudson Valley School portrayed the changing American landscape. On the left are the Native Americans and on the right the New Americans. The unspoiled wilderness gives way to the glorious future. Both are suffused in sunshine: nostalgia for paradise is balanced by hope of heaven.

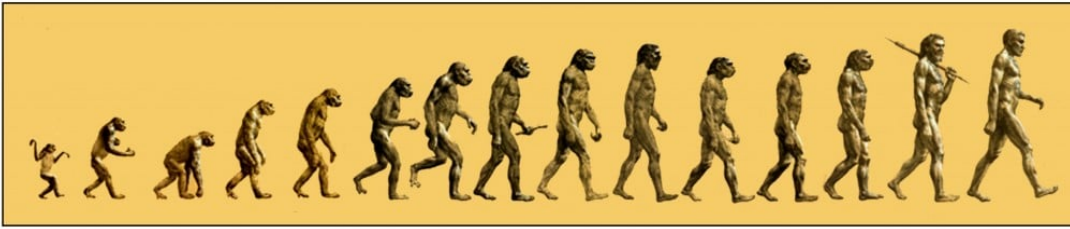


March of Progress

The Theory of Evolution inverted the Great Chain of Being. God did not create the world and all that is within it. Rather, the world evolved from inanimate to animate and from simple to complex. Man descended from earlier humanoid species, that themselves had descended from monkeys. The universe developed from bottom up rather than from top down.

Religion generally rejected this world view. However some religious philosophers tried to combine evolution with divine purpose. Man was perhaps evolving toward a perfect being, an Omega Point where everything would be understood, time would cease, and God and man become one. (Teilhard de Chardin, 1959).

The evolution of man was often portrayed as a *March of Progress*. The most famous of these illustrations was by Rudolph Zaillinger for the Time-Life book on *Early Man* (Howell, 1965):



The idea of the *March of Progress* was conceived in much the same way as the Great Chain of Being, although the sequence was temporal rather than hierarchical. Yet it remained a chain, and we often engage in a futile search for missing links.

Zaillinger's picture suggests a linear sequence, with each humanoid species evolving into the next. This is completely wrong. Evolution has multiple branches, with most of the branches ending with extinction. Evolutionary progress is better illustrated by a bush than by a ladder (Gould, 1989). Furthermore, the evolution of man appears to have depended much more on chance contingencies than on an inevitable path. This does not make progress directionless, but does underline its precariousness.

Brave New World

As the Enlightenment progressed, the Common Man began refused to stay subservient. The Divine Right of Kings no longer held; revolutions occurred; democracy began to flourish. In the 20th Century governments began to grant Universal Suffrage.

However, we may have become too confident. Butterfield (1931) pointed out the human tendency to conceive of past history as necessarily progressing to the perfection of the present. Our present happiness simply confirms that our past policies were correct. The Great War shook this simple faith. Where could one place such terrible carnage in any concept of progress?

The tendency to see the present as the best of all possible worlds persists. After the fall of the Berlin Wall, Francis Fukuyama announced the *End of History* (1989). Fascism had been

defeated; communism had failed; democracy had triumphed:

What we may be witnessing is not just the end of the Cold War, or the passing of a particular period of post-war history, but the end of history as such: that is, the end point of mankind's ideological evolution and the universalization of Western liberal democracy as the final form of human government.

All that was then needed was to export democracy to the rest of the world. Today we live with the violent results of this idea. The world and human society are far more complex than they appear. Progress may be both desirable and possible, but it will require more foresight than we have shown so far.

Angelus Novus

Not everyone subscribed to the idea that progress is beneficial. The first half of the 20th Century undermined everyone's faith. The rise of fascism in Europe, the war that it unleashed, the horror of the Holocaust, and the use of nuclear weapons were strong lines of evidence that history was descending into evil rather than progressing toward good.



Walter Benjamin gave terrifying poetic voice to this

possibility by evoking a 1920 painting of Paul Klee:

A Klee painting named "Angelus Novus" shows an angel looking as though he is about to move away from something he is fixedly contemplating. His eyes are staring, his mouth is open, his wings are spread. This is how one pictures the angel of history. His face is turned toward the past. Where we perceive a chain of events, he sees one single catastrophe which keeps piling wreckage upon wreckage and hurls it in front of his feet. The angel would like to stay, awaken the dead, and make whole what has been smashed. But a storm is blowing from Paradise; it has caught in his wings with such violence that the angel can no longer close them. This storm irresistibly propels him into the future to which his back is turned, while the pile of debris before him grows skyward. This storm is what we call progress. (Benjamin 1941, 257–8)

Benjamin's warnings were disregarded in the years of peace and prosperity that followed World War II. In recent years, however, the idea that progress can be evil has been reconsidered:

To believe in progress is to believe that, by using the new powers given us by growing scientific knowledge, humans can free themselves from the limits that frame the lives of other animals. This is the hope of nearly everybody nowadays, but it is groundless. For though human knowledge will very likely continue to grow and with it human power, the human animal will stay the same: a highly inventive species that is also one of the most predatory and destructive. (Gray, 2003, p. 4)

If anything about the present century is certain, it is that the power conferred on 'humanity' by new technologies will be used to commit atrocious crimes against it. (Gray, 2003, p. 14)

It is not hard to find historical examples of progress leading to problems (Wright, 2006). For example, the invention of flint arrows facilitated hunting but may have also led to the extinction of the very game that early man was pursuing. In addition, arrows provided yet another way for human beings to murder each other. Wright considers this early weaponry an example of a “progress trap” something that initially improves our lives but ultimately makes them worse.

Many of the problems brought on by progress are linked to human failings, particularly to selfishness. Wright considers the discovery of agriculture in this light:

The invention of agriculture is itself a runaway train, leading to vastly expanded populations but seldom solving the food problem because of two inevitable (or nearly inevitable) consequences. The first is biological: the population grows until it hits the bounds of the food supply. The second is social: all civilizations become hierarchical; the upward concentration of wealth ensure that there will never be enough to go around. (Wright, 2006, p. 108).

Modern democracies base their economies on capitalism. As well as being inherently unfair, capitalism cannot survive without continually increasing consumption. This has led to our current ills of pollution and climate-change:

Capitalism lures us on like the mechanical hare before the greyhounds, insisting that the economy is infinite and sharing therefore irrelevant. Just enough greyhounds catch a real hare now and then to keep the others running till they drop. In the past it was only the poor who lost this game; now it is the planet. (Wright, 2006, p. 124).

Nevertheless

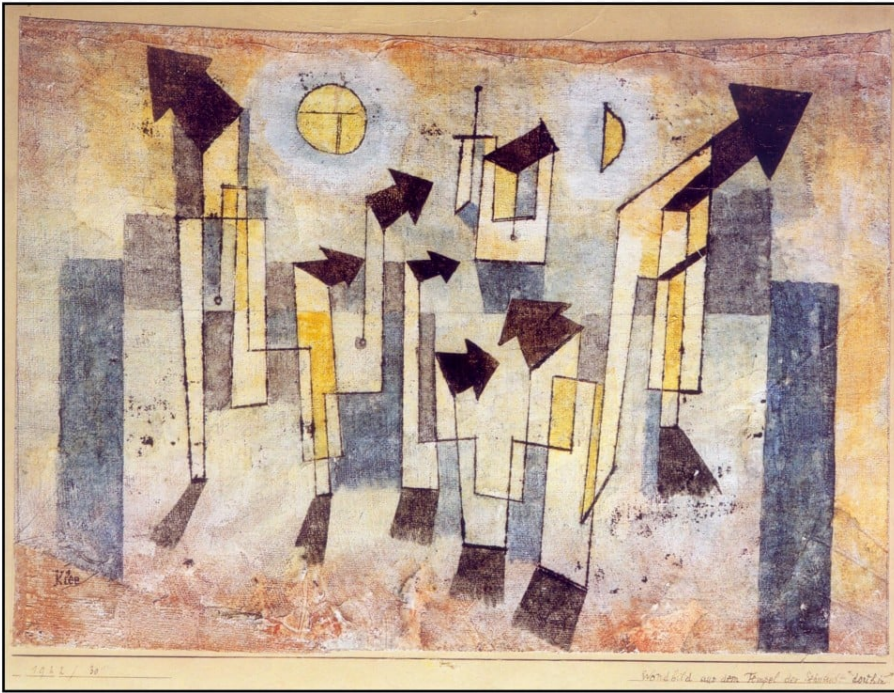
Though we must properly consider the problems that we face, we must not lose sight of the fact that we are getting better

even if the pace is slow and variable. Despite the tremendous loss of life in the two world wars of the 20th Century, we are less murderous now than in the past (Pinker, 2011, 2015). Though governments are far from perfect, the people of the present world have more rights now than in the days of kings. And even if science can lead to such terrible things as nuclear war, it has also provided us with the benefits of modern agriculture, transportation, communication and medicine.

We are right to be careful. Yet we should not do away with progress and retreat to the past. The paradise that we think we remember is not real. The future dystopias we imagine are warnings not necessary predictions.

Temple of Longing

To balance Benjamin's vision of the angel we might conclude with another of Paul Klee's paintings, *Mural from the Temple of Longing* (1922). The colors of the painting come from the desert. The surface is weathered as if by wind and sand. The shapes likely represent a mountain village in North Africa. Klee had been irrevocably changed by a brief sojourn in Tunis in the summer of 1914, and themes from that visit recur in many of his paintings. The blues of the picture suggest twilight, and the circular and semicircular shapes in the upper part of the picture may hint at a moon both full and waxing.



The various vertical constructions terminate in arrows which move away from us, upward and deeper into the space of the picture. Arrows occur many times in Klee's paintings and mean many things: the passage of time, the movement of things, and the force of desire. Here they may represent thoughts or questions:

The father of the arrow is the thought: how do I expand my reach? Over this river? This lake? That mountain? (Klee, 1925, p. 54)

A faith in progress is necessary. We should not simply accept our present state. We should long for a better world. However, we should always question how we should change the present to the future. And we should proceed with caution.

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Determined to Be Free

Scenario

Imagine yourself 20 years from now. A brilliant cognitive neuroscientist claims to be able to read your brain and predict your future behavior. She studied with Sam Harris in Los Angeles and then completed her postdoctoral work with Chun Siong Soon and John-Dylan Haynes in Berlin. She knows her stuff and she uses the most advanced technology.

You will be able to press one of five buttons. Before you do so, the neuroscientist will take a scan of your brain, analyse it and predict which button you will choose. She will pay particular attention to the posterior cingulate gyrus and the rostral prefrontal cortex. She is willing to bet you that her prediction will be correct.

If you take the bet, you believe in free will. If you do not, you are a determinist – or in this context a “neuro-determinist.”

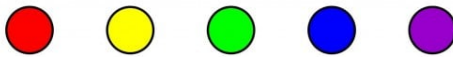
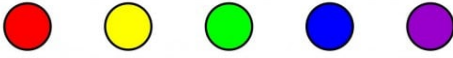

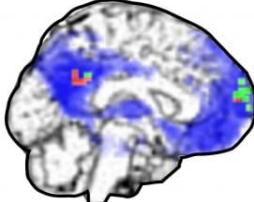
Faites vos jeux!

Paradigm: You can press one of five buttons.

Scan: Before you choose, your brain will be scanned, and its activity analysed to predict your choice.

Wager: You can bet that your choice will not be predicted.

Choice:


$$\int_{-\infty}^0 m^2 dt$$

Concept of Determinism

Modern determinism was most clearly stated by Pierre-Simon Laplace in 1812. He proposed that an intelligence – whether God or Demon, whether real or hypothetical – could completely predict the future from the present if the intelligence knew all the “forces by which nature is animated” and could measure the exact “situation” of everything in the present universe:

We ought then to regard the present state of the universe as the effect of its anterior state and as the cause of the one which is to follow. Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it – an intelligence sufficiently vast to submit these data to analysis – it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present to its eyes (Laplace, 1812/1902, p 4).

Determinism is the basic premise of science, which attempts to discern the causal laws by which the universe operates

(Earman, 1986; Hoefer, 2010). Everything is caused by something else. Nothing is a *causa sui* (cause of itself). The universe contains no freely acting anything or anybody.

Determinism is usually interpreted in terms of what will happen. However, in Laplace's definition it also casts its net backward: if we know everything about the present then we can tell exactly what happened in the past.

What is not always recognized is that Laplace wrote his definition of determinism in the introduction to his book *A Philosophical Essay on Probabilities*. Now, probability is what we use when we cannot predict exactly what will happen. A hypothetical vast intelligence might, but we cannot. We estimate the odds rather than predict the outcomes.

If the concept of determinism is taken seriously, then the present is determined by the immediate past, that past is itself determined by what preceded it, and so on. Ultimately, everything must have been decided when the world began, and all our actions determined 13.8 billion years ago at the moment of the Big Bang. In the words of Omar Khayyam:

With earth's first clay they did the last man knead,
And there of the last harvest sowed the seed.
And the first morning of creation wrote
What the last dawn of reckoning shall read.

(Fitzgerald translation, 5th Version LXVIII)

Determinism is a powerful working hypothesis but it may not be universally applicable. In the early 20th century, we became aware that atomic and sub-atomic processes are not deterministic (Ismael, 2015). They follow exact rules, but these are expressed in terms of probabilities rather than certainties.

Most biologists consider that at the levels of chemistry and physiology, quantum uncertainty averages out and we are "for

all intents and purposes" fully determined. At macroscopic levels, quantum uncertainty therefore plays no significant role in the prediction of the future.

My suggestion, however, is that the universe veers away from strict determinism both at levels of extreme simplicity – quantum uncertainty – and at levels of extreme complexity – conscious choice.

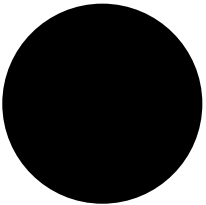
Problem of Chaos

Sometimes, as Edward Lorenz (1996) has shown, fully determined systems are liable to chaos. Chaos occurs "when the present completely determines the future, but the approximate present does not approximately determine the future" (Lorenz, 2005).

The movie below provides an example of a typical deterministic system – billiard balls on a billiard table. If the rules by which the system operates and the positions and velocities of the balls are exactly known, the future of the system can be precisely predicted. The life of a billiard ball goes from collision to collision. Although there are occasional near misses there is no choice.

On the left is the actual system. It is not perfect – the table is frictionless and the balls are inelastic (there is only so much an old man can program) – but it does follow deterministic laws. On the right is the modeled system. If we initiate movement in the white ball, our prediction fits exactly with what happens.

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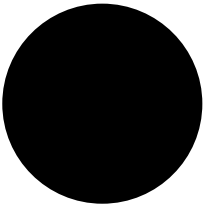


Some determined systems, however, are chaotic. In a chaotic system our predictions can be wildly off the mark if our measurement of the initial state of the system is not exact. Chaos is usually considered in terms of complex systems such as the weather: butterflies in Brazil causing tornados in Texas. However, chaos also occurs in very simple systems, even in billiards.

The next example shows the same deterministic system on the left as in the previous movie. On the right is the prediction. This time the measurement of the initial position of the white ball was out by one pixel. The measurement of the velocity vector was exact.

At the very beginning the prediction is approximately correct. After the first few seconds, however, the model shows no relationship whatsoever to the actual.

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Chaos is an inherent part of physical determinism. It is therefore often impossible to measure the state of the world with sufficient accuracy to give any meaningful predictions of what will actually occur. Our model of the future may look nothing like what it will be.

Chaos does not disprove determinism: chaos is completely determined. However it makes it very difficult to prove that determinism underlies everything. That hypothesis would require that we be able to measure the universe with absolute accuracy. That we cannot do.

Limits of Prediction

Even without chaos, complete predictability is impossible. The universe contains neither time nor space enough to map its own future.

Laplace was wrong to claim that even in a classical, non-chaotic universe the future can be unerringly predicted,

given sufficient knowledge of the present. (Wolpert, 2008).

✘ The proof is related to Gödel's Incompleteness Theorem and Turing's Halting Problem. A Turing machine reads an infinite tape one symbol at a time. According to its internal state at the time of reading, the machine then changes the symbol written on the tape, moves the tape, and changes its state. The Turing machine is a model of a computer. We cannot predict when the machine will stop. We are unable to know if a problem is soluble before it is solved. We cannot predict the entire future before it has already occurred.

