CULTURAL CLIMATES AND TECHNOLOGICAL ADVANCE IN THE MIDDLE AGES

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To establish facts, and the more obvious relations among facts, has never satisfied the consciences of historians. We are driven to ask not only what happened but also why it happened. Historical explanation, of course, is seldom a matter of one billiard ball striking another, of "causes" in the narrow sense. It is much more often a process of gradual illumination of the fact to be explained by gathering around it other facts that, like lamps, seem to throw light on it. At last the historian arrives at a sense that the central fact on which he is focusing has become intelligible.

In 1959 when I finished the manuscript of a book on medieval technology,[1] I was painfully aware of its greatest defect: it identifies and describes a few major aspects of the unprecedented technological activity that occurred in the medieval West, but it fails to explain the phenomenon observed. To tell the truth, I was much more sure of the *what* than the *why*. Four years later I had become bold enough to publish a preliminary inventory of possible reasons, not all of equal weight but none mutually exclusive, for medieval technological advance.[2] This is not, however, the sort of problem that stands still. The present state of scholarship demands a new effort to understand it.

I

There is much to be understood. The technological creativity of medieval Europe is one of the resonant facts of history.[3] Beginning obscurely as early

[1] *Medieval Technology and Social Change* (Oxford 1962), hereafter *Med. Techn.*

[2] "What Accelerated Technological Progress in the Western Middle Ages?" in *Scientific Change*, ed. Alistair C. Crombie (London 1963) 272-291.

[3] The most comprehensive survey of medieval European technology is that by Bertrand Gille in *Histoire générale des techniques*, ed. Maurice Daumas, 1 (Paris 1962) 429-598, and 2 (1965) 2-139. See also Friedrich Klemm, *Der Beitrag des Mittelalters zur Entwicklung der abendländischen Technik* (*Beiträge zur Geschichte der Wissenschaft und der Technik* 2, Wiesbaden 1961), and my "The Expansion of Technology, 500-1500 A. D." in *The Fontana Economic History of Europe* ed. Carlo M. Cipolla, 1, chapter 4 (London 1969 issued as pamphlet).

as the sixth century, within three hundred years the northern peasantry created a novel agricultural system that, in proportion to expenditure of human labor, was probably the most productive in the world.[4] In the eighth century the Franks revolutionized their methods of warfare, and thereafter their descendants consistently maintained the initiative in improving military technology, as distinct from military organization. From about the year 1000 onward—although the movement was foreshadowed in the ninth century—the West produced new labor-saving mechanical devices and explored new applications of power to production, thus providing the industrial basis for burgher capitalism. Starting in the sixth century, but particularly after 1200, Europe led in the development of ship design and the nautical arts.

While the medieval West's cousinly cultures, Byzantium and Islam, long remained more sophisticated in most other respects, in technology they were laggards as compared with Europe. Only contemporary China—from which the West borrowed much[5]—could compare with Europe in inventiveness and eagerness for useful novelties. The emergence of the mechanical clock in the second quarter of the fourteenth century, however, by enlarging the number of craftsmen skilled in making and correlating moving metal parts in machines, led in Europe to heightened activity that soon gave to the Occident a clear technical superiority even over China.

Romans had been no less predatory than were Europeans of the late Middle Ages, but the Caesars were so ill equipped that they could not extend their rapacity greatly beyond the basin of the Mediterranean. By 1492, however, Europe had developed an agricultural base, an industrial capacity, a superiority in arms, and a skill in voyaging the ocean which enabled it to explore, conquer, loot, and colonize the rest of the globe during the next four centuries and more. This unification of world history was a unique event. Its implementation, and that of the Imperialist Age, 1500-1950, was provided largely by the Middle Ages.

Moreover, modern technology is the extrapolation of that of the Western Middle Ages not merely in detail but also in the spirit that infuses it. The later thirteenth century in Europe marks the moment of crisis in the history of mankind's relation to the natural evironment: it produced "the invention of invention" of which the practical effects were soon felt. The earlier record of technology around the globe is scattered and often lacking in continuity; it recounts a generally slow accumulation of isolated specific inventions,

[4] The salutary effect of this upon the standards of living among German peasants in the eleventh century is shown in my "The Life of the Silent Majority," in *Life and Thought in the Early Middle Ages* ed. Robert S. Hoyt (Minneapolis 1967) 85-100.

[5] No student of European technology can neglect Joseph Needham, *Science and Civilization in China*, 4 vols. in 6 to date (Cambridge, Eng. 1954-1970).

their spread and elaboration. But in the Middle Ages, in Europe alone, invention became a total and coherent project.[6] From the later Middle Ages onward, world technology was increasingly European technology.

Technicians at that time in large numbers[7] began to consider systematically all the imaginable ways of solving a problem. About 1260, the Franciscan Roger Bacon, pondering transportation, confidently prophesied an age of automobiles, submarines, and airplanes.[8] Since arrow wounds were then a medical problem, about 1267 Theodoric, successively bishop of Bitonto and Cervia, in his treatise on surgery noted that for the extraction of arrows "quotidie enim instrumentum novum, et modus novus, solertia et ingenio medici invenitur."[9] Clocks were a great problem, and proposals for their improvement were frequent before the solution was found. On the basis of the recently introduