5. *Demise of the Dogmatic Universe*

1895 CE– 1950 CE

Maturation of Abstract Algebra and the Grand Fusion of Geometry, Algebra and Topology

Logic, Set Theory, Foundation of Mathematics and the Genesis of Computer Science

Modern Analysis

Electrons, Atoms and Quanta

Einstein's Relativity and the Geometrization of Gravity; The Expanding Universe

Preliminary Attempts to Geometrize Non-Gravitational Interactions

Subatomic Physics: Quantum Mechanics and Electrodynamics; Nuclear Physics

Reduction of Chemistry to Physics; Condensed Matter Physics; The 4^{th} State of Matter

The Conquest of Distance by Automobile, Aircraft and Wireless Communication; Cinematography

The 'Flaming Sword': Antibiotics and Nuclear Weapons

Unfolding Basic Biostructures: Chromosomes, Genes, Hormones, Enzymes and Viruses; Proteins and Amino Acids

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Environmental Events that Impacted Civilization

1898–1923	*Bubonic plague* pandemic kills 20 million people in China , India, North Africa and South America
1900	The Galveston (TX, USA) *hurricane* kills 8000 persons
1902	The eruption of the Mt. Pelée *volcano* (Martinique) kills 30, 000 people
1906	The San-Francisco *earthquake*
1908	The Messina *earthquake* kills 160, 000 people
1908	The Tunguska *bolide explosion*
1912	The 'Titanic' disaster
1917–1920	Worldwide Influenza pandemic kills 80 million people, mostly in Europe and Asia
1921–1930	*Cholera*, *smallpox* and *typhus* pandemic in India kills ca 2 million people
1923	The Tokyo *earthquake*
1931–1950	*Floods* of the Yellow and Yangtze Rivers in China (1928, 1929, 1931, 1936, 1938, 1950) kill 22 million people
1942	*Hurricane* at the Bay of Bengal kills 40, 000 people
1970	*Cyclone storm* and *tsunami* kill 500, 000 people at the Bay of Bengal
1976	*Earthquake* in Tangshan (China) kills 650, 000 people
1983–1985	Famine in Ethiopia kills ca 1 million people

Political and Religious Events that Impacted World Order

1904–1905	Russia and Japan at war
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1936–1939	The Spanish Civil War
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1949	Independence of India
1949	Foundation of the Republic of China
1949–1989	The 'Cold War'
1950–1953	The Korean War
1965–1975	The Vietnam War
1991	The Soviet Union officially ceased to exist
2001	The 'Nine-Eleven' event – Muslim terror hits the USA

1895 CE **Wilhelm Conrad Röntgen** (1845–1923, Germany). Physicist. Discovered X-rays while experimenting with electric current flow in partially evacuated glass tube (cathode-ray tube). In 1912, **Max von Laue** (1879–1960, Germany) determined its wave-lengths by means of diffraction through regularly-spaced atoms in crystals.

Although Röntgen was unaware of the true nature of these 'rays', he found that they affected photographic plates, and took the first anatomical X-ray photograph [the bones of his wife's hand]. His discovery heralded the age of modern physics and revolutionized diagnostic medicine. He was the recipient of the first Noble prize for physics, in 1901.

Röntgen was educated at Zürich and was then professor of physics at the universities of Strassbourg (1876–1879), Giessen (1879–1888), Würzburg (1888-1900) and finally Münich (1900–1920).

1895 CE **Auguste** (**Marie Louis**) **Lumière** (1862–1954, France) and his brother **Louis Jean** (1864–1948) developed a satisfactory camera and projector and made the first motion-picture film-show to the general public.

Inspired by Edison's *kinematoscope* they invented the *cinematograph*: a claw mechanism to pull the film a fixed distance past the projection (and camera) lens while the light was cut off by a shutter. Their choice of 16 frames per second remained the standard filming and projection rate through all the years of silent films.

1895–1896 CE **Hendrik Antoon Lorentz** (1853–1928, Holland). A leading physicist. Established the notion that electromagnetic radiation originates due to harmonic oscillations of charged particles *inside* atoms or molecules[1]. Lorentz suggested that a strong magnetic field ought to affect these oscillations and change the wavelength of the emitted radiation. This prediction was verified in 1896 by **Pieter Zeeman** (1865–1943, Holland), a pupil of Lorentz, and in 1902 they were awarded the Nobel prize in physics for their discovery.

Since the electron theory of Lorentz could not explain the results of the Michelson-Morley experiment, he was forced to concoct the 'Lorentz transformation' equations as an ad hoc device to overcome the difficulty.

Lorentz was born in Arnhem. During 1878–1923 he was a professor of theoretical physics at Leyden University.

[1] According to Maxwell's theory, electromagnetic radiation is produced by oscillations of electric charges, but charges that produce *visible light* were not known at that time.

1895–1909 CE **Georg (Yuri Viktorovich) Wulff** (1863–1925, Russia). Crystallographer. Discovered that the shape of small crystals can be explained, to some extent, by a variational principle similar to that of the isoperimetric problem[2], and that their remarkable difference in structure results from the difference in the corresponding potential energies; physically, a crystal with small surface irregularities will tend to *lower its free surface energy* and this becomes the dominating factor in its shape formation.

Wulff was born in Nezhin, the Ukraine. He studied at the Universities of Warsaw (1880–1892) and Odessa (1892–1899). He then held professorial positions at Kazan and Moscow (1918–1925). Wulff showed that for every given volume, there is a unique convex body whose boundary surface has less energy than does the boundary surface of any piecewise smooth body of the same volume. In his 1895 thesis, Wulff showed that for a constant volume, the surface energy per unit area at any point on the surface depends only on the direction of the tangent plane to the surface at that point.

Moreover, the total surface energy would be minimized when the specific surface energies for each face (K_i) were proportional to the perpendicular distances (n_i or *Wulff vectors*) from a central point to each face such that $K_1 : K_2 : K_3 : \cdots = n_1 : n_2 : n_3 : \ldots$. In modern studies of crystal growth the geometric algorithm for determining the equilibrium form derived from the theorem is known as *Wulff's construction.*

1895–1901 CE **Guglielmo Marconi** (1874–1937, Italy). Inventor and electrical engineer. Became the first person to send radio communication signals through the air[3]. In 1895 he sent a wireless telegraph code signal to a distance of 2 km and in 1901 he send a code signal across the Atlantic Ocean from England to Newfoundland.

Marconi was the last in the long chain of contributors during 1884–1897: He combined **Ruhmkorff's** induction-coil, the stable *spark oscillator* of **Augusto Righi** (1850–1920, Italy), the *coherer* of **Eugene Branly** (1844–1940,

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[2] In three dimensions, the perfectly smooth symmetrical sphere has the smallest free surface energy (area) when compared to all other smooth shape-sake bodies of the same volume. If however a region in space is bounded by a *finite collection of pieces of smooth surfaces* (piecewise smooth) there is an infinite number of possible surface energies; nevertheless, for each such admissible energy, the unique minimum is a convex region bounded by *planes*. The solution to this minimal problem, the optimal crystalline region, can be determined by the *Wulff construction.*

[3] The Russian claim to fame in this field is **Alexander Stepanovich Popov** (1859–1906), a physicist who devised the first *aerial* (1897), although he did not use it for radio communication. He also invented a detector for radio waves (1895).

France), **T.C. Onesti**[4] and **Oliver Lodge**, and the *antenna* of **Alexander Popov** into a workable system.

1895–1904 CE **Horace Lamb** (1849–1934, England). Applied mathematician. A student of **Stokes** and **Maxwell**; Professor at Adelaide, Australia (1875–1885) and University of Manchester (1885–1920). Author of *Hydrodynamics* (1895). Laid the foundation to modern theoretical seismology and contributed to the theory of the tides.

1895–1906 CE **Pierre Curie** (1859–1906, France). Physical chemist. Among the founders of modern physics. Discovered radium and polonium with his wife **Marie Curie** (1898), and the law that relates some magnetic properties to changes in temperature (*Curie's law*; *Curie point*). Established an analogy between paramagnetic materials and perfect gases and between ferromagnetic materials and condensed fluids.

Curie was a son of a Paris physician. Studied and taught physics at the Sorbonne, where he was appointed professor in 1904. He was run over by a dray in the rue Dauphine in Paris in 1906 and died instantly.

1895–1909 CE **Thorvald Nicolai Thiele** (1838–1910, Denmark). Mathematician with interest in astronomy. Derived a continued-fraction expansion of a given function, the convergents of which serve as *rational approximations* of the function (1909). Thiele taught in Copenhagen as well as being chief actuary of an insurance company.

1895–1915 CE **Wallace Clement Sabine** (1868–1919, U.S.A.). Physicist. Founded the science of *architectural acoustics.* Until 1895, criteria for what constituted a good acoustic hall were lacking. Sabine, a young physics instructor at Harvard University, was called on to attempt a remedy of the intolerable acoustics of the auditorium of the recently completed Fogg Art Museum[5]. He defined the parameters for good acoustical qualities before trying to translate them into practical considerations — dimensions, shapes, and building materials. He became later Hollis Professor of Mathematics and Natural Philosophy at Harvard.

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[4] **Temistocle Calzecchi Onesti** (1853–1922).

[5] In the Fogg Art Museum it was almost impossible to understand speakers in the lecture room.

Architectural Acoustics

Before Sabine, good acoustical design consisted chiefly of imitating halls in which music sounded good. Poor acoustic design consisted of superstitious practices, such as stringing useless wires across the upper spaces of a church or auditorium. Sabine identified the persistence of sound *(i.e., the excessive reverberation) as the factor that rendered speech unintelligible. He reduced the reverberation by placing felt on particular walls.*

Sabine was the first to define reverberation time*, one important parameter of lecture halls and auditoriums. His definition was the time that it takes, after a sound is turned off, for the reverberant sound level to become barely audible. (When accurate electronic measurement of sound level became possible many years later, this turned out to be a fall in sound level of 60 db.)*

From a series of ingenious experiments Sabine deduced a mathematical model that has a relation to the full-wave model (wave equation plus boundary conditions) of classical acoustics similar to that of radiative heat transfer to electromagnetic theory or of kinetic theory to classical mechanics. His idealization that sound fills a reverberant room in such a way that the average energy per unit volume in any region is nearly the same as in any other region, applies best to large *rooms whose characteristic dimensions are substantially larger than a typical wavelength.*

It also applies to live *rooms, for which the time determined by the ratio of the total propagating energy within the room to the time rate at which energy is being lost from the room is considerably larger than the time required for a sound wave to travel across a representative dimension of the room.*

When a sound source is in a room, sound waves emanating from the source will propagate until they strike the walls. Some energy will be absorbed by it and a weaker wave will be reflected back. The reflected wave will propagate until it reaches another wall where it is again reflected with partial absorption. This process continues until all the sound energy is eventually absorbed. The overall array of randomly criss-crossing rays is called the reverberant *sound field.*

The basic assumption of geometrical acoustics *is that the room walls are irregular enough so that the acoustic energy density W is distributed uniformly through the room. For this to be true, a large number of standing waves must be involved. Since each standing waves can be considered to be made up of a number of plane traveling waves, reflecting from the walls at appropriate angles, the sound in the room at the point characterized by the position vector*

$\boldsymbol{r}$ can be represented by an assemblage of harmonic plane waves, each going in a direction (φ, θ), each with pressure amplitude $A(\boldsymbol{r}, \varphi, \theta; \omega)$, intensity $I = \frac{|A|^2}{\rho c}$ (ρ = density; c = sound velocity), and energy density $W = \frac{|A|^2}{\rho c^2}$. These entities are given by the corresponding integrals

$$p(\boldsymbol{r}, \omega) = \int_0^{2\pi} d\varphi \int_0^{\pi} A(\boldsymbol{r}, \theta, \varphi) e^{i\boldsymbol{k}\cdot\boldsymbol{r} - i\omega t} \sin\theta d\theta$$

($\boldsymbol{k}$ = wave number vector; k, θ, φ its spherical components),

$$I(\boldsymbol{r}, \omega) = \frac{1}{\rho c} \int_0^{2\pi} d\varphi \int_0^{\pi/2} |A(\boldsymbol{r}, \theta, \varphi; \omega)|^2 \cos\theta \sin\theta d\theta$$

(power per unit area normal to $\boldsymbol{k}$),

$$W(\boldsymbol{r}, \omega) = \frac{1}{\rho c^2} \int_0^{2\pi} d\varphi \int_0^{\pi} |A(\boldsymbol{r}, \theta, \varphi; \omega)|^2 \sin\theta d\theta.$$

Geometric acoustics makes here two basic assumptions:

(1) The energy flow I is homogeneous and isotropic*, i.e., the average value of $|A|^2$ over a small region in space is independent of $\boldsymbol{r}$, θ and φ.*

(2) The absorbtive properties of the wall surface are represented by a single parameter, averaged over all directions of incidence and integrated over the total wall area of the room. This quantity a, called the absorption *of the room, has dimensions of area.*

The first assumption leads to the simple relation $I = \frac{1}{4}cW$ for the diffused sound field in a room, when each direction of propagation is equally likely (compared with $I = cW$ for unidirectional *plane wave). The second assumption, when coupled to the energy balance equation*

$$V\frac{dW}{dt} + Ia = 0$$

(V = volume of the room), leads to the solution

$$I = I_0 e^{-\left(\frac{ac}{4V}\right)t},$$

where I_0 is the initial value of the intensity.

The reverberation time τ is defined to be the time at which $I/I_0 = 10^{-6}$, or $\tau = \frac{V}{ac}\,55.3$ (Sabine, 1895). The reverberation time can be calculated from the room's volume and the total absorption. If τ is too long, it can easily be decreased by hanging additional curtains or sound absorbent panels.

When it is too short, electronic feedback system is used; a microphone on the ceiling picks up the incoming signal which is delayed and then re-emitted by loudspeakers.

Although τ is an important parameter related to a room's acoustic behavior, it is by no means the only one. Typical values of τ are about 0.3 sec for living rooms or up to 10 sec for large churches. Most large rooms have reverberation times between 0.7 and 2 sec. If the reverberation time is too short, sounds appear 'dead' as the lack of echo produces a very clipped sound. If τ is too long, speech becomes incoherent, and echoes drown the speaker.

Sabine appreciated both the physical *aspect of measuring and predicting the transmission and decay of sound in concert halls, and the* psychological *aspect: what makes a good hall good? He experimented to find the preferred reverberation time for musical performance.*

There are two general problems in architectural acoustics, and each has many aspects. One problem is, what do we want? *(e.g., what enables performers to play well? When they do play well, what is it that make them sound good?). The other problem is,* how can we attain what is good for the performers and what is good for the audience?

Thus, concert-hall design requires great attention both to excluding external noise and to not producing noise. Satisfactory ensemble playing depends on early reflections of sound from behind and above the performers; each player must hear all the rest by means of reflectes sound that is not too much delayed.

In spite of the progress made since Sabine's time, major errors have been committed in the design of music halls. Philharmonic Hall in Lincoln Center, Manhattan, opened on September 12, 1962. There were echoes at some seat locations. The members of the orchestra couldn't hear themselves and others play. There was a lack of subjectively felt reverberation. There was inadequate diffusion of sound through the hall. Worst of all, there was an apparent absence of low frequencies: it was difficult to hear the celli and double basses. In short — it was a disaster.

It turned out that the overhead acoustic panels did not reflect low-frequency components with sufficient strength into the main audience area. This was partly the result of poor scaling *(to properly reflect musical notes of different wavelengths from an acoustic panel, the panel's geometric dimensions must be at least comparable in size with the longest wavelength present in the sound. In actual fact they were much too small).*

During 1967–1974, **Manfred Schroeder** *(Germany) and his collaborators, undertook to compare more than 20 European concert halls. They played back a certain piece of music (a multichannel tape recording of Mozart's*

Jupiter symphony played by the BBC orchestra in an anechoic room) over several loudspeakers on the stages of various concert halls. In each hall they made two channel tapes of what a dummy head heard when seated in several locations. They then put listeners in an anechoic room at Göttingen and played back to them what the dummy head heard in various concert halls. By analyzing the judgments of these listeners, Schroeder and his colleagues learned that listeners liked:

- Long reverberation times (below 2.2 seconds).
- Sound to differ at their two ears.
- Narrow halls better than wide halls. (In a wide hall the first reflected sound rays reach the listener from the ceiling. In narrow halls the first reflections reach the listener from the left and right walls, and these two reflections are different.) The less preferred halls revealed a consistent absence of strong laterally traveling sound waves.

Thus, good acoustics — given proper reverberation time, frequency balance, and absence of disturbing echoes — is mediated by the presence of strong lateral sound waves that give rise to preferred stereophonic sound. In old-style high and narrow halls, such lateral sound is naturally provided by the architecture.

By contrast, in many modern fan-shaped halls with low ceiling, a monophonic sound, arriving in the symmetry plane through the listener's head, predominates, giving rise to an undesirable sensation of detachment from the music. To increase the amount of laterally traveling sound in a modern hall, highly efficient sound scattering surfaces have been recently invented (1990).

These reflection phase gratings are based on number-theoretic principles and have the remarkable property of scattering nearly equal acoustic intensities into all directions. Such broadly scattering surfaces are now being introduced into recording studios, churches, and even individual living rooms. The sound, dispersed from the ceiling, is scattered into a broad lateral radiation pattern (horizontal plane). The far-field (Fraunhofer diffraction) of such grating is approximated by the spatial Fourier transform of the acoustic signal.

The Korteweg–de Vries Equation (1895)[6]

In 1834, *the British engineer* ***John Scott Russell*** *(1808–1882) was consulted as to the possibility of utilizing steam navigation on the Edinburgh-Glasgow canal. He then undertook a series of experiments, in which he observed and reported (1844) the existence of solitary gravity waves in the canal. He deduced the empirical equation* $U^2 = g(h_0 + \eta_0)$, *where* U *is the wave's speed,* h_0 *the undisturbed depth of water,* g *the acceleration of gravity and* η_0 *the amplitude of the wave.*

A theoretical study of wave motion in inviscid incompressible fluid by ***J. Boussinesq***[7] *(1871)* and ***Lord Rayleigh*** *(1876) verified Russell's equation and showed that the wave profile* $z = \eta(x,t)$ *is given by*

$$\eta(x,t) = \frac{\eta_0}{\cos h^2\{\beta(x-Ut)\}}$$

where

$$\beta = \frac{1}{2h_0}\sqrt{3\frac{\eta_0}{h_0}},$$

$$\frac{\eta_0}{h_0} \ll 1,$$

$$U \approx \sqrt{gh_0}\left(1 + \frac{1}{2}\frac{\eta_0}{h_0}\right).$$

These authors did not, however, write down the equation for which $\eta(x,t)$ *was a solution. This final step was completed in* 1895 *by* ***D.J. Korteweg***[8]

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[6] To dig deeper, see:

- Drazin, P.G. and R.S. Johnson, *Solitons*: *An Introduction*, Cambridge University Press: Cambridge, 1990, 226 pp.
- Tabor, M., *Chaos and Integrability in Nonlinear Dynamics*, Wiley, 1989, 364 pp.
- Shen, S.S., *A Course on Nonlinear Waves*, Kluwer, 1994, 327 pp.
- Lamb, G.L. Jr., *Elements of Soliton Theory*, Wiley, 1980, 289 pp.

[7] **Boussinesq** (1842–1929, France).

[8] **Diederik Johannes Korteweg** (1848–1941, Holland). Applied mathematician. Educated at Delft as an engineer but later turned to mathematics. Was a professor of mathematics at the University of Amsterdam (1881–1918). Collaborated with **J.D. van der Waals** on various research topics in statistical mechanics and thermodynamics.

and ***G. de Vries****. Their equation, for waves on the surface of shallow water, was*

$$\frac{\partial \eta}{\partial t} + c_0\left(1 + \frac{3}{2h_0}\eta\right)\frac{\partial \eta}{\partial x} + \frac{1}{6}c_0 h_0^2 \frac{\partial^3 \eta}{\partial x^3} = 0$$

where $c_0 = \sqrt{gh_0}$.

This is essentially a one-dimensional wave equation in which non-linearity and dispersion occur together. It is known today as the 'KdV equation' and it has solutions known as solitons. It is characteristic of non-linear wave propagation in weakly dispersive media governed by a dispersion relation $\omega = c_0 k - \beta k^3$, *in which the relation between frequency* ω *and wave number* k, *involves the amplitude.*

Note that the soliton solution is exact and describes a traveling permanent profile, which does not change its shape and propagates with constant speed. This is due to a balance between the two competing effects of non-linearity and dispersion. It is this property which gives the KdV equation its universal nature.

Indeed, it was discovered throughout the 20^{th} *century that the equation and its modifications have many diverse applications such as: waves in a rotating atmosphere (Rossby waves), ion-acoustic waves in plasma, pressure waves in a liquid-gas bubble mixture, the non-linear Schrödinger equation and anharmonic lattice vibrations.*

1895–1915 CE **Herbert George Wells** (1866–1946, England). Novelist, sociologist, and historian. Wrote fantastic scientific romances in which he combined scientific speculations with a strain of sociological idealism: *The Time Machine* (1895), *The Island of Doctor Moreau* (1896), *The Wheels of Chance* (1896), *The Invisible Man* (1897), *The War in the Air* (1908), *The War of the Worlds* (1898), *First Men in the Moon* (1901), *The Food of the Gods* (1904), *A Modern Utopia* (1905). His novel *The World Set Free* (1914), predicted atomic bombs, atomic war and world government.

1895–1949 CE **Élie Joseph Cartan** (1869–1951, France). One of the foremost mathematician of the 20^{th} century, and one of the architects of modern mathematics. A principal founder of the modern theory of Lie groups and Lie algebras, a contributor to the theory of subalgebras and discoverer of the general mathematical form of *spinors*[9] (1913), 14 years ahead of physics. His work achieved a synthesis between continuous group, Lie algebras, differential equations and geometry.

Cartan's thesis (1894) was on the structure of continuous groups of transformations, and most of the ideas which directed all his subsequent work are to be found in it. The principal part of the thesis was devoted to the classification of simple Lie algebras over the complex field, and it completed the work of **Lie** and **Killing** on this subject.

About 1897 Cartan turned his attention to *linear associative algebras* over real and complex fields. In 1899 he began his work on Pfaffian forms, including such topics as contact transformations, invariant integrals and Hamiltonian dynamics, and his great contributions to differential geometry. Within this framework he invented the calculus of *differential forms* (1897) and introduced the concept of *wedge product*. His *exterior calculus* is anchored in the pioneering studies of **Poincaré** and **Édouard Jean Baptist Goursat** (1858–1936).

During 1904–1909 Cartan made substantial contributions to the theory of infinite *continuous groups*. In 1913 he developed systematically the theory of *spinors*, by giving a purely geometrical definition of these mathematical entities. This geometrical origin made it easy to introduce spinors into Riemannian geometry, and particularly to apply to them the idea of parallel transport.

Cartan further contributed to geometry with his theory of symmetric spaces which have their origin in papers he wrote in 1926. It developed ideas first studied by Clifford and Cayley and used topological methods developed by Weyl. This work was completed by 1932.

The discovery of the general theory of relativity in 1916 turned the attention of many mathematicians, including Cartan, to the general concept of geometry, and nearly all of Cartan's work from this time onwards is devoted to the development of a general theory of *differential geometry* (1917–1949). It forms a most vital contribution to modern mathematics.

Thus, in 1922 he proposed and developed a gravitational theory with *non-symmetric connection* (geometry with *torsion*). The result was the *Einstein-Cartan equations* which include, in addition to Einstein's ten equations for the metric $g_{\mu\nu}$, a system of equations for the torsion tensor. The source in the torsion equation is represented by a tensor that is defined by the spin properties of matter.

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[9] For further reading, see: Cartan, E., *The Theory of Spinors*, Dover Publications: New York, 1981, 157 pp.

It is indeed remarkable that this work was begun when he was nearly 50, and carried on until he was 80 — a most striking exception to **Hardy**'s dictum that mathematics is a young man's game.

Cartan was born in Dolomien, a village in the south of France. His father was a blacksmith. Cartan's elementary education was made possible by a state stipend for gifted children. In 1888 he entered the École Normale Superieur, where he learned higher mathematics from **Picard**, **Darboux** and **Hermite**. His research work started with his famous thesis on continuous groups, a subject suggested to him by a fellow student, recently returned from studying with **Sophus Lie** in Leipzig.

He was made a professor at the Sorbonne in 1912. The report on his work, which was the basis for this promotion, was written by **Poincaré**. He remained in the Sorbonne until his retirement in 1940.

In 1903 Cartan married Mlle Marie-Louis Bianconi. Besides a daughter, there were three sons of the marriage — **Henri Paul Cartan** (b. 1904), a distinguished mathematician in his own right who made significant advances in the theory of analytic functions, theory of sheaves, homological theory, algebraic topology and potential theory.

His other son, Jean, oriented himself toward music, and had already emerged as one of the most gifted composers of his generation, when he was cruelly taken by death. His third son, Louis Cartan, a professor of physics, was arrested by the Germans at the beginning of the Resistance and murdered by them in 1943.

Besides several books, Cartan published about 200 mathematical papers. His mathematical works can be roughly classified under three headings: group theory, systems of differential equations and geometry. These themes are constantly interwoven with each other in his work. Almost everything Cartan did is more or less connected with the theory of Lie groups.

The Calculus of Differential Forms[10]

The calculus of alternating differential forms (also known as the exterior calculus or Cartan calculus) enables one to make a systematic generalization to n-dimensional spaces of vector analysis in the plane and in three dimensional space. Thus, the theory provides a convenient and elegant way of phrasing Green's, Stokes', and Gauss' theorems. In fact, the use of differential forms shows that these theorems are all manifestations of a single underlying mathematical theory and provides the necessary language to generalize them to n dimensions.

This calculus has applications, among other things, to differential geometry and theoretical physics (e.g., relativity theory, electrodynamics, thermodynamics, analytical mechanics, particle physics). There is a very close connection between alternating differential forms and skew-symmetric tensors. The calculus of differential forms carries to manifolds (especially those that do not include a metric or a covariant derivative) such basic notions as gradient, curl and integral. Further, it enables an index-free treatment of differential geometry.

In the following, the algebraic structure of differential forms (DF) will be outlined from an axiomatic viewpoint. Then, the deep-seated reasons for the apparently arbitrary definitions will be anchored in vector analysis, and finally motivated by physical applications.

- *A real-valued twice-differentiable function $f(x, y, z)$ is an 0-form. It can be considered as a rule that assigns to each point in R^3 a real number. This generalizes to any n-dimensional manifold.*
- *Formal expressions such as*

  $$\omega = A(x,y)dx + B(x,y)dy \qquad \text{and}$$
  $$\omega = A(x,y,z)dx + B(x,y,z)dy + C(x,y,z)\,dz$$

  are 1-forms. The first is a 1-form in the XY plane (or any 2-dimensional manifold), while the second is a 1-form in 3-dimensional space. [A, B, C will be assumed to be real-valued infinitely differentiable functions, although this is not necessary for the derivation of some of the results.]

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[10] To dig deeper, see:

- Flanders, H., *Differential Forms with Applications to the Physical Sciences*, Dover, 1989, 205 pp.

- *The formal expression*

$$\eta = A(x,y,z)dxdy + B(x,y,z)dydz + C(x,y,z)dzdx$$

  is a 2-form in a 3*-space (i.e. a* 3*-dimensional manifold or* R^3*). The 2-form* $\eta = A(x,y)dxdy$ *is a special case for* $B = 0,\ C = 0,\ \frac{\partial A}{\partial Z} = 0$*, and also the general case in two dimensions. The order of the differentials is essential in this product-notation;* $dxdy = -dydx$*, etc. In general* $\omega_1\omega_2 = -\omega_2\omega_1$ *for any pair of 1-forms.*

- *The formal expression* $\mu = A(x,y,z)dxdydz$ *is a 3-form. The order of the differentials is again essential, modulo cyclic permutation:* $dxdydz = dzdxdy = -dzdydx$*, etc.*

In 3*-space there exist only 0-forms, 1-forms, 2-forms, and 3-forms, while in* 2*-space, there are only 0-forms, 1-forms, and 2-forms. In the manifold case, the above expressions hold in any given local coordinate system.*

Algebraic structure*: The system of DF in* 3*-space, for instance, is a linear associative algebra (Grassman algebra) with a basis of* 8 *elements:*

$$1,\ dx,\ dy,\ dz,\ dxdy,\ dydz,\ dzdx,\ dxdydz$$

whose coefficients belong to the field of continuous functions, and whose multiplication table is specified by:

$$dxdy = -dydx, \quad dydz = -dzdy, \quad dzdx = -dxdz,$$

$$dxdx = 0, \quad dydy = 0, \quad dzdz = 0.$$

The product of a k-form and an m-form is a $(k+m)$ *form, where the integer prefix is the form's degree (dx is a* 1*-form, dxdy a* 2*-form, etc.).*

If $m+k > n$*, the number of variables, then there will be repetitions, and such a product will be zero. Since a 0-form is merely a function, multiplication by a 0-form does not affect the degree of the form. [Example:* $(xdx - zdy + y^2dz)(x^2dydz + 2dzdx - ydxdy) = (x^3 - 2z - y^3)dxdydz$*.]*

Geometrical structure*: One can naturally define the line integral of a 1-form* $\omega = Adx + Bdy + Cdz$ *along a curve* γ*. Let* γ *be a smooth simple curve, with parametric equations* $x = x(t),\ y = y(t),\ z = z(t),\ a \le t \le b$*, and oriented in such a way that the positive direction of* γ *is associated with* *the direction which* $x(t), y(t), z(t)$ *traverse as* t *increases from* a *to* b*; the same curve with the opposite orientation is denoted* $-\gamma$*. Then*

$$\int_\gamma \omega \equiv \int_a^b \left[A\{x(t), y(t), z(t)\}\frac{dx}{dt} + B\{x(t), y(t), z(t)\}\frac{dy}{dt} \right.$$
$$\left. +C\{x(t), y(t), z(t)\}\frac{dz}{dt} \right] dt.$$

In this way a 1-form can be thought of as a rule that assigns a real number to each oriented curve[11]*. Note that* $\int_{-\gamma}\omega = -\int_\gamma \omega$ *since reversal of orientation of a curve changes the sign of the integral.*

A 2-form may be similarly interpreted as a surface functional, namely a function that associates with each oriented $2D$ *surface a real number. Again, using the local parametrization* $x = x(u, v)$, $y = y(u, v)$, $z = z(u, v)$ *with* (u, v) *belonging to a domain* D *in* R^2*, we have for a surface* S *and 2-form* η*:*

$$\int_S \eta = \int_S (Adxdy + Bdydz + Cdzdx)$$
$$= \int_D \left[A\{x(u, v), y(u, v), z(u, v)\}\frac{\partial(x, y)}{\partial(u, v)} + B\{x(u, v), y(u, v), z(u, v)\}\frac{\partial(y, z)}{\partial(u, v)} \right.$$
$$\left. +C\{x(u, v), y(u, v), z(u, v)\}\frac{\partial(z, x)}{\partial(u, v)} \right] dudv$$

where

$$\frac{\partial(x, y)}{\partial(u, v)} = \begin{vmatrix} \frac{\partial x}{\partial u} & \frac{\partial x}{\partial v} \\ \frac{\partial y}{\partial u} & \frac{\partial y}{\partial v} \end{vmatrix}; \qquad \frac{\partial(y, z)}{\partial(u, v)} = \begin{vmatrix} \frac{\partial y}{\partial u} & \frac{\partial y}{\partial v} \\ \frac{\partial z}{\partial u} & \frac{\partial z}{\partial v} \end{vmatrix}; \qquad \frac{\partial(z, x)}{\partial(u, v)} = \begin{vmatrix} \frac{\partial z}{\partial u} & \frac{\partial z}{\partial v} \\ \frac{\partial x}{\partial u} & \frac{\partial x}{\partial v} \end{vmatrix}.$$

Note that, if η *would have a* $dxdx$ *term (which formally vanishes), the determinant* $\frac{\partial(x,x)}{\partial(u,v)}$ *has equal rows, and hence vanishes. Also, if we interchange*

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[11] In general, given a *1-form* and a smooth curve γ, the value of the line integral will depend on γ. However, when two curves are *parametrically equivalent*, then a *1-form* will assign the same value to both. The same is true for smoothly equivalent surfaces and *2-forms*. All these integrals can be extended to curves and surfaces embedded in any n-space ($n \geq 2$). If the space is a manifold, the integrals need to be broken up into single–coordinate–system pieces.

Parametrical equivalence: if (in any coordinate–system neighborhood through which γ passes) $x = \phi(t)$ on γ_1 with $a \leq t \leq b$ and γ_2 is given by $x = \phi\,[f(t)]$ over $\alpha \leq t \leq \beta$, and the function $f(t)$ maps the interval $[\alpha, \beta]$ onto $[a, b]$ in a one-to-one, differentiable manner with $f'(t) > 0$, then (and only then) are the curves γ_1 and γ_2 said to be parametrically equivalent.

x and y, the corresponding determinant changes sign; etc. This renders a geometrical motivation for the rules $dxdx = 0$, $dydx = -dxdy$, with similar results for the other Jacobian determinants.

Finally, a 3-form ν in 3-space *assigns a real number to each 3D submanifold Ω of the* 3-space *in question. The number is $\int_\Omega \nu = \int_\Omega f(x,y,z)dxdydz$ which is just the ordinary triple integral of f over Ω.*

All these integrals are true geometric entities – because they do not depend on the choice of local manifold coordinate systems, nor upon the parameterizations (coordinate systems) of the submanifolds integrated over (curves, surfaces and higher submanifolds). This concludes the description of the geometrical hierarchy.

DIFFERENTIATION OF FORMS IN 3-SPACE*: In general, if ω is a k-form, its differential $d\omega$ will be a $k+1$ form. Thus if A is a 0-form* (function) *then dA is (locally) the 1-form $dA = \frac{\partial A}{\partial x}dx + \frac{\partial A}{\partial y}dy + \frac{\partial A}{\partial z}dz$. If ω is a 1-form $Adx + Bdy + Cdz$ whose local coefficients are functions, then $d\omega$ is the 2-form $d\omega = (dA)dx + (dB)dy + (dC)dz$.*

If ω is a 2-form in 3-space *$Adydz + Bdzdx + Cdxdy$, then $d\omega$ is the 3-form $d\omega = (dA)dydz + (dB)dzdx + (dC)dxdy$, where $d\omega$ is to be locally computed by evaluating dA, dB, and dC, and then computing the indicated products.*

Since dA is a 1-form, $(dA)dx$ is indeed a 2-form and *$(dA)dydz$ is a 3-form.* [For example: *$\omega = x^2ydydz - xzdxdy$, $d\omega = (2xy - x)dxdydz$.*] *The operator d is known as the exterior derivative*[12]. *The derivative of a* 3-form *may be computed in the same fashion, but since it will be a 4-form in three variables, it will automatically be zero. Differentiation of forms in two variables is done in the same fashion*[13]. *The foregoing rules for multiplication and differentiation have in store for us a number of surprises:*

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[12] There are three kinds of derivatives in differential geometry and tensor analysis:

- *The covariant derivative* in the direction of the contravariant vector $\boldsymbol{A}$ (∇_A); acts on *any* tensor; it depends only on $\boldsymbol{A}$ but not its derivatives.
- *The Lie derivative* (L_A); depends on $\boldsymbol{A}$ *and* its derivatives.
- *The exterior derivative*; acts on any totally antisymmetric, covariant tensor (= differential form) to yield a form with rank higher by one; it is also covariant.

The last two derivatives exist even in spaces without an affine connection, Γ^m_{ik}, but ∇_A exist only in an affine space (a space endowed with a connection).

[13] The rules may seem arbitrary, but in fact they "happen" to fit with the rule of the transformation of the area element through a coordinate transformation.

- *The product of two 1-forms in* $\mathbb{R}^3$ *yields the general formula*

$$\omega_1\omega_2 = (Adx + Bdy + Cdz)(adx + bdy + cdz)$$
$$= \begin{vmatrix} B & C \\ b & c \end{vmatrix} dydz + \begin{vmatrix} C & A \\ c & a \end{vmatrix} dzdx + \begin{vmatrix} A & B \\ a & b \end{vmatrix} dxdy \Rightarrow (\boldsymbol{\omega}_1 \times \boldsymbol{\omega}_2).$$

In the above equation we treat (A, B, C) *and* (a, b, c) *as the respective components of the vectors* $\boldsymbol{\omega}_1 = A\boldsymbol{e}_x + B\boldsymbol{e}_y + C\boldsymbol{e}_z$, $\boldsymbol{\omega}_2 = a\boldsymbol{e}_x + b\boldsymbol{e}_y + c\boldsymbol{e}_z$, *and* $(\times)$ *is the usual vector product operation.*

- *The product of a 1-form* $\omega = Adx + Bdy + Cdz$ *by the 2-form* $\nu = adydz + bdzdx + cdxdy$ *in a 3-space yields the 3-form* $(aA + bB + cC)dxdydz$. *Its scalar function coefficient can be written as the scalar product of the local vectors* $\boldsymbol{\omega} = A\boldsymbol{e}_x + B\boldsymbol{e}_y + C\boldsymbol{e}_z$ *and* $\boldsymbol{\nu} = a\boldsymbol{e}_x + b\boldsymbol{e}_y + c\boldsymbol{e}_z$, *namely:* $(\boldsymbol{\omega} \cdot \boldsymbol{\nu})$.

- *If* $\omega = A(x, y, z)dx + B(x, y, z)dy + C(x, y, z)dz$, *then*

$$d\omega = \left(\frac{\partial C}{\partial y} - \frac{\partial B}{\partial z}\right) dydz + \left(\frac{\partial A}{\partial z} - \frac{\partial C}{\partial x}\right) dzdx + \left(\frac{\partial B}{\partial x} - \frac{\partial A}{\partial y}\right) dxdy \Rightarrow \operatorname{curl} \boldsymbol{\omega},$$

where $\boldsymbol{\omega} = A\boldsymbol{e}_x + B\boldsymbol{e}_y + C\boldsymbol{e}_z$.

- *If* $\nu = a(x, y, z)dydz + b(x, y, z)dzdx + c(x, y, z)dxdy$, *then*

$$d\nu = \left(\frac{\partial a}{\partial x} + \frac{\partial b}{\partial y} + \frac{\partial c}{\partial z}\right) dxdydz \Rightarrow \operatorname{div} \boldsymbol{\nu},$$

where $\boldsymbol{\nu} = a\boldsymbol{e}_x + b\boldsymbol{e}_y + c\boldsymbol{e}_z$.

The above examples hint to a strong link between vector analysis and differential forms. But prior to the establishment of the nature of these connections one must summarize the historical background:

Let $u = f(x, y)$, $v = g(x, y)$, then $du = \frac{\partial f}{\partial x}dx + \frac{\partial f}{\partial y}dy$, $dv = \frac{\partial g}{\partial x}dx + \frac{\partial g}{\partial y}dy$ and

$$dudv = \left(\frac{\partial f}{\partial x}\,dx + \frac{\partial f}{\partial y}\,dy\right)\left(\frac{\partial g}{\partial x}\,dx + \frac{\partial g}{\partial y}\,dy\right)$$
$$= \left(\frac{\partial f}{\partial x}\frac{\partial g}{\partial y} - \frac{\partial f}{\partial y}\frac{\partial g}{\partial x}\right) dxdy = \frac{\partial(u, v)}{\partial(x, y)}\,dxdy.$$

This ensures that a surface integral $\int_S \eta$, for any *2-form* η and 2-submanifold S in any 2-space, does not depend on local coordinate–system choices. Similar reasoning applies to forms of any degree in any dimensionality.

Early efforts to establish an algebra for points of the plane *(which has the same rules as the algebra of numbers) met with success because a suitable definition for multiplication could be found, namely, the (commutative) product of ordered–real–pair points*

$$(x_1, x_2)(y_1, y_2) = (x_1y_1 - x_2y_2, \quad x_1y_2 + x_2y_1).$$

The motivation for this rule may be seen by making the correspondence $(a, b) \leftrightarrow a + bi$ *between the plane and the field of* complex numbers. *If* $p = (x_1, x_2)$ *corresponds to* $z = x_1 + ix_2$ *and* $q = (y_1, y_2)$ *corresponds to* $w = y_1 + iy_2$, *then we see that*

$$zw = (x_1 + ix_2)(y_1 + iy_2) = (x_1y_1 - x_2y_2) + i(x_1y_2 + x_2y_1)$$

which corresponds to the point which is given as the product of p *and* q.

With this example in mind, one may attempt to find a similar definition for multiplication of points in 3-space. By algebraic methods, it can be shown that no such formula exists (if we require that the ordinary algebraic rules remain valid).

However, going to the next higher dimension, ***Hamilton*** *(1843) discovered that a definition for multiplication of points in* E^4 *could be given which yields a system obeying all the algebraic rules which apply to real numbers (i.e., the field axioms) except one; multiplication is no longer commutative, so that* (pq) *and* (qp) *may be different points. This system is called the algebra of* quaternions.

It was soon seen that it could be used to great advantage in analytical mechanics. By restricting points to a particular 3-space embedded in E^4, ***Gibbs*** *and others developed a modification of the algebra of quaternions which was called* vector analysis, *and which gained widespread acceptance and importance, particularly in physics.*

Let us now compare the system of vector analysis with the system of differential forms in three variables based on the four examples given above. We first notice that there is a certain formal similarity between the multiplication table for the unit vectors $\boldsymbol{e}_i \times \boldsymbol{e}_j = \sum_{k=1}^{3} \epsilon_{ijk}\boldsymbol{e}_k$ *and the corresponding table for the basic differential forms* dx, dy, *and* dz. *In the latter, however, we do not have the identification* $dxdy = dz$ *which corresponds to the relation* $\boldsymbol{e}_x \times \boldsymbol{e}_y = \boldsymbol{e}_z$. *This suggests that we link elements in pairs:*

$$\begin{matrix} dx \\ dydz \end{matrix} \leftrightarrow \boldsymbol{e}_x \quad \begin{matrix} dy \\ dzdx \end{matrix} \leftrightarrow \boldsymbol{e}_y \quad \begin{matrix} dz \\ dxdy \end{matrix} \leftrightarrow \boldsymbol{e}_z.$$

To complete these, and take into account 0-forms and 3-forms, we adjoin one more correspondence:

$$\begin{matrix} 1 \\ dxdydz \end{matrix} \leftrightarrow 1.$$

We are now ready to set up a two-to-one correspondence between differential forms on one hand, and vector- and scalar-valued functions on the other. To any 1-form or 2-form will correspond a vector function, and to any 0-form or 3-form will correspond a scalar function. The rule of correspondence is indicated below:

$$\left.\begin{array}{r} A\,dx + B\,dy + C\,dz \\ A\,dy\,dz + B\,dz\,dx + C\,dx\,dy \end{array}\right\} \leftrightarrow A\boldsymbol{e}_x + B\boldsymbol{e}_y + C\boldsymbol{e}_z,$$

$$\left.\begin{array}{r} f(x,y,z) \\ f(x,y,z)\,dx\,dy\,dz \end{array}\right\} \leftrightarrow f(x,y,z).$$

In the opposite direction, we see that a vector-valued function corresponds to both a 1-form and to a 2-form, and a scalar function to a 0-form and to a 3-form. It then transpires that the single notion of multiplication among differential forms corresponds to both the scalar and vector products among vectors.

What vector operations correspond to differentiation of forms? Let us compare the differential of an 0-form $df = \frac{\partial f}{\partial x}dx + \frac{\partial f}{\partial y}dy + \frac{\partial f}{\partial z}dz$ *with the vector gradient of a scalar function* $\operatorname{grad} f = \frac{\partial f}{\partial x}\boldsymbol{e}_x + \frac{\partial f}{\partial y}\boldsymbol{e}_y + \frac{\partial f}{\partial z}\boldsymbol{e}_z$. *These are tied through the relation* $df = d\boldsymbol{r} \cdot \nabla f$.

As we proceed to 1-forms, it was shown earlier that its differential corresponds to the curl of the corresponding vector function. Finally, it was shown that the differential of a 2-form corresponds to the divergence of the corresponding vector function. Briefly, then, the single operation of differentiation in the system of differential forms corresponds in turn to the operations of taking the gradient of a scalar field and taking the curl and the divergence of a vector field. This is indicated schematically as follows:

$$
\begin{array}{ccccccc}
\begin{array}{c} f \\ \textit{scalar} \\ \textit{function} \end{array} & \longrightarrow & \begin{array}{c} f \\ \textit{0-form} \end{array} & \longrightarrow & \begin{array}{c} df \\ \textit{1-form} \end{array} & \longrightarrow & \begin{array}{c} \operatorname{grad}(f) \\ \textit{vector} \\ \textit{function} \end{array}
\end{array}
$$

$$
\begin{array}{cccccccc}
 & & & \begin{array}{c} \omega \\ \textit{1-form} \end{array} & \longrightarrow & \begin{array}{c} d\omega \\ \textit{2-form} \end{array} & \longrightarrow & \begin{array}{c} \operatorname{curl}(\boldsymbol{V}) \\ \textit{vector function} \end{array} \\
\begin{array}{c} \boldsymbol{V} \\ \textit{vector} \\ \textit{function} \end{array} & \begin{array}{c} \nearrow \\ \\ \searrow \end{array} & & & & & & \\
 & & & \begin{array}{c} \omega^* \\ \textit{2-form} \end{array} & \longrightarrow & \begin{array}{c} d\omega^* \\ \textit{3-form} \end{array} & \longrightarrow & \begin{array}{c} \operatorname{div}(\boldsymbol{V}) \\ \textit{scalar function} \end{array}
\end{array}
$$

Next, let $\omega = A(x,y,z)dx$. *Then*

$$d\omega = d(A)\,dx = \frac{\partial A}{\partial x}\,dxdx + \frac{\partial A}{\partial y}\,dydx + \frac{\partial A}{\partial z}\,dzdx = \frac{\partial A}{\partial y}\,dydx + \frac{\partial A}{\partial z}\,dzdx$$

and

$$dd\omega = d\left(\frac{\partial A}{\partial y}\right)\,dydx + d\left(\frac{\partial A}{\partial z}\right)\,dzdx = \frac{\partial^2 A}{\partial z\partial y}\,dzdydx + \frac{\partial^2 A}{\partial y\partial z}\,dydzdx = 0,$$

where we have used the symmetry of the mixed derivatives and the fact that $dydzdx = -dzdydx$. *A similar argument holds for* Bdy *and* Cdz.

Using the above results we see that the statement $ddf = 0$, *holding for a 0-form* f, *corresponds to the vector identity* $\operatorname{curl}(\operatorname{grad} f) = 0$ *and the statement* $dd\omega = 0$, *holding for a 1-form, corresponds to the vector identity* $\operatorname{div}(\operatorname{curl}\boldsymbol{V}) = 0$.

Our final connections between vector analysis and differential forms will be made by relating the integral of a form to integrals of certain scalar functions which are obtained by vector operations.

To see this we let $\boldsymbol{F} = A\boldsymbol{e}_x + B\boldsymbol{e}_y + C\boldsymbol{e}_z$ *define a continuous vector field in some region in space, and let* $\omega = Adx + Bdy + Cdz$ *be the corresponding 1-form. If* γ *is a smooth curve in the said region, and* $\boldsymbol{t}(s)$ *is a unit tangent vector to* $\gamma(s)$ *(where* s *is the arc length) then*

$$\begin{aligned}\boldsymbol{F}\cdot\boldsymbol{t} &= (A\boldsymbol{e}_x + B\boldsymbol{e}_y + C\boldsymbol{e}_z)\cdot\left(\frac{dx}{ds}\boldsymbol{e}_x + \frac{dy}{ds}\boldsymbol{e}_y + \frac{dz}{ds}\boldsymbol{e}_z\right)\\ &= A\frac{dx}{ds} + B\frac{dy}{ds} + C\frac{dz}{ds}\end{aligned}$$

and

$$\int_\gamma \boldsymbol{F}\cdot\boldsymbol{t}ds = \int_0^\ell \left(A\frac{dx}{ds} + B\frac{dy}{ds} + C\frac{dz}{ds}\right) ds = \int_\gamma \omega,$$

with ℓ *the length of the curve* γ*. The situation for integrals of 2-forms is similar.*

The theorems of Green, Stokes, and Gauss can be translated into the language of differential forms. They are all shown to be special cases of what is called the generalized Stokes' theorem, connecting an integral of a differential form ω *with an integral of its derivative* $d\omega$*. Symbolically*

$$\int_{\partial M} \omega = \int_M d\omega,$$

where M *is a* $k+1$ *dimensional manifold with boundary manifold* ∂M *and* ω *is a k-form.*

The demonstration[14] *of this statement in the case of Green's theorem is immediate since*

$$\int_\gamma \omega = \int_{\partial D} (Pdx + Qdy) = \int_D \left(\frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y}\right) dxdy = \int_D d\omega,$$

where D *is a region in the* xy *plane and* ∂D *is its boundary curve* γ*. Similarly, for Stokes' theorem, if* Σ *be and oriented 2D surface embedded in* R^3 *and* $\partial\Sigma$ *its closed bounding curve (suitably oriented), we find:*

$$\begin{aligned}\int_{\partial\Sigma} \omega &= \int_{\partial\Sigma} \boldsymbol{F}\cdot d\boldsymbol{s} = \int_{\partial\Sigma} (Adx + Bdy + Cdz)\\ &= \int_\Sigma \left[\left(\frac{\partial C}{\partial y} - \frac{\partial B}{\partial z}\right) dydz + \left(\frac{\partial A}{\partial z} - \frac{\partial C}{\partial x}\right) dzdx + \left(\frac{\partial B}{\partial x} - \frac{\partial A}{\partial y}\right) dxdy\right]\\ &= \int_\Sigma d\omega.\end{aligned}$$

Finally, for a region R *in* R^3 *and its closed-surface boundary* ∂R*, with suitable orientations:*

$$\begin{aligned}\int_{\partial R} \omega &= \int_{\partial R} [Adydz + Bdzdx + Cdxdy]\\ &= \int_R \left[\frac{\partial A}{\partial x} + \frac{\partial B}{\partial y} + \frac{\partial C}{\partial z}\right] dxdydz = \int_R d\omega.\end{aligned}$$

---

[14] These are *not* in lieu of rigorous mathematical proofs.

This statement is the supercompact form of Gauss' divergence theorem, stating that the flux of a vector field out of an oriented closed surface equals the integral of the divergence of that vector field over the volume *enclosed by the surface. [In all these cases the orientations of volumes, curves and surfaces are related via the right hand rule]*

EXACT DIFFERENTIAL FORMS *constitute a special class of DF for which* $\omega = d\eta$ *[e.g.,* $\omega = 2xydx + x^2dy + 2zdz = d(x^2y + z)$*]. Clearly,* $\int_\gamma \omega = f(p_1) - f(p_0)$, *where integration extends from* p_0 *on* γ *to* p_1 *on* γ.

If γ *is closed and* f *single-valued, then* $p_0 = p_1$ *and* $\int_\gamma \omega = 0$. *In this case the line integral is* path-independent. *Furthermore, it follows directly from* $\omega = df$ *that* $d\omega = ddf = 0$ *throughout the region. This can be summarized by the flow-diagram*

$$\begin{tikzcd} \begin{array}{c}\text{1-form } \omega \\ \text{exact in } \Omega\end{array} \arrow[rr] \arrow[dr] & & \begin{array}{c}\displaystyle\int_\gamma \omega \text{ independent} \\ \text{of path in } \Omega\end{array} \\ & \begin{array}{c} d\omega = 0 \\ \text{in } \Omega\end{array} \arrow[ur] & \end{tikzcd} ,$$

where Ω *is any sub-region in* R^n.

The notions of exactness and of path independence may also be given in vector form: If a vector field $\boldsymbol{F}$ *can be written as* $\boldsymbol{F} = \operatorname{grad} f$, *where* f *is the* potential *of the field, then* $\int_\gamma \boldsymbol{F} \cdot d\boldsymbol{s} = f(p_1) - f(p_0)$. *For instance, if we let* $U = -f$ *be the* potential energy, *then* $\boldsymbol{F}$ *represents its force field.*

THE WEDGE PRODUCT *(WP): It is convenient to denote the multiplication of differential forms with a special symbol, the wedge* $\wedge$, *instead of just a juxtaposition that we used hitherto.*

Thus, for example, the product of the 1-forms $\omega = a_\mu dx^\mu$ *and* $\omega' = b_\nu dx^\nu$ *(both covariant vectors!) will be written as*

$$\omega \wedge \omega' = \frac{1}{2}(a_\mu b_\nu - a_\nu b_\mu) dx^\mu \wedge dx^\nu$$

and called the wedge product.

With $x^1 = x$, $x^2 = y$, $x^3 = z$, *we find as before*

$$\begin{aligned} \omega \wedge \omega' = (a_1b_2 - a_2b_1)dx \wedge dy &+ (a_2b_3 - a_3b_2)dy \wedge dz \\ &+ (a_3b_1 - a_1b_3)dz \wedge dx. \end{aligned}$$

With this notation, the product of differential 1-forms appear in a new light — as a totally antisymmetric form which takes in the vectors $\boldsymbol{a}(a_1, a_2, a_3)$, $\boldsymbol{b}(b_1, b_2, b_3)$ *and yields a number.*

Now, since in dyadic notation

$$\begin{aligned}\boldsymbol{ab} - \boldsymbol{ba} = (a_1b_2 - a_2b_1)\,(\boldsymbol{e}_x\boldsymbol{e}_y - \boldsymbol{e}_y\boldsymbol{e}_x) + (a_2b_3 - a_3b_2)\,(\boldsymbol{e}_y\boldsymbol{e}_z - \boldsymbol{e}_z\boldsymbol{e}_y)\\ + (a_3b_1 - a_1b_3)\,(\boldsymbol{e}_z\boldsymbol{e}_x - \boldsymbol{e}_x\boldsymbol{e}_z),\end{aligned}$$

we can set a one-to-one correspondence between the components of this totally antisymmetric tensor of the second rank and the terms of the wedge product $\omega \times \omega'$, *provided we also set the correspondence* $dx \leftrightarrow \boldsymbol{e}_x,\ dy \leftrightarrow \boldsymbol{e}_y,\ dz \leftrightarrow \boldsymbol{e}_z$, *and also* $dx \wedge dy \leftrightarrow \boldsymbol{e}_x\boldsymbol{e}_y - \boldsymbol{e}_y\boldsymbol{e}_x$, *etc. In this sense*

$$\omega \wedge \omega' \Leftrightarrow \boldsymbol{ab} - \boldsymbol{ba} \equiv \mathfrak{I} \times (\boldsymbol{b} \times \boldsymbol{a}).$$

Because of this correspondence, we may speak of the wedge product of 1-forms in the sense of DF, *and at the same time write*

$$\boldsymbol{a} \wedge \boldsymbol{b} = \boldsymbol{ab} - \boldsymbol{ba}$$

for the associated vectors. Note that $a_1b_2 - a_2b_1$ *is the signed area of the projection of the* $\boldsymbol{ab}$ *parallogram on the* xy *plane, etc.*

The wedge product has the usual distributive and associative properties of abstract algebra over a field:

$$\begin{aligned}\boldsymbol{a} \wedge (\boldsymbol{b} + \boldsymbol{c}) &= \boldsymbol{a} \wedge \boldsymbol{b} + \boldsymbol{a} \wedge \boldsymbol{c},\\ (\boldsymbol{a} + \boldsymbol{b}) \wedge \boldsymbol{c} &= \boldsymbol{a} \wedge \boldsymbol{b} + \boldsymbol{b} \wedge \boldsymbol{c},\\ \alpha(\boldsymbol{a} \wedge \boldsymbol{b}) &= \boldsymbol{a} \wedge \alpha\boldsymbol{b} = \alpha\boldsymbol{a} \wedge \boldsymbol{b},\end{aligned}$$

with $\boldsymbol{a}$, $\boldsymbol{b}$ *any forms and* α *is a scalar (0-form).*

But it is anticommutative (if $\boldsymbol{a}$, $\boldsymbol{b}$ *are 1-forms, or in general, if the degrees of* $\boldsymbol{a}$, $\boldsymbol{b}$ *are both odd):*

$$\boldsymbol{a} \wedge \boldsymbol{b} = -\boldsymbol{b} \wedge \boldsymbol{a}.$$

Specializing again to the case where $\boldsymbol{a}$, $\boldsymbol{b}$ *are 1-forms, the antisymmetric tensor* $\boldsymbol{a} \wedge \boldsymbol{b}$ *can be written symbolically in determinant form*

$$\begin{vmatrix} a_i & b_i \\ a_j & b_j \end{vmatrix}.$$

One can then extend $\wedge$ *to triple and higher products. For example, the totally antisymmetric tensor* of the third rank $\boldsymbol{a} \wedge \boldsymbol{b} \wedge \boldsymbol{c}$ has the determinant form

$$T_{ijk} = \begin{bmatrix} a_i & b_i & c_i \\ a_j & b_j & c_j \\ a_k & b_k & c_k \end{bmatrix}.$$

Explicitly, in triadic form,

$$T = \boldsymbol{abc} + \boldsymbol{cab} + \boldsymbol{bca} - \boldsymbol{cba} - \boldsymbol{acb} - \boldsymbol{bac}$$

is the proper definition of the triple wedge product $\boldsymbol{a} \wedge \boldsymbol{b} \wedge \boldsymbol{c}$*. This rank-3 tensor, or triadic, also known as a trivector, is antisymmetric in all its indices.*

The associated 3-form is obtained by the triple wedge product of three 1-forms corresponding to $\boldsymbol{a}$, $\boldsymbol{b}$ and $\boldsymbol{c}$*:*

$$\begin{aligned} \omega \wedge \omega' \wedge \omega'' &= (a_1 dx + a_2 dy + a_3 dz) \wedge (b_1 dx + b_2 dy + b_3 dz) \wedge (c_1 dx + c_2 dy + c_3 dz) \\ &= \begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix} dx \wedge dy \wedge dz, \end{aligned}$$

where the determinant is the 3-dimensional *oriented volume of the parallelopiped spanned by the vectors* $\boldsymbol{a}$, $\boldsymbol{b}$ and $\boldsymbol{c}$.

Science and Non-Science

The perspectives of science are, like those of philosophy and religion, thought-structures for viewing the world. Science aims to attain objective truth, and scientific ideas ought to be ones in which we can trust as a matter of fact rather than opinion, and which are not subject to doubt and fads as are the beliefs of the religions, or even philosophies. Thus, the overall purpose of the scientific method is to make valid distinctions between the false and the true in nature, so as to render a true picture of realities and their underlying mechanisms and principles.

Nevertheless, the average scientist (by the very nature of his textbook-oriented education and the fact that his progress and success depend in many cases on the acceptance of given ideas) is as narrow, rigid and dogmatic as the orthodox theologician.

In contradistinction to science and the scientific method we recognize certain related disciplines: pseudoscience is false science, a body of 'knowledge' which is a mere belief, like astrology, alchemy, phrenology, Mesmerism, pangenesis, creationism, etc. Many of the theories of science, like the phlogiston and caloric theories, were not so much pseudoscience as protoscience: early first guesses that served well in their time. Indeed, the Ptolemaic geocentric astronomy, with its complex system of epicycles, would have quite adequately predicted planetary motion if only those astronomers who credited it had access to Fourier Analysis.

Theories for which there is no concrete evidence like panspermia belong to the realm of quasi-science.

At the frontiers of science, the scientific method leads us sometimes to a multiplicity of doubts, where questions rather than answers prevail. There — we have no immutable answers, but rather hypotheses embracing the observable evidence[15].

This condition gave rise to a popular kind of imaginative literature known as science fiction (SF) which deals principally with the impact of actual and imagined science on society and individuals.

Unlike fantasy, which deals with the impossible, SF describes events that could actually occur, according to accepted possible theories. While ordinary

15 Thomas S. Kuhn in his book "*The Structure of Scientific Revolutions*", Chicago Univ. Press, 1970) went as far as saying that scientists are 'puzzle solvers', not problem solvers.

'fiction' concerns itself more centrally with faith, psychology or history, SF is motivated by scientific knowledge.

Hence, the essential difference between SF and other forms of literature is, of course, that we are dealing with science *fiction. In some respects the very term seems to suggest a contradiction: how can the known and the make believe be part and parcel of the same creation. How can we reconcile the world of reason, manifest in technology, and the mysticism of spiritual experience?*

The basic themes of SF include space travel, time travel, and marvelous discoveries or inventions. Most modern SF stories are set in the future, but some take place in the past or even in the present day. Some are set in another universe. Some SF stories give detailed scientific explanations. Other stories simply thrust the reader into a strange time or place.

Like all fiction, SF make frequent use of myths, *those archetypal stories which provide the symbols that help us shape our world. The roots of SF, like the roots science itself are in magic and mythology.*

Science fiction is not like other writing about science; it looks forward *where other kinds usually look back, speculate — where other consolidate.*

The good SF writer is essentially a creative artist first, who knows or understands and sympathises with one or more scientific thought. In a world where even group of scientists (e.g., physicists and geneticists) can scarcely understand each other, the SF writer sets himself as a kind of translator between different ways of seeing the world, not just todays, but tomorrow's world.

SF recognizes the germ of future development and enlarges upon it from different angles and in fanciful ways. It presupposes in its readers a willingness to consider possibility rather than fact. Prophetic accuracy is neither essential nor important ingredient of SF.

History[16]

The history of SF is also the history of humanity's changing attitude toward space and time. It is the history of our growing understanding of the universe and the position of our species in that universe. Like the history of science itself, the history of this literary form is thin and episodic until about four centuries ago, when the scientific method began to replace more authoritarian and dogmatic modes of thought, and people at last could see that the earth is not the center of the universe.

In the following survey of the history of SF we see it as a movement away from mythology toward realism; from a mythic way of seeing the world to a rational or empirical way of seeing it. As human science developed, human fiction changed with it. This movement involves a change in the world from one which lacks a clear distinction between natural and supernatural to a world in which the distinction is very clear and from which supernatural events are excluded[17].

The history of SF until 1950 *is divided into five stages:*

I. *Collective prehistoric myths*

Human beings felt the world to be alive with spiritual presence: divinities inhabited every bush and waterfall. People learned to fear and worhip especially those gods they sensed behind the most owesome of natural phenomena — tempests, earthquakes, and the fertility of plants and animals. Our primitive ancestors knew a world that was timeless in one sense and tightly bound up by time in another.

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[16] For further reading, see:

- Wuckel, D. and B. Cassiday, *The Illustrated History of Science Fiction*, Ungar: New York, 1989, 251 pp.
- Bleiler, E.F., *Science Fiction – The Early years*, The Kent State University Press, 1990.
- Scholes, R. and E.S. Rabkin, *Science Fiction: History. Science. Vision*, OUP, 1977, 258 pp.
- Bleiler, E.F., Ed. *Science-Fiction Writers*, Charles Scribner's Sons: New York, 1982.

[17] Fiction which *is* aware of this difference but deliberately presents supernatural events, is called *fantasy*.

It was a world without history, with no sense of historical change that might lead to situations different from those which people already knew; it was a world bound to the seasonal flow of time, planting and harvesting, sweating and shivering, thanking the gods for blessings and begging them to end punishments. The seasons required religious rituals, which were held to contribute to the great temporal cycle, without which humanity would surely perish. The rituals enacted episodes from the lives of the gods, explaining the creation of the world, and preserving in the memory of humanity the values of which the gods were believed to approve. These memories and values, when separated from their ritual enactment, we call myths. *Myths are the ancestors of all other fictions. They have immense inertia, persisting in time as a conservative force, teaching the old values, the old ways — resisting the new.*

Prehistoric myths abound with tales of fantastic voyages and adventures. The richest source of myths is the Bible *(the creation story etc.). Greek mythology gave us the story of the pioneer aviators Daedalos and Icaros.*

II. Ancient social utopias and fantasies *(ca 800 BCE–200 CE)*

Utopias *were the creation of an age of arbitrary authority and frequent (albeit creative) disorder, in which the security and prosperity of the majority could be imperilled at any moment by the wilful behavior of a determined and powerful individual or minority. These were the wishful systems devised, by men of good will, for the constraint of the turbulent individual by means of institutions and laws. Their objective was order, their by-products were general prosperity and peace, and their foudation were a strict hierarchy in which each person not only knew and kept his proper station but enjoyed it. During this period scientific fantasy showed itself as a mingling of literature, science, and social theory.*

Hesiod *(ca 800 BCE) in his* Dreams of the Golden Age, *the Biblical visions of the* Hebrew prophets *(ca 800–300 BCE) and* ***Aeschylos*** *(ca 525–456 BCE) contain such elements.* ***Aristophanes*** *(ca 450–388 BCE) also investigated fundamental problems by distancing them through fantasy, as in* The Birds, The Frogs, *and the* Ecclesiazusae.

Social utopias rose to special importance in the prehellenist period; in the 5^{th} *century BCE up to the beginning of the* 4^{th} *century BCE* ***Hippodamos of Miletos*** *and* ***Phaleas of Chalcedon*** *sketched hierarchical social models, which anticipated some of the thoughts of* ***Plato*** *(427–347 BCE). In* The Republic, *Plato advocated the abolition of private wealth and the introduction of a kind of consumer communism.*

Other utopias were sketched by ***Euhemeros*** *(ca 340–260 BCE) and* ***Jambulos*** *(ca 200 BCE).*

The first true SF on record is that of the Greek writer ***Lucian of Samosata*** *(125–190 BCE). In about* 160 *CE he wrote* Vera Historica *(The True History) in which he described trips to the moon.*

III. The late Renaissance, reformation and the scientific revolution (1492–1752)

Science fiction's roots lie deep in the Renaissance, an epoch characterized above all by violent socioeconomical changes caused by a transition from feudalism to capitalism. The explosive technological development seen during the Renaissance was intricately bound up with the progress of science in opening up the world. The new methods of research that were thereby perfected were founded upon experiment, observation, and experience.

Copernicus*' heliocentric cosmos,* ***Gutenberg****'s invention of the printing press with moveable type, the voyages of discovery led by* **Columbus**, ***da Gama*** *and* ***Magellan*** *— each was an immense achievement in its own right; together they were the basis for a flowering of the sciences, arts, and literature on an unprecedented scale.*

The alterations in the means of production led to a transition from a theocentric to an anthropocentric world views. The emphasis was now on people and the power of the personality, the might of the individual. The revolutions of the epoch became the objective sources for the later humanist movement and for the development of a deeply humanist view of the world and mankind.

Philosophy strove for the liberation of humanity from the fetters of theological dogma. Renaissance art did away with medieval conventions and turned towards the realities of life, to the activities of humans in their changing world. From these contradictory processes new genres of literature peculiar to the new age sprang up. The modern novel began to crystallize; the epic was already loosing its importance. The Renaissance gave rise to the gradual merging of traditional imaginative fantasy with scientific ideas. Thus the Renaissance saw the birth of scientific fantasy, or, what is now called — science fiction.

The main contributors to SF during this period were:

Thomas More *[Morus, 1478–1535 (executed)]. En English statesman and humanist*[18]*. In his Utopia (1516) he set his ideal society on an island at the very edge of the world. (The word utopia literally means: nowhereland).*

Ludovico Ariosto *(Italy, 1474–1533). In his Orlando Furioso (1532) he describes a fictional voyage to the moon.*

The idea of the first robot, the legendary Golem, is attributed to the chief Rabbi of Prague, the philosopher, savant and Kabbalist, ***Yehuda Liwa*** *(1588). He was an historical figure, a friend of* **Tycho Brahe** *and* **Johannes Kepler***. In real life he was a sober theologian, not a man to meddle with magic, but the legend about him was rather different.*

To protect his people against the pogroms, the tale goes, Liwa and two assistants went in the dead of the night to the River Moldau, and from the clay of the riverbank they fashioned a human figure. When Liwa inscribed the Holy Name upon its forehead, the golem opened its eyes and came to life. It was incapable of speech, but had superhuman strength. It became Liwa's servant and worked as a sanitar within the temple. Only Liwa could control it, but eventually the golem could not be controlled at all. It ran amok, attacking its creator. Its career of destruction ended only when Liwa plucked the sacred name from its forehead. Magically, the golem was once again reduced to clay.

Thommaso Campanella *(Italy, 1568–1639)was a Dominican friar. His utopia (1602) Civitas Solis (The Sun State) describes an ideal communal society which, like More's, is located at the furthermost reaches of the known world.*

Christopher Marlowe *(1564–1593, England) wrote (1604) The Tragical History of Dr. Faustus.*

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[18] He was born in London. During his college years in Oxford, he became familiar with representatives of the "new learning" (which meant Greek learning), and he would fain have followed in their footsteps, but his father, Justice Sir Thomas, wanted him to make law his career. Toward the end of the century he became acquainted with Erasmus, who influenced him deeply in many ways. His *Epistola ad Martinum Dorpium* was a defense of Erasmus' *Moriae encomium* and of the new learning; his masterpiece, *Utopia*, revealed not only his piety and love of education and learning, but also his consciousness of social wrongs. It is a satire on English (or European) conditions, for life in Utopia is the reverse in almost every respect of English life. More gives an elaborate description of the good society, which brotherhood, universal education, and religion combined with toleration would make possible. Not only was he one of the first defenders of the education of women, but he suggested that women be admitted to the priesthood.

Francis Bacon *(1561–1626, England) wrote New Atlantis (1627). This work uses the theme of a marvelous voyage to describe a society based on experimental science and the practical wonders that science could create.*

Johannes Kepler *(1571–1630, Germany) described a trip to the moon in his Somnium (1634). This book was the first SF that tried to tell a story with scientific accuracy.*

Cyrano de Bergerac *(1619–1655, France), in his L'autre mondes (1642, 1650), combined the philosophical systems of* **Descartes** *and* **Gassendi** *in two SF stories: in the first he describes for the first time a motorized lift-off into space in a rocket propelled spaceship through which he reaches the moon. In his second he describes a flying machine which takes him into the realm of the sun.*

In 1719*, after economic and social ups and downs and tireless work in a multitude of fields,* **Daniel Defoe** *(1660–1731, England) at* 59 *published his book The Life and Strange and Surprizing Adventures of Robinson Crusoe of York. This book owes its origin to the Renaissance sailor-discoveries and the picarresque fictions of many literary predecessors, and to various portrayals of island life. It follows the philosophy of John Locke, that nature and common sense are motivating forces at the source of all individual and social evolution; knowledge won from experience triumphs, and achieves success for the individual.*

The astronomical discoveries of the 17^{th} *century and* **Torricelli***'s discovery of outer space (1643) have shown how precarious was man's grip of the universe, and enhanced man's primordial fears — fears that science itself helped to create.*

Science fiction tried to deal with these fears in two ways: first, by alleviating it through rationalization (inventing myths to limit and control these fears); second, use of the scientific method to modify his environment and therefore, ultimately, his density. These two themes occur and reoccur, through the history of SF, since the scientific revolution to the present day.

As SF developed during the 1700*'s, it produced its first literary masterpiece; Gulliver's Travels (1726) by* **Jonathan Swift** *(1667–1745, England). In his book Swift subjected to rational analysis, the economic and social aspects of the postrevolutionary age in England*[19]*.*

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[19] We find in *Gulliver's Travels* (1726) a literary reference to the two moons of Mars. But these moons were first observed by Asaph Hall in 1877. How could have Swift known? The answer is quite simple: In 1610 **Galileo** used one of the earliest astronomical telescopes to discover the 4 moons of Jupiter. When **Kepler** heard of this, he immediately assumed that Mars must have two moons.

The first story of visitors from other planets was Micromégas (1752) by ***Voltaire*** *(1694–1778, France).*

Many of the basic ingredients for science fiction had appeared in embryo form by the early 18^{th} *century. Even if SF is taken as no more than a kind of fictional humanism, it was clearly not sufficient for its growth merely to have a widespread inculcation of scientific 'facts', acceptance of the experimental method or the stimulus of apocalyptic forebodings.*

These, however tenuously, in the shape of biblical fundamentalist dogma, the beginning of experimental science in ***Roger Bacon****, the experimental laboratories of the Renaissance, and the conviction of an imminent call to final judgment – are all influences on medieval literature which yet produced no science fiction.*

It was additionally necessary for the belief to be established, amongst at least a substantial minority, that Man could, through the use of the scientific method, modify his environment and therefore, ultimately, his destiny.

IV. The industrial revolution, the Victorian period and the turn of the 20^{th} *century* *[1776 (first steam engine) –1913]*

The second great epoch for SF literature is closely related to the scientific and technical, political and social, military and intellectual developments in Western civilization during the 19^{th} *century.*

Indeed, the palpable progressiveness of science and technology, and the similar concreteness of political change in revolutionary Europe and America at the end of the 18^{th} *century, forced people to begin perceiving the world in new ways. Above all, humanity was finally faced with a future at once real and unknown, stimulating and terrifying.*

The industrial revolution, via the steam engine, had a profound effect on the very structure of society; on one hand, it increased mass misery, poverty and hardship. These elements influenced the Ghotic novel, which featured horror, violence and the supernatural.

After all, the planets are organized according to geometrical law: Venus has no moons, the earth has one, and so Mars — between earth and Jupiter — must have two to form a geometrical progression! This conclusion has always been accepted as true, and well known to Swift.
[Jupiter, incidentally, has 14 moons (1994)]. Kepler was lucky enough to have his belief *seem* right, and hence scientific. But the scientific knowledge was still based, in part, on belief.

On the other hand, most authors were deeply impressed by the fact that the new machines were able to multiply a hundredfold the muscle power of the worker, that new secrets were being wrung from nature every day, that products were being moved to and fro on the world market quicker than ever before, and that radio created the means of immediate communication worldwide.

The belief soon surfaced that science alone would be able to bring into being a superior mode of life. Thus this second phase of SF is characterized primarily by its sense of euphoria. The leading authors of this era are:

***Ernst Theodor Amadeus Hoffmann** (1776–1822,* Germany*) was intensly preoccupied with the Mesmerian theory of animal magnetism (1813) and intelligent machines (1814). Other fantasy tales by Hoffmann contain ideas that play important roles throughout SF: vampirism, strange beings in animal form, non-decaying dead bodies and much more.*

Mary Wollstonecraft Shelley** (1797–1851, England) created (1818) the monstrous figure of Frankenstein — the archtype of the restless scientist not to be deflected from his own research and experimentation. Like his famous predecessor, the single-minded questor,* **Marlowe's Faust,* Frankestein *is ready to break down the boundaries of knowledge, giving not a moment's thought to considerations of the rightness or morality of his activities. Not satisfied with half solutions or compromise, he must aim directly at the summit, become a godlike figure, a second creator. This over-reaching, of course, means his eventual fall is so much the greater.*

Mary Shelley blended the old theme of the artificial creation of life with the new contemporary genre of the Gothic novel. She thus introduced the hideous, the heinous, the cryptic, and the criminal into literature and combined them with "scientific" elements.

***Edgar Allan Poe** (1809–1849, U.S.A.) developed the SF short story. In 'The Unparalleled Adventures of One Hans Pfaall' (1835), he describes a journey to the moon. Perhaps under the influence of Cook's voyages (1773–1774) he wrote 'The Narrative of Arthur Gordon Pym at Nantucket'.*

*Under the combined influence of Mary Shelley and Poe, the Scotish poet **Robert Louis Stevenson** (1850–1894) wrote 'Dr. Jekyll and Mr. Hide (1886), where a scientist, obsessed with his pursuit of knowledge and enlightment, is temporarily changed into a monstrous alter ego. He thus layed the foundations for an investigation into the duality of human nature by splitting it clearly into good and bad.*

***Henry Rider Haggard** (1856–1925, England) wrote* 34 *novels of history and adventure. His best novels are based on his experience in Africa; King Solomon's Mines (1885) became a young people's classic. It is the story of* *search for the legendary lost treasure of King Solomon. She (1887) is the story of Ayesha ('She who must be obeyed'), a white goddess of Africa who is* 2000 *years old but still appears young and beautiful.*

Haggard was a firm believer in the evolutionary theories of Darwin. The memorable fantasy element in the book is Ayesh's surprising death as She baths herself in a "life-giving" flame (that seems strangely prophetic of nuclear power!) and slowly reverts — in a reverse of Darwinian "ontogeny recapitulates phylogeny" — from a smashingly beautiful woman to a 2000-*year-old ugly ape.*

Ayesha's memorable transformation in death recurs in the mainstream utopian novel Lost Horizon (1933) by ***James Hilton***[20] *(1900–1954, England) — when a beautiful "immortal" woman living well beyond her years in the salubrious atmosphere of Shangri-La (a secret Tibetian monastery) leaves her home with her new English lover only to turn wrenchingly into an ugly, aged crone during her passage out. The utopianism of Shangri-La has its ingenious combination of the careless rapture of an unpolluted "magic" atmosphere and the practice of passive Eastern mysticism. The message is clear — an utopian place of ideal perfection is an impractical scheme for social improvement.*

When Poe needed a fiction catalyzer to set off his moon voyage, he invented an atomic component of hydrogen discovered by a chemist at Nantes, France. Poe had no way of knowing that there had just been born at Nantes someone who would become the most catalytic figure in the history of SF.

Jules Verne *(1828–1905, France) was the first classic writer of SF literature, who specialized in science fiction. His subject is nature. The voyages extraordinaires explore worlds known and unknown: the interior of Africa, the interior of the earth, the deeps of the sea, the deeps of space. Characteristically, Verne's voyagers travel in vehicles that are themselves closed worlds, snug interiors from which the immensity of nature can be appreciated in upholsered comfort (e.g., the Nautilus). The basic activity in Verne is the construction of closed and safe spaces, the enslavement and appropriation of nature to make place for man to live in comfort. Verne's novel is built upon an unresolvable incompatibility between a fundamental materialistic ideology and a literary form that projects the world as ultimately magical in nature. He thus produced narratives that mediate between spiritualistic and materialistic world views.*

Verne draws on new discoveries, experiments in physics and chemistry, and and technological discoveries of his immediate present. He led his characters to parts of the world that at the time were largely unknown and unexplored.

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[20] He went on to write his masterwork *Good Bye, Mr. Chips* (1934). In 1935 he came to live in Hollywood, where he wrote film screenplays.

These backgrounds enhanced the exotic nature of the adventurers described. For instance, Verne describes Africa (Five Weeks in a Balloon, 1863); the delta swamps of Florida (North Against South, 1873); Siberia and China (Michael Strogoff, 1871); the Arctic and the North Pole (The Adventures of Captain Hatteras, 1866); India (Around the World in 80 *Days, 1873); the depths of the ocean (20,000 Leagues Under the Sea, 1869); the interior of the earth (Journey to the Center of the Earth, 1864); the deeps of space (From the Earth to the Moon, 1865)*[21].

The era in which Verne was writing was an era of unbounded belief in

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[21] An unknown manuscript, written by Verne in 1863, was discovered in 1989 by his great grandson Jean Verne in Toulouse. The novel *Paris in the* 20^{th} *Century* centers on the year 1963 and describes a society run by high finance and technology. In the story Verne anticipates the Daimler automobile (invented 1885), the electric chair (invented 1888) and the modern telefax machine.

The *principle* of the 4-stroke internal combustion engine was proposed in 1862 by **Alphonse Beau de Rochas**, of which Verne may have read!

Hard as it is to believe, the fax machine is older than the telephone and patents for the first prototype date back to 1843. The first commercial fax system called the *pantelegraph* was invented by the Italian priest **Giovanni Caselli** (1855). This was a relatively complicated system: an iron point crossed by a current was used to write onto a paper impregnated with a solution of potassium cyanate which is decomposed, leaving a blue mark on the paper. Despite the difficulties in synchronizing the transmitting needle and the receiving needle, the Caselli system was installed between Paris Amiens and Marseille in 1856. Verne must have known about this enterprise prior to 1863.

In 1980, modern fax machines came into being with a fax standard that allows *digital signal* to be sent over regular telephone lines in one minute or less. The pictures or text are converted to binary form and sent via standard telephone lines. On the other end, the fax machine decodes the bits and reconstructs the image.

However, Verne sometimes abused science for primarily fictional purposes: In *From the Earth to the Moon* (1865), for example, Verne has his ballistic spaceship fired from a mine 35 meters deep hole in Florida. He knew perfectly well that a hole of that depth anywhere in Florida would be under water; his straight-faced show of scientific accuracy ironically masked a satire on American ingenuity.

In *Purchase of the North Pole* (1889), some amateur scientists conspire to change the earth's axis by explosives, thus melting the polar ice cap and making accessible vast mineral wealth. Verne chose to ignore what he knew perfectly well — that the experiment would be likely to devastate all coastal cities as it would free the ice-bound land masses — not for the purpose of satire but for the simpler joy of working out the problem of axis-shifting, and the consequences be damned!

The great claim made for 20,000 *Leagues Under the Sea* is that Nemo's *Nautilus* *science. Mankind rules the natural world and the limitless power of technology was the tool through which he ruled. This was the credo of the* 19^{th} *century bourgeoisie, and was the formula according to which Verne created the characters in his fictions.*

Enlightenment had paved the way to compulsory education which — according to the demands of the new forms of production — was accomplished in more and more countries and led to the growth of the reading public. The need for information in all classes of society, but especially the new middle classes, continued to increase with the growth of international trade — and as traveling became easier.

*Apart from books, there were newspapers and magazines of all kinds, and in particular, family journals, which bridged the gap between knowledge and entertainment. The now very high turnover in books helped finance research in high grade paper production and in printing itself. This led to the invention of the cylindrical paper-making machine (**John Dickinson**, 1809, England), the new steam press (**Friedrich König**, 1810–1811, Germany) and machine-aided book-sewing and book-binding methods.*

Through such developments, book production was simplified and the product made cheaper to buy. Print run multiplied and the structure of literary genres was irrevocably changed, with more and more authors working for the press.

New forms of publicity, pamphlets and early eye-witness reports had an effect on the purer forms of storytelling: the serialization of novels, stories, and travel books in magazine was tried, first of all in France, and found to be highly popular. Writers adapted their techniques to these new conditions by developing literary methods of creating and maintaining suspense. Other fundamental aspects of sale were the increasing members of new lending libraries spreading like wild fire.

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accurately predicts the development of the submarine. In fact, Verne was creating the fictional context, fully *against* the facts of contemporary science, that would give the submarine the thrill of the fantastic — and then he used much of the book to make this fantastic plausible.

Without detracting from such inventive detail as electric lighting, chemical oxygen production, seaweed cigars, and so on, one should note that **David Bushnell**, who coined the name *submarine*, first successfully tested his *Turtle* in 1775; **Robert Fulton** demonstrated a functional steam submarine in the Seine in 1807 (this ship, incidentally, was named *Nautilus*); and the Confederate States of America, in 1864, successfully used the 9-man submarine *Huntley* — to sink the United States frigate *Housatonic*. Verne doubtless knew all this.

Only when set against this background can the far-reaching effectiveness of Jules Verne work be fully appreciated.

Since Verne was so extraordinarily successful with his basic structure, it is really not to be wondered at that many writers sought to borrow his formula. Elements of his concepts were common in adventure fiction up through the middle years of our century. Moreover, Verne's best works still rank at the forefront of SF. Versions are produced on stage, on film, or on television; famous actors do not turn down the chance to play the parts of Verne's characters. The roots of this success may be traced to Verne's skill in combining strenous and exciting action with accurate observation of human capacity and value under most adverse conditions, in addition to immense optimism conveyed in his books.

In the 130 *years that passed since Verne embarked on his career, science and technology have made advances of which it was impossible for the author of* From the Earth to the Moon *even to dream.*

***Edward Everett Hale** (1822–1909, U.S.A.), an American Unitarian clergyman (and chaplain to the U.S. Senate), editor and humanitarian. In his SF book* The Brick Moon and Other Stories *(1869) he rendered the first serious, extended consideration of an artificial satellite launched into space. This story, however, did not have much historical influence.*

***Edward George Earle Bulwer-Lytton** (1803–1873, England). First Baron. Historical novelist and playwright in Victorian England and politician. Best known for his novel* The Last Days of Pompeii *(1834) and the SF* The Coming Race *(1871). In the last novel he describes a world inside the earth inhabited by a strange underground race with superman technology (robots, death-rays, non-conventional power sources etc.).*

***Samuel Butler** (1835–1901, England) is best known for his satirical SF novel* Erewhon *(1872) that ridicules English institutions and customs through the eyes of a traveler in a strange new world. [Erewhon — a backward rendition (almost) of the word "nowhere".] The Butler's new society is developed not from the scientific penetration of political and social problems but rather from the individual extrapolation of Darwinian ideas, to which Butler vehemently objected.*

The similarities between Butler and Bulwer-Lytton lie in the fact that both envisage a future in which the social structure they know stays largely unchanged and both have little belief in the possibility of a social flowering of mankind. They unite against the loss of individual identity, and place their hope for change principally in the use of technological and scientific discoveries.

Sir Arthur Conan Doyle *(1859–1930, England) is most known for his detective fiction hero Sherlock Holmes (1887–1915), but he wrote also a SF series based on the figure of Professor Challenger. One of these novels is The Lost World (1912), his most important contribution to the literature of SF. It is also most central in illustrating his artistic and scientific vision. The novel tells about an expedition to the upper Amazon where the group discovers an ape-man society throught to be the missing link in human evolution. The power of The Lost World lies in a consummate balance of adventure, skilled characterization, novelty of story line, and adept use of scientific themes. Doyle's use of concepts taken from paleontology and evolutionary theory gives the action verisimilitude.*

In The Poison Belt (1913) Doyle speculates that humanity may not be the culmination of evolution, but only a temporary development to be surpassed and supplanted by other higher organisms unlike it in form. The power of the story lies in Doyle's moral thesis that humanity is given a second chance to fulfill its moral destiny on earth. It must recognize its feebleness before the infinite latent power of the universe. Thus, Doyle's vision of the future of mankind is shaped, not in scientific progress, but in progressing to a higher level of moral awareness through a recognition of a world beyond this life; materialism and conventional religion only further distort our view.

Herbert George Wells *(1866–1946, England). Novelist, historian, science writer and one of the most important pioneers of moderm SF.*

He was born some three years after Verne's first major success with Five Weeks in a Balloon. His fiction embodies stimulating ideas of unrivalled originality. Wells the man is as entertaining as his fiction, for he retained until the end a diabolical mixture of a sentimentalist, a moralist, a patriot, a racist, a member of a secret society and a dreamer. Out of the 120 *books that bear his name — a small but significant proportion of them are SF. Among his best known novels in this field are: The Time Machine (1895), The Invisible Man (1897), The War of the Worlds (1898) and The First Men in the Moon (1901).*

Wells made significant strides forward from the Vernian model of SF. He did not confine himself to the fictional conquest of geographical areas of the natural world known to exist though as yet still not fully explored. Wells toyed with ideas wholly new — time travel, contact with other beings, aliens, wars between worlds etc. He thus first introduced into literature those ideas and themes that for nearly a century have formed the basis of SF throughout the world and that still inspire authors now to try new variations.

The Time Machine (1895) includes references to contemporary prerelativistic interpretation of time as a 4^{th} *dimension. Wells was by no means the first writer to confront the present with either the past or the future.*

In **Mark Twain***'s humorous novel A Connecticut Yankee in King Arthur's Court (1899) and* **Edward Bellamy***'s Looking Backward (1888), the heroes are sent into the past and the future respectively.*

The Time Machine was however the first SF story wherein a machine is envisaged that enables travel through time at will, and in this respect it can claim to be the first example of a new branch of SF.

The War of the Worlds (1898) was certainly motivated by the "discovery" of **Schiaparelli** *(1877) of canals on Mars. Wells took* **Lowell***'s premise of intelligent Martians (1896), added to it the aggressive nature attributed since ancient times to the blood red planet named for the god of war, and used Lowell's scientific descriptions of Mars to extrapolate the nature and aims of the race which invades earth. This line was later extended by Edgar Rice Burroughs in his novel A Princess of Mars (1912).*

Nowadays, people believe anything, and they exist in a world-situation of insecurity. The Victorians of the 1890's were reasonably secure, reasonably arrogant. Wells took advantage of that situation: instead of our being the imperialists, the conquerors — supposing something arrived that fully intended to conquer us? Wells' nastiness really wounds because there is the poison of moral purpose at its tip. The Martians are what we may become! The conquering Martians are at once the products and victims of evolution. For all their pride, they fall prey to bacteria.

The most important novel exploring technology and its future in the epoch under consideration is The Tunnel (1913) by **Bernhard Kellerman** *(1879–1951, Germany). Kellerman's fantasy tells of a tunnel dug out under the Atlantic Ocean connecting Europe and America. It followed the spectacular sinking of the Titanic in the Atlantic by only two years. The impression of this catastrophe was still vivid in the minds of readers, rendering them particularly receptive to the notions of the author with his suboceanic burrowings.*

Apart from the concessions to the age in which he lived (for example, anti-Semitic elements, which are incidentally also to be found in the work of Jules Verne), this novel is a model of exploiting futuristic technology. Kellerman presents on the one hand the possibilities inherent in modern industrial society, and on the other hand, explores the dangers that threaten humanity through its existing contradictions.

The name of **Edgar Rice Burroughs** *(1875–1950, U.S.A.) burst onto the world scene in 1912 with two novels published one after the other in the pulp magazine All-Story. The first was a serial titled Under the Moons of Mars (republished in book form in 1917 as A Princess of Mars); the second was Tarzan of the Apes. His biggest success in terms of popularity and monetary reward came from the Tarzan stories and films. However, Burroughs was known from the start, far and wide, for his non-Tarzan science fiction as well.*

Although science per se plays little part in his work (and it is safe to say that he knew and cared little about it), owing to their huge commercial success, they found countless imitators and did have a profound effect on the development of SF form in America after WWI. Tarzan *became one of the most famous characters in fiction and outlived Burroughs in novels and film.*

By 1975, *more than* 36 *million copies of Tarzan books, in* 56 *languages, had been sold, making Tarzan an international superman folk-hero.*

Prior to becoming a best-selling novelist, Burroughs had behind him a career as a soldier, policeman, Sears Roebuck manager, gold-miner, cowboy and storekeeper. He had two towns named after him, but never visited Africa. His stories, according to many critics, belong to the lowest stratum of literature: narrow mental world, weak plotting, paper-thin characters, cumbersome and amateurish style. Yet the readers gobbled up Burroughs, always seemingly hungry for more.

The glorification of strength and the outdoor life and simplistic solutions to the problems of a rapidly changing world were popular ideas during the time of Theodore Roosevelt. Tarzan was also a unique superman, since he reconciled elitism and democracy.

V. Dystopia *(1921–1950)*

Social and political arguments, which appeared in much early science fiction, were emphasized even more in the 1900*'s. One of the main literary currents that dominated SF during the above epoch was the newly formed* dystopia *or anti-utopia; while utopian fiction portrays ideal worlds, anti-utopian fiction sees these ideal worlds as nightmares.*

Since the 18^{th} *century, some prophetic anticipations of scientific achievements were made by physicists and SF writers alike:* ***Newton*** *(1728) in* The System of the World *(a popular version of the third book of the* Principia*) envisaged man-made satellites.* ***Jules Verne*** *(1863) anticipated rocket-launching, non-classical power source through which his* Nautilus *was propelled, incandescent lighting (1870, nine years before Edison's patent was granted) and ocean-landing of spacecraft*[22]*.* ***Mark Twain*** *(1898) forecasted television, which he named* telectroscope*.* ***Cleve Cartmill*** *(1944) correctly hypothesized, in a story called* Deadline*, how one may construct an atom bomb — as the Manhattan project was then doing in extreme secrecy. (He*

[22] **F.R. Molton** stated unequivocally in an astronomy textbook (1930) that SF stories about interplanetary travel were totally impossible and that anyone knowing the physical forces involved would know them to be so!

was interrogated by military intelligence). ***Frank Quattrochi*** *(1955) predicted the heart-lung machine.*

In the United States, magazines called pulps *have played the major role in development of SF.* ***Hugo Gernsback*** *founded the first pulp,* Amazing Stories *(1926). In 1930 he became the first person to use the term* science fiction. *The early pulp magazines concentrated on scientific marvels, but turned increasingly to major social concerns after* ***John W. Campbell*** *Jr. became editor of* Astounding Science Fiction *(1937). Campbell developed a group of writers who dominated the field in the mid-1900's, including* ***Isaac Asimov*** *and* ***L. Sprague de Camp****.*

Science fiction gained a wider audience after WWII ended in 1945. Its popularity grew as developments in atomic energy and space exploration showed that much SF was more realistic than many people believed.

Karel Čapek *(1890–1938, Czechoslovakia), Czech humanist, prolific man of letters and a working journalist throughout his career. A critical observer of certain manifestations of the time. Čapek did most of his writing during the unsettled period between the first and second World Wars. In his travels in numerous countries throughout the world, and in his own country, he recognized an increase in violence, and saw the dangers inherent in manipulating people and subjecting them to faceless power. In these circumstances, it is perfectly understandable that Čapek should choose to estrange himself from individual and social trends by means of SF at the beginning of the 1920's.*

In rapid succession he published a series of works that are of equal interest in terms of the history of mainstream literature and in terms of the history of SF literature. Chief among those are the play R.U.R. (Rossum's Universal Robots[23], *1920) and* Krakatit[24] *(1924). In the years succeeding this burst of literary fantasy, Čapek turned his attention to the small everyday things in life. Only in 1936 did he revert to the metaphorical mode of SF in* The War with the Newts. *In all these works, Čapek shows his concern of man's destruction of himself by science; the danger to mankind arising from contradictions between the advances of technology and the stagnation in human ethical maturation.*

In R.U.R. *the robots represent a complex of symbolic meanings; the threatening aspects of the industrial dehumanization of the work force as well as the pathos that surrounds the victims of the assembly line. Through this*

[23] Taken from the Czech *robota*, meaning 'forced labor'. This word was invented by Čapek's brother Josef.

[24] A name of a *castle* planted in the same unstable soil as **Franz Kafka**'s (1883–1924). Both men inevitably responded to the same cultural traumas as the Austro-Hungarian Empire entered its death throes.

ambivalence, the image of the robot represents the logical outcome for the helpless masses. (In the play, the robots are not mechanical metallic creatures but androids-living organic simulacra–indistinguishable at first glance from humans.)

The title of Krakatit *gives an immediate hint of what is to come by recalling the devastating aftermath of the famous* 1883 *eruption of the volcano Krakatoa. In the novel,* Krakatit *is a superexplosive atomic substance, something like an atomic bomb, through which a dictator wants to conquer the world. Instead,* Krakatit *destroys those who try to misuse it.*

The War with the Newts *is one of the masterworks of SF. It is basically an anti-Nazi satire and a grim sense of what the future might hold in store for mankind. It is not surprising that the Gestapo tried to arrest the dead Čapek. But Čapek died before the Germans could kill him and before WWII could provide him with material that might simultaneously inspire the intensity of* Krakatit *and the complex thrust of* The War with the Newts. *Čapek's influence has been for the most part indirect, although his humane breeziness arguably infuses the work of some SF writers today.*

Aldous Huxley *(1894–1963, England) wrote the classic dystopia* Brave New World *(1932), a title taken from Shakespeare's* Tempest. *It describes a male-dominated world in which the population is perfectly controlled and people are genetically engineered in carefully regulated mental and physical sizes and types. The author employs characters as mouthpieces for the dialectic of his tale. They engage in Socratic dialogues. In* Brave New World, *the products of science have overwhelmed the poise of human reason.*

Huxley's great fear was not that what science could do should not be done, but that science would become the only *thing that man did — and, after all, this turns to be too little.*

The brave new world is boring. In the use of science to find safety, discipline and courage have become obsolete. A civilization ordered solely by science, sex, and drugs kills the spirit. People become mere cattle. Savagery may be preferable. The savage knows little joy and ecstasy, but by the almost limitless capacity for pain that he had learned, he can imagine, dream of, and therefore in a way attain a transcendence of the richest possible pleasure of his body. Other persons in the novel might die, but only the death of the savage can be profoundly tragic.

Virtually all that Huxley had to say in his SF centered on earth and on mankind. He tried to anatomize the confusion of human science, art, and spirit.

George Orwell *(1903–1950, England), novelist and political writer; can be considered as a SF writer if we define utopia as a sociopolitical subgenre* *of science fiction. He wrote Animal Farm (1945), a political allegory — a satire on the Russian revolution and its monstrous perversion of the vision of democratic socialism. His last novel 1984 (1949), a nightmare, is a culmination of Orwell's intellectual and artistic development: a dystopian nightmare that fuses all the themes derived from his reading, his personal history, and his involvement with some of he more significant sociopolitical issues of his time.*

1984 most fully dramatized Orwell's fear that a totalitarian state could legitimize its power by "altering" the past, present and future, that it could control its subjects' perception of reality by consciously manipulating language. The interpretation of language and experience, which constitutes one of the major themes of the novel, has interested thinkers from Aristotle to Karl Marx;

The specific relationship between language and political power had been discussed before, but after the Holocaust, born of the masterful evil rhetoric of the Nazi Führer, Orwell's brilliant dramatization of these themes takes on additional significance and power. (The Nazis used symbols in such a way that people did not only think about hate, but expressed hate. The Führer did not use language to teach the Germans to think; he provided them with forms through which they could act.) Orwell's sociopolitical legacy is therefore two-fold:

- *"Reality" and "meaning" are not identical with "fact". Meaning arises in social relationship that exist in and through the communication of significant symbols, most notably in language.*
- *History was not something to be created but rather discovered*[25]*, and intellectual freedom lay in being able to report this history. If people cannot know, canot be certain about events, they all fall victims to the most irresponsible propaganda.*

Orwell meant, 1984 to be a warning, not a prophecy. The book's gloom is often referred to his illness and his growing conviction of the manipulability

[25] At his point Orwell's position is at par with arguments from such historians as **Benedetto Croce** (1866–1952, Italy), who insisted that all history is "present" history in the sense that it is impossible to create an objective historical narrative. History is not a mere description of the past, but an evaluation of it, with EACH GENERATION RENDERING ITS OWN VALUE JUDGMENT OF IT. The interpretation of history creates history, by constructing the mind's self-creative value judgment of events. Since the philosophical interpretation of the present generation will one day be history, philosophy and history must be considered identical.

of the human mind. The book's despair comes not just from the fact that tyranny is universal and that the individual is doomed, but from the bottomless selfishness of the human being.

Born Eric Arthur Blair in Bengal, India, son of an official in the Indian civil service. He returned with his parents to England, and after education at Eton, joined the Burmese police. Returning to Europe (1927) he chose to live among the deprived, and completed his rebirth by adopting a new name. Until 1935 *he lived with the poor, tramped over the English countryside. He participated one year (1936–1937) as a common soldier in the Spanish Civil War on the side of the Republicans, where he became disillusioned with Communism. After* Animal Farm *appeared, Orwell took a house on Jura in the Hebrides. He died of tuberculosis soon after writing his last novel,* 1984*.*

As scientific ways of understanding the world developed in the 17^{th} *and* 18^{th} *centuries, fiction became more and more realistic, and the realistic novel came more and more to dominate the world of fiction. Fantasy was considered a minor form, suitable for children or as light reading for adults, but not really "literature", not really serious.*

In the 19^{th} *century, realism developed new techniques for representing a whole social scene accurately and finally new ways of making individual psychology available to readers. The realistic novel presented* this *world in* this *time, competing with history and journalism as a way of recording the truth of contemporary experience. So powerful was this fictional form, that many writers and critics believed it to be the end of a long process of evolution. At last we had learned how to tell the truth in fiction! But truth is elusive and has a way of turning to dust and ashes whenever we try to stop it from growing and changing.*

All during the time of the rise of realism, a number of things had been going on which tended to counteract the realistic movement and prepared the way for a great shift in human awareness. The physical scientists, as they perfected their instruments of vision and measurement, began to explore worlds which in relation to ordinary human experience seem fantastic. Cosmic space and atomic space began to reveal their secrets, and in doing so posed problems which only "fantastic" speculation seemed able to solve.

Arthur Charles Clarke *(b. 1917, England). Science fiction novelist, scientist and prophet of space flight. Anticipated (1945) artificial communication satellites in synchronous orbits. Established in his novels futuristic technologies and scientific developments.*

Clarke joined the fledgling British Interplanetary Society at 17*, becoming its chairman while completing his B.Sc. at Kings College, London, in the late* 1940*'s. In Interplanetary Flight (1950) and The Exploration of Space (1951)* *he expounded his technical knowledge and enthusiasm for the 'space age' to a wide public and made him a foremost popularizer of space travel.*

At the same time he made his debute in the front rank of postwar SF writers. With Stanley Kubrick he wrote the script for 2001: a Space Odyssey (1968), perhaps the most imaginative of all SF films. In his novels he portrays man's encounter with alien intelligence as the chief turning point in a future which is cosmic and evolutionary rather than mundane and catastrophic. He conceives of man as on a continuous odyssey, facing that giant staircase as a challenge his heritage demands that he accept. Clarke has been a most influential voice in shaping SF in the epoch of the recent and continuing scientific revolution.

***Isaac Asimov** (1920–1992, U.S.A.). Influential writer of SF during the second half of the* 20^{th} *century. He wrote nearly* 500 *books on a wide gamut of scientific and non-scientific subjects. He was a pioneer in elevating the SF genre from pulp-magazine adventure to a more intellectual level that dealt with sociology, history and science.*

The special character in Asimov's work derives from the last fact that the robots stand side by side with the humans. His robot stories are consistent with his 'three rules of robotics' (1942):

(1) A robot may not injure a human being, or through inaction allow a human being come to harm.

(2) A robot must obey the orders given it by human beings except when such orders would conflict with the First Law.

(3) A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

Asimov was born to Jewish parents in a suburb of Smolensk called Petrovich. His parents Judah and Rachel Berman Asimov moved to New York in 1923 *and settled in Brooklyn. He graduated from Columbia University (1948) with a Ph.D. in chemistry and gained the rank of associate professor in biochemistry at the Boston University (1955). In* 1958 *he reached an agreement with that University whereby he would perform no substantial duties and receive no salary, but would retain his faculty rank and status.*

Early 20^{th} *century science fiction was inspired largely by astronomy and to a lesser extent by physics and mathematics. These sciences, together with the preoccupation with gadgets and with a little chemistry thrown in, dominated the scene until about* 1948.

After WWII the biological sciences emerge as major elements in the genre. Having escaped at last from the unpromising side track into which this fiction *had long been diverted by the man-made bug-eyed monsters sired, or rather dammed, biology began to emerge as an SF inspiration with early* 20^{th} *century writers but it was slow to gain prominence until the WWII, when plastic surgery in particular made a considerable impact.*

By the early 1960s psychology and sociology had become a major source of science fiction stimulus and the mathematical sciences, including economics and cybernetics, were also in great evidence. The 1970s saw an even greater change, the almost total rejection of scientific reason.

Until 1945 science could be seen as the friend of mankind; modern medicine has brought about a great increase not only in longevity but in the capacity to enjoy life physically, an increase which has affected our aspirations.

However, after the explosion of the first atomic bomb its evident capacity to destroy humanity turned science into a potential enemy; the prospect of a sudden cataclysmic end to all human life has destroyed the hope slowly engendered through the 18^{th} *and* 19^{th} *centuries that science and reason would bring about an inevitable millenium. Thus we resurrected the monster of Dr. Frankenstein and the devil of Faust — forbidden, uncontrollable and therefore dangerous knowledge.*

Modern man has now come full cycle again to the more vigorous fears and uncertainties of earlier time. This is amplified by the fact that today, the sheer mass of scientific knowledge is beyond individual comprehension, despite the far higher level of general education. We have to some extent returned to the situation of the primitive man who required his myths and mysteries as protection against forces which he could neither fully understand nor control.

Because of all this, SF was firmly established as a particularly sensitive form of literature for reflecting the moods and psychoses of its host society.

1895–1932 CE **Charles Scott Sherrington** (1857–1952, England). Neurophysiologist. Formed the scientific basis of modern neurology; coined the terms *neuron* and *synapse*; demonstrated that reflexes in higher animals are integrated activities of the total organism; made lifelong study of the mammalian nervous function. Shared (with **Edgar Douglas Adrian**) the Nobel Prize for physiology or medicine (1932).

Postulated (1906) that neural reflexes must use more than one neuron; so he proposed a synapse and a neurotransmitter substance to connect the two nerve cells. Developed (1913–1930) modern techniques for recording nerve activity and outlining the nature of communication between nerves and between nerves and muscles.

Sherrington was born in London. He took his medical degree at Cambridge (1885). Taught at London University, where he became professor of pathology (1891–1895). He was then professor of physiology at Liverpool (1895–1913) and Oxford (1913–1931).

1895–1945 CE Leading Western poets and novelists from the turn of the 20^{th} century to WWII:

- Oscar Wilde 1854–1900
- Joseph Conrad 1857–1924
- Axel Munthe 1857–1949
- Arthur Conann Doyle 1859–1930
- Rudiard Kipling 1865–1941
- Ladislas Stanislas Reymont 1867–1925
- John Galsworthy 1867–1933
- Maxim Gorky 1868–1936
- Felix Salten 1869–1945
- Ivan Bunin 1870–1953
- Marcel Proust 1871–1922
- Hayim Nahman Bialik 1873–1934
- Robert Frost 1874–1963
- R.M. Rilke 1875–1926
- Thomas Mann 1875–1955
- Jack London 1876–1916
- Carl Sandburg 1878–1967
- Upton Sinclair 1878–1968
- James Joyce 1882–1941
- Jaroslav Hasek 1883–1923
- Franz Kafka 1883–1924
- Sinclair Lewis 1885–1951
- S.Y. Agnon 1887–1970
- Fernando Pessoa 1888–1935
- T.S. Eliot 1888–1965
- Karl Capek 1890–1938
- Franz Werfel 1890–1945
- Lajos Zilahy 1891–1974
- Edna St. Vincent Millay 1892–1950
- E.E. Cummings 1894–1962
- Erich Maria Remarque 1898–1970
- Bertolt Brecht 1898–1956

• Ernest Hemingway	1899–1961
• John Steinbeck	1902–1968
• William Saroyan	1908–1978
• Dylan Thomas	1914–1953

1896 CE First modern *Olympic Games* in Athens, Greece; the first known Olympic contest took place in the Stadium of *Olympia* in 776 BCE.

In 394 CE, Emperor Theodosius ordered the games ended, but they continued until 426 CE (304th Olympiad), when an earthquake destroyed the Stadium of Olympia. A second earthquake (521 CE) buried the ruins of the structure.