David Wolpert's work means that "No matter what laws of physics govern a universe, there are inevitably facts about the universe that its inhabitants cannot learn by experiment or predict with a computation." (Collins, 2009). The most we can hope for is a "theory of almost everything" (Binder, 2008).

However, even though we cannot prove determinism, we cannot disprove it. It continues to be a reasonable working hypothesis for most situations.

Lack of predictability is a characteristic of free will. A test for free will (Lloyd, 2012) might involve the following criteria: the ability to make decisions, the use of recursive reasoning in making those decisions, the ability to predict the future, and the inability to predict what one will decide. If you are in the process of deciding how to act and if you cannot predict how you will decide, you are in a state of free will.

Quantum Uncertainties

One way out of the problem that quantum uncertainty poses for determinism is to claim that yet-unknown deterministic laws underlie quantum events. Once we discover these laws we will be able to re-cast quantum mechanics so that all events are exactly rather than stochastically determined. The problem

with such a “superdeterminism” is that in order to derive the underlying laws governing quantal processes we would have to observe events at subquantal levels. That would require using subquantal measuring devices, and that would run up against Heisenberg’s Uncertainty Principle (Hilgevoord & Uffink, 2006). I think indeterminism is here to stay. The only thing we can be certain about is ultimate uncertainty.

Quantum uncertainty may provide a way for our behavior not to be fully determined by antecedent causes. We would need to imagine some way for unpredictable quantum events to change brain activity. Penrose and Hameroff (2011) have suggested that quantum events in the neuronal microtubules – the Orchestrated Objective Reduction of Quantum States – could underlie our choices of one action over another.

However, making free will depend on quantum uncertainty is unsatisfying in that it reduces free will to chance rather than choice. Random is not the same as free. If we make our decisions on the basis of random quantum events, we are just subject to the tyranny of the atom rather than the will of God.

Even Sam Harris agrees:

Chance occurrences are by definition ones for which I can claim no responsibility. And if certain of my behaviors are truly the result of chance, they should be surprising *even to me* (Harris, 2012).

However, randomness can still play a role in free choice. We might decide to base our decisions on a random event, such as flipping a coin, so as to be fair to both sides of a question. We might also use a random process to add noise to a decision (like raising the temperature in an annealing process), or to determine how many options to evaluate or for how long (e.g. Dennett, 1978). For Peter Tse (2013) free will is caused by the “criterial selection” of random synaptic activity in

cerebral cortex.

Logical Problems

Two contradictory statements can be made in relation to free will and determinism (van Inwagen, 1983, 2008):

(i) Freedom of the will is not possible if the world is completely determined. Free will means that we are sometimes in the position with respect to a contemplated future act that we are able either to perform the act or to do otherwise. If we can indeed do otherwise – if two different futures can equally follow from the same present – then the future is not determined. The claim that we can choose between these two futures is incompatible with the idea that the past and the laws of nature together determine, at every moment, a unique future.

(ii) However, free will cannot act without determinism. If we make a decision, we can only carry it out if our behavior is determined by that decision – if action potentials travel down the nerves to the muscles, if the muscles move the limbs, and if the limbs perform the intended physical acts. Unless the world is deterministic, we cannot exercise our free will.

So we cannot have free will if the universe is completely determined, and free will is meaningless if the universe is not determined. There are two ways out of this conundrum. We can accept that the universe is determined, and conclude that our idea of free will is an illusion. Or we can agree with van Inwagen that free will is true and conclude that the world is not completely determined.

Van Inwagen considers free will to be true because he cannot imagine human life without personal moral responsibility. If there is no free will, everything we do is determined before we have anything to do with it. We need not think; we are never responsible for our actions; any idea of justice is meaningless. All evil will be exculpated by fMRI evidence that

the brain was just unable to be good.

A world where people do not believe in free will is not pleasant. Simply suggesting to subjects that there is no free will encourages dishonesty and mischief. The less someone believes in free will, the more likely he or she will cheat if the opportunity presents (Vohs & Schooler, 2008), and the more likely she or he will indulge in anti-social acts if they will not be discovered (Baumeister et al., 2009).

So, even if we are not free, should we act as if we were? This is a strange way to live our lives.

However, we can take positions other than that of full determinism in relation to the problem of free will:

	Free Will Impossible	Free Will Possible
Determinism True	Determinism	Compatibilism
Determinism False	Nihilism	Libertarianism

Van Inwagen's position is one of philosophical "libertarianism." (This is not the same as political libertarianism, which disputes the laws of society rather than the laws of science.)

Most of us believe that we have free will, but we are also convinced that the universe is determined. We are "compatibilists" – determinism is true but so is free will. We do not know how the two co-occur, but somehow they must. In surveys of what we believe, compatibilists are in a clear majority: 75% of normal folk (Nahmias et al, 2005), and 80% of biologists (Graffin & Provine, 2007). Even 60% of philosophers, those that should not support logical contradictions, consider themselves compatibilists (Bourget & Chalmers, 2014). The other 40% are evenly divided between undecided, libertarians and determinists.

Dan Dennett is the most prominent of our present

compatibilists. But he is unclear about exactly how free will can exist in a world of causes. Something to do with human knowledge and communication:

Our autonomy does not depend on anything like the miraculous suspension of causation but rather on the integrity of the processes of education and mutual sharing of knowledge. (Dennett, 2003).

Evolution and Free Will

Darwin thought that free will was a delusion. Since we are not conscious of the instincts that actually drive our actions, we only think that we freely choose. In fact we do not.

The general delusion about free will obvious – because man has power of action, & he can seldom analyse his motives (originally mostly instinctive, & therefore now great effort of reason to discover them: this is important explanation) he thinks they have none. (from Darwin's *Notebooks*, about 1839, edited by Barrett et al., 1987, p 608; these notes are discussed in Wright, 1994, p. 350).

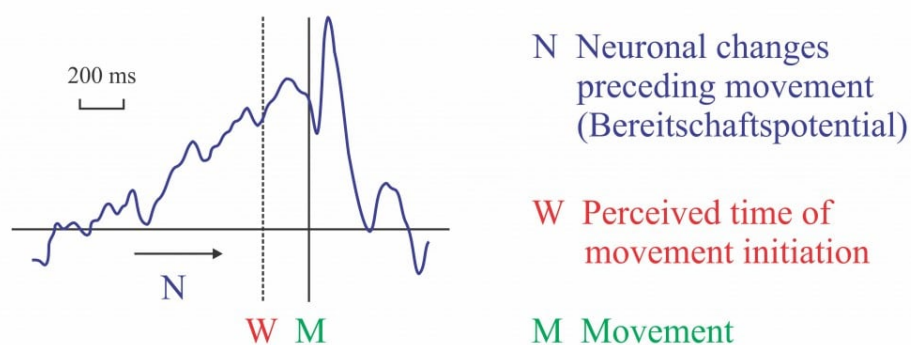
Evolution is often considered as part of a general determinism. Selection occurs according to hard and fast rules. Species that cannot survive to reproduce do not continue. Yet indeterminism rests at the very heart of Darwin's theory. Evolution depends on two processes: the production of offspring with variable characteristics and the selection of those offspring that survive in a world of limited resources. The variation is largely a result of genetic mutations and these are caused by indeterministic quantum events.

Some people have likened cognitive processing to Darwinian evolution (e.g., Edelman, 1987). In evolution, various species are created and only the most adaptive are selected. In cognition, various possible actions are considered and only the most appropriate are selected.

A major problem is why evolution determined that consciousness and free will occur. Human beings are certainly the most successful of all earth's species. This would suggest that consciousness and free will are highly adaptive traits that have been selected to facilitate our survival. Evolution is a deterministic process. Yet by selecting out the fittest, evolution has led to consciousness and free will. We have been determined to be free.

Neurodeterminism

Neuroscience entered the philosophical arena in the early 1980s when Benjamin Libet evaluated the relations between volition and the readiness potential (or *Bereitschaftspotential*) recorded from the scalp. The readiness potential began up to a second before the movement but the subject consciously perceived the time of movement initiation at about 200 ms before the movement. The brain decides unconsciously; awareness follows after.



Similar experiments have recorded unit activity in the human frontal cortex beginning about 2 seconds before the act (Fried et al., 2011) and fMRI activation patterns (Soon et al., 2008, 2013) between 4 and 10 seconds prior to the act.