The Olympics were held every four years, and were used in Greece as a system of dating for literary purposes (but never adopted in every-day life); all events were dated from 776 BCE. The beginning of the year of the Olympiad was determined by the first full moon after the summer solstice, the longest day of the year. The full moon fell about the first of July. Each interval of four years was known as an *Olympiad*.

1896 CE **Arthur Schuster** (1851–1934, England). Applied Fourier analysis to determine periodicities of geophysical and astronomical time-series.

1896 CE **Max von Gruber** (1853–1927, Austria). Bacteriologist and physician. Discovered the specific *agglutination* of bacteria by the serum of an organism immune to a certain disease, such as typhoid fever and cholera. This reaction, which bears his name, is used to identify unknown bacteria and was first utilized by **Fernand Widal** in his test for diagnosis of typhoid fever. This discovery paved the road for clinical diagnosis of many contagious diseases.

Gruber studied in Vienna and Münich. He was professor at Graz (1883–1887), Vienna (1887–1902) and Münich (1902–1923).

1896 CE **Jacques Solomon Hadamard** (1865–1963, France). Outstanding mathematician. Proved the '*Prime-number theorem*'[26], which states that

[26] After proving the 'Prime-number theorem', Hadamard was fascinated by what went on in the mind of a creative mathematician. He set down his ideas in a book entitled *The Psychology of Invention in the Mathematical Field* (1945), in which he made a powerful case for the role of the subconscious. In his book he divided the act of mathematical discovery into four stages: *preparation*, *incubation*, *illumination* and *verification*.

$\pi(n)$, the number of primes less or equal to n, approaches $\left\{\frac{n}{\ln n}\right\}$ for large value of n. This conjecture was made by Gauss (1792) and Legendre (1778).

In 1852 and 1859 **Chebyshev** and **Riemann**, respectively, provided incomplete proofs to this theorem. Riemann was able to link the zeros of the Zeta function to the properties of $\pi(n)$, but he did not supply any proof for this connection. For about thirty years, other mathematicians tried to prove the main result enunciated in Riemann's paper — but to no avail. Only in 1896 was it proven independently and simultaneously by Hadamard and **Charles de la Vallée-Poussin** (1866–1962, Belgium), both using analytic methods[27]. Interestingly enough, the complex-variable methods used by Hadamard in his proof found applications in the theory of radio waves.

In 1932 **Edmund Landau** (1877–1938, Germany) and **Norbert Wiener**, using 'Tauberian theorems', simplified Hadamard's proof. Hadamard introduced the word *functional* (1903) when he studied

$$F(f) = \lim_{n\to\infty} \int_a^b f(x) g_n(x)\, dx.$$

Fréchet (1904) defined the derivative of a functional.

Hadamard also obtained important results in the theory of functions of complex variable [*multiplication theorem*, *3-circles theorem*, *gap theorem* and the *factorization theorem*], partial differential equations, theory of variations, functional analysis, geometry, hydrodynamics, theory of determinants and integral equations.

Hadamard's contributions are partly reflected in such terms as *Hadamard's inequality*, *Hadamard variational formula*, *Hadamard matrices*[28] and *Hadamard transform optics*.

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[27] In 1892 Hadamard proved that $\xi(t) = \Gamma\left(\frac{s}{2}+1\right)(s-1)\pi^{-s/2}\zeta(s)$, is of the form $\xi(t) = C\prod_1^\infty \left(1 - \frac{t^2}{\lambda_n^2}\right)$, $\qquad \sum_1^\infty \frac{1}{|\lambda_n^2|} < \infty$ where $s = \frac{1}{2} + it$.

[28] A Hadamard matrix H_n of order n is an $n \times n$ array, the elements of which are either $+1$ or -1, such that the scalar product of any two distinct rows or columns is zero. Thus H_n must satisfy $H_n H_n^T = H_n^T H_n = nI_n$. Examples are $H_1 = [1]$, $H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$. Its determinant is $\pm n^{n/2}$ (n even), its maximum eigenvalue is $\sqrt{n}$ and its inverse is $H_n^{-1} = \frac{1}{n} H_n^T$.
Hadamard matrices are realized in optical spectroscopy and image processing, with applications in chemistry, medical diagnosis, infrared astronomy, high energy physics and radar. The basic method which underlines these various applications is *multiplexing*. In conventional spectroscopy, for example, electromagnetic radiation is sorted into distinct bundles of rays corresponding to different colors. Thus each bundle is labeled by the apppropriate freqeuncy, wavelength

Hadamard was born in Versailles. He originated from a Jewish family of Lorraine. There are traces of Hadamards, printers in Metz, in the 18^{th} century, and also a remarkable great grandmother who lived during the French Revolution. Before Jacques was born the family settled in the Paris area. His father taught humanities in high school; his mother was a good pianist. He achieved the highest score ever obtained in the entrance examinations to the École Polytechnique, France's greatest school of science and, in Hadamard's youth, the foremost world institution of its type. He chose, however, École Normale Superier (1884), where he studied under **Jules Tannery**[29] and **Émile Picard**.

He was a professor of mathematics at Bordeaux (1893–1896), Sorbonne

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or wavenumber. The spectrum of the radiation is found by measuring the intensity of each bundle. Alternatively, the bundles can be multiplexed: instead of measuring the intensity of each bundle separately, we can measure the total intensity of *various combinations* of *bundles*. After measuring n suitably chosen combinations, the individual intensities of n different bundles can be calculated, and the spectrum obtained. Finally, by combining multiplexed radiation from different parts of the picture and from different frequency bands, it is possible to reconstruct a color picture of a scene.

The primary purpose of multiplexing is to maximize the radiant flux incident on the detector, in order to improve the signal-to-noise ratio of the final intensity display.

So where does Hadamard enter in the scheme of things? — in the design of the *mask* which splits the source beam into bundles! This mask is essentially a two-dimensional grid made of two basic elements: open and closed slots. Each element of the beam is either transmitted or absorbed. [To overcome the difficulty that there is no way of registering a negative signal with an ordinary light detector, a Hadamard matrix can always by written as difference of special matrices whose elements are 1 or 0.] Knowing the special algebra of Hadamard matrices, one can design the multiplexing spectrometer accordingly.

29 **Jules Tannery** (1848–1910, France). Known primarily for his treatise on elliptic functions and his controbutions to the history and philosophy of mathematics. Discovered the summation formula

$$\sum_{n=1}^{\infty} \frac{x^{2^{n-1}}}{x^{2^n}-1} = \begin{cases} \frac{1}{x-1}, & \text{if } |x|>1, \\ \frac{x}{x-1}, & \text{if } |x|<1. \end{cases}$$

The special case $x=2$ yields the interesting result

$$\sum_{n=1}^{\infty} \frac{2^{2^{n-1}}}{2^{2^n}-1} = 1.$$

(1896–1909), College de France (1897–1935) and École Polytechnique (1912–1935).

As a brother-in-law of Alfred Dreyfus, Hadamard took an active interest in the *Dreyfus case*. The dangers of Hitlerism were recognized by Hadamard at an early stage and he worked to alleviate the plight of German Jewry. He escaped from France in 1941 to the United States, and moved to England to engage in *operational research* with the Royal Air Force. He had three sons and two daughters. The two elder sons were killed in action in WWI within an interval of less than two months. The third son was killed in North Africa in WWII.

Hadamard loved music and used to have a small orchestra for amateurs in his house: **Einstein** played in it whenever he was in Paris. Duhamel, the writer, was the flautist, Hadamard played the violin and Mme Hadamard played the piano, supplementing by playing the parts of the brass instruments when required.

1896 CE **Henry Ford** (1863–1947) and **Charles Brady King** drove their first gasoline cars in Detroit, MI. That same year, **Ransom Eli Olds** (1864–1950), drove his first gasoline car in Lansing, MI. Also in 1896, **Alexander Winton** successfully tested his own automobile in Cleveland. In 1903, **David Dunbar Buick** (1854–1929) built his first car in Detroit. Most of these pioneer American automakers later began the mass production of cars in the United States.

1896–1900 CE **Antoine Henri Becquerel** (1852–1908, France). Physicist. Discovered radioactivity in uranium ores and identified beta particles with Thomson's electrons.

He embarked on the subject through his interest in the relation between absorption of light and the stimulated emission of phosphorescence in some uranium compounds. Influenced by the discovery of X-rays by Röntgen, he decided to test an hypothesis that uranium salts emit X-rays when irradiated by sunlight. He found in 1896 that the uranium salts would eject penetrating radiation (as revealed by their effect on a photographic plate) even when they were not excited by the ultraviolet in sunlight. He then postulated the existence of invisible phosphorescence.

Becquerel was a member of a scientific family extending through several generations[30]. He received his formal scientific education at the École Polytechnique (1872–1874) and engineering training at the school of Bridges and

[30] This family of physicists includes:

- **Antoine-César** (1788–1878). Professor, Musée d'Histoire Naturelle (1837–1878); one of the creators of the science of electrochemistry.

Highways (1874–1877). In addition to his teaching and research posts he was for many years an engineer in the department of Bridges and Highways. He became a professor of physics in 1895. For his discovery of radioactivity he shared the 1903 Nobel prize for physics with the Curies.

1896–1902 CE **Walter Reed** (1851–1902, US). Surgeon and pioneer medical researcher who led to the eventual eradication of Yellow fever and typhoid fever.

Born in Belroi, Virginia and received his MD degree from the University of Virginia. He joined the Army Medical Corps (1875), served as an army surgeon in Arizona (1876–1889) and Baltimore (1890–1893), and was professor of bacteriology at the Army Medical College (1893–1902).

Much of his work was centered on epidemic diseases: malaria, diphtheria, hog cholera, typhoid fever and Yellow fever, showing them to be caused by bacilli or viruses. Discovered (1898) that the Yellow fever virus was transmitted by the mosquito *Aedes aegypti*. Walter Reed Hospital in Washington D.C. was named after him.

1896–1902 CE **Robert Hjalmar Mellin** (1854–1933, Finland). Mathematician. Introduced the *Mellin transform*[31] into linear applied mathematics

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- **Alexandre-Edmond** (1820–1891). Son of the above. Succeeded to his professorship (1878–1891). Contributed to photochemistry. Discovered (1839) that when two pieces of metal were immersed in an electrolyte, an electric charge developed when one of the pieces was illuminated. But although he discovered the electrochemical effects of light, he did not offer any practical suggestion for its use.

- **Antoine-Henry** (1852–1908). Son of the above. Succeeded to his professorship (1892).

[31] Let $f(r)$ be a real function defined in the interval $(0, \infty)$ such that $f(r)$ is piecewise continuous and of bounded variation in every finite subinterval $[a, b]$, where $0 < a < b < \infty$. If in addition both integrals

$$\int_0^1 r^{\sigma_1 - 1}|f(r)|\,dr, \quad \int_0^1 r^{\sigma_2 - 1}|f(r)|\,dr$$

are finite for suitably chosen real numbers σ_1 and σ_2, then the Mellin transform of $f(r)$ is defined by the formula

$$F(s) = \int_0^\infty f(r) r^{s-1}\,dr,$$

where $s = \sigma + i\tau$ is any complex number in the strip $\sigma_1 < \mathrm{Re}\ s < \sigma_2$. The as a powerful tool of solving problems in elasticity theory and potential theory. The Mellin transform arises from the multiplicative structure of the real line in the same way as the Fourier transform arises from its additive structure.

Mellin was pupil of **Mittag-Leffler** and then studied in Berlin (1881–1882). He was later a professor of mathematics at the University of Helsinki.

1896–1916 CE **Arnold** (**Johannes Wilhelm**) **Sommerfeld** (1868–1951, Germany). Outstanding physicist, and a prodigious producer of future Nobel prize winners. Introduced the quantization of the action integral $\int pdq$, which paved the way for modern quantum theory (1911). Defined the fine-structure constant of electromagnetic interaction, $\alpha = 2\pi e^2/hc \simeq 1/137$. In classical physics, he is known for his contributions to the theories of the gyroscope, diffraction of light (1896), and propagation of radio waves.

Sommerfeld's investigations of atomic spectra led him to suggest that, in the Bohr model of the atom, the electrons move in *elliptical orbits* as well as circular ones. From this idea he postulated the azimuthal quantum number. He later introduced the magnetic quantum number as well. Sommerfeld also did detailed work on wave mechanics, and his theory of electrons in metals proved valuable in the study of thermoelectricity and metallic conduction.

Sommerfeld was born in Königsberg, Prussia. He was educated in his native city and then became an assistant at the University of Göttingen. He served as a professor of physics at Munich (1906–1931), where he did most of his important work. Sommerfeld was a gifted teacher and educator. His 5-volume treatise '*Lectures on Theoretical Physics*' still serves today as a graduate textbook. Among his students were **W. Pauli**, **W. Heisenberg** and **H. Bethe**.

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inversion of $F(s)$ is given by the formula

$$f(r) = \frac{1}{2\pi i}\int_\Gamma F(s)r^{-s}\,ds,$$

where Γ is a straight line parallel to the imaginary axis lying inside the strip.

The *Mellin transform* is related to the Laplace and Fourier transforms and is the appropriate tool to use for solving problems in two-dimensional elasticity theory and potential theory involving angular regions.

The *Mellin transform pair* appeared in Riemann's famous memoir on prime numbers and it was later formulated more explicitly by **E. Cahen** (1894). But the first one to put it on a rigorous basis and point some of its applications was Mellin, and that is why the transforms bears his name.

1896–1920 CE **Vilfredo Pareto** (1848–1923, Italy and Switzerland). Economist, sociologist and engineer. Developed methods of mathematical analysis in the study of economic and sociological problems.

Pareto extended Walras's theory of general economic equilibrium, and sought to extend it to the entire range of social phenomena. In his sociological theories, Pareto argued for the superiority of the *elite*, claiming that society was always composed of elites and masses.

While his sociological theories are controversial, Pareto's contributions to economics have come to be recognized as immensely important during the second half of the 20th century.

In his economic theory, Pareto rejected the treatment of utility as a *cardinally* measurable quantity whose maximization involved the comparisons of one person's happiness with another's; instead, he treated it as *ordinal* concept (i.e. one implying only a *ranking* by each individual of alternatives available to him), and defined a corresponding optimum as a condition of society from which it is impossible to make any one individual subjectively better off without simultaneously making at least one other individual worse off. This idea of '*Pareto optimum*' — according to which the economic system can, in principle, generate an optimal distribution function of welfare among its individual members — is the fundamental concept of modern welfare economics.

Pareto's work led modern economists to the finding that the conditions for such an optimum will be satisfied by a Walrasian general equilibrium, where *each consumer is maximizing utility and each producer maximizing profits*, all under conditions of perfect competition (i.e. with no single consumer or producer able to influence, on his own, any market price).

Pareto also made significant contributions to the empirical study of *income distribution*, enunciating what came to be known as *Pareto's Law*, or the *Pareto distribution of incomes.* This purported to describe the pattern of inequality of incomes which any society will tend to generate, regardless of its economic system.

Pareto was born in Paris, France, and embarked on his research after a successful career in industry. He then became a professor at Lausanne (from 1893). In his book *Mind and Society* (1916), he stressed the irrational elements in social life and emphasized the role of leading groups (elites) in society. He criticized democracy and saw history as a succession of aristocracies. Because of his antidemocratic attitudes, he is considered an intellectual forerunner of fascism. Indeed, the ideology of Italian fascism was largely based on his theory.

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