These experiments have led to a theory of volition that has been called "neuro-determinism." Perhaps a better term might be "Libetarianism." Our actions are willy-nilly determined by cerebral processes about which we are unaware. We only become

conscious of what we are doing just before we do it. We do not control our actions, we just watch them taking place.

The 200 ms between the awareness of response-initiation and its occurrence could make it possible to inhibit or “veto” a response in process. Thus we can be consoled with the idea that even if we don’t have free will, we have “free won’t.” Yet recent experiments have shown that even this might be unconsciously driven (Filevich et al., 2013).

One problem with the neural measurements is that we do not know what they represent. Many different cerebral processes contribute to the readiness potential – estimating time, preparing to respond (or not), monitoring performance, etc. Some of these can be unconscious and can correlate significantly with later acts. Yet such processes do not necessarily cause the act – the mind can always change at the last minute (or millisecond).

In addition, our concept of volition is multidimensional (Roskies 2010). It can refer to the general intentions that one has in regard to a particular situation, the planning of how and when to respond, and the specific initiation of an act. A subject’s voluntary participation in a *Bereitschaftspotential* experiment involves his or her agreement to do what is asked by the experimenter, the setting up of the necessary timing and motor programs to control the responses, and the final initiation of the act. Any or all of these processes may contribute to the physiological recordings at different times.

Nevertheless, these physiological findings have led many scientists and philosophers to claim that our idea of free will is illusory:

Our sense of being a conscious agent who does things comes at a cost of being technically wrong all the time. The feeling of doing is how it seems, not what it is (Wegner,

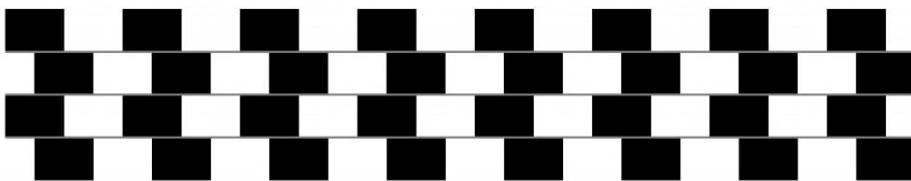
2002).

Free will is an illusion. Our wills are simply not of our own making. Thoughts and intentions emerge from background causes of which we are unaware and over which we exert no conscious control. We do not have the freedom we think we have (Harris, 2012)

Farewell to the purpose-driven life. Whatever is in our brain driving our lives from cradle to grave, it is not purposes. But it does produce the powerful illusion of purposes (Rosenberg, 2011).

Eddy Nahmias (2015) has suggested that we call their position “willusionism.”

I submit that this idea is wrong – free will is not an illusion. Now, this is an illusion!



The argument that a particular experience is illusory presupposes that other experiences are veridical. Indeed we only know that something is illusory if we can prove by some other experience that reality has been distorted. Despite the illusion of the tilting tiles in Richard Gregory’s café-wall, we can prove with a spirit level that they are actually all horizontal.



So in order to show that a particular experience of volition is illusory, there would have to be other experiences of

volition that are not illusionary and that are demonstrably different from the one considered illusionary.

Those who have proposed that free will is an illusion also point to clear evidence that we often do not know why we behave in a particular way. Psychoanalysis has long shown that we invent plausible but false reasons for how we act. This quotation is from Ernest Jones, one of Freud's early disciples:

... the large majority of mental processes in a normal person arise from sources unsuspected by him. ... No one will admit that he ever deliberately performed an irrational act, and any act that might appear so is immediately justified by distorting the mental processes concerned and providing a false explanation that has a plausible ring of rationality (Jones, 1908).

The psychoanalytic idea of rationalization has been supported by numerous recent psychological studies showing the effects of subliminal stimulation, the extent of our unconscious prejudices, and the vagaries of intuitions. We often are far more certain about things than we should be on the basis of the actual evidence (Burton, 2008).

Michael Gazzaniga's studies of split-brain patients showed how the left hemisphere can invent totally inaccurate explanations for our actions. He suggests that the left-hemisphere language-system tries to make sense of our experience but that sometimes the story it comes up with is false:

It is the left hemisphere that engages in the human tendency to find order in chaos, that tries to fit everything into a story and put it into a context ... even when it is sometimes detrimental to performance (Gazzaniga, 2011).

So perhaps we are always wrong? I think not. Just like the argument from illusion, the argument from rationalization only works if we are sometimes right. We have to know the real

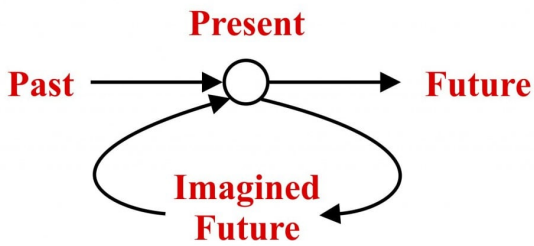
explanation in order to show that our rationalization is false.

Nature of Free Will

Only a small part of what we do is under conscious or controlled processing. Most of what we do occurs automatically. We are therefore often mistaken about why we acted in a particular way. We are not aware of causes outside of ourselves or hidden from conscious scrutiny, and we may invent reasons that are unrelated to what actually occurred, so that we can make sense of ourselves and our actions.

Nevertheless, we sometimes come to a decision about how to act by deliberately weighing the future consequences of several possible actions and choosing the most appropriate. We bring to bear on the problem all that we have so far learned about what things entail. For really important decisions, we often consult with others. We seek advice about what to do, ask our friends how they would decide in our position, and present scenarios for their comments. Freedom is inherently social. As mentioned above in relations to Dan Dennett's compatibilism, free will has something to do with human knowledge and communication.

The future does not determine the present. That is not the way time flows. But the imagined future can determine the present. Once a feedback loop is created, time and causality become complicated. In causal circles, cause and effect can be simultaneous rather than sequential. Once we conceive of consequences, the future becomes part of the present and we can base our actions on how the future will (or should) be.



These ideas of the “imagined future” are similar to the concept of episodic simulation proposed by Dan Schacter and his colleagues (Schacter, 2012; Szpunar et al., 2014) and the thoughts behind Carl Hoesfer’s *Freedom from the inside out* (2002).

Such future-directed thought can have a top-down effect on the present. In particular, acts of free will can form a “self” – a set of predispositions to act in a characteristic way, sometimes automatically and sometimes deliberately (Kane, 2011, 2014).

Every undetermined self-forming choice is the initiation of a novel pathway into the future, whose justification lies in that future and is not fully explained by the past.” (Kane, 2011)

In a way the exercise of free will is like setting a legal precedent. Past decisions can then contribute to present choices.

Return to the Scenario

And so we return to the hypothetical wager from the beginning of this post. Should we bet that our actions cannot be predicted? Will it be possible 20 years from now for a brilliant neuroscientist to predict our actions before they occur?

In the experiments of Eddy Nahmias and colleagues (2014), subjects were asked about just such a scenario: a future neuroscientist reads the brain activity of a person called

Jill and predicts what Jill will do. More than 80% of subjects accepted that this will be possible, but still claimed that Jill has free will if she is acting according to her own reasons. They believe that “the brain scanner is simply detecting how free will works in the brain” (Nahmias, 2015).

The astute among you may wonder whether during the scan you could fervently and honestly intend to press the red button. But then, once you have made your bet, on second thought you might wilfully decide to press one of the other buttons. After all, even at the last millisecond you can change your mind. You do not usually do this. That is why the brain scanner can often predict your behavior. But you always can change your mind.

I would take the bet.

Conclusion

I have considered physical determinism and pointed out its limitations in quantum uncertainty, chaos and incomputability. I have shown that complete determinism is in logical conflict with free will. I have reviewed some of the evidence that suggests that our unconscious brain determines what we might falsely believe to be our free choices. And I have refused to accept that evidence, arguing that we are still free whenever we base our actions on an evaluation of their consequences.

Determinism rules but only within limits. At the level of the atom there is quantum uncertainty. At the level of the brain there is conscious choice.

In our brains, most of what happens follows the laws of determinism, with the past causing the present and the present causing the future. Most of what we do is unconscious. Yet some acts are deliberately chosen after a conscious evaluation of what will happen. These are as much determined by the imagined future as by the actual past. As such they are both determined and free.

Note: This posting was derived from a talk given at the Rotman Research Institute Annual Conference. A pdf of the slides and the notes for the talk is available for download.

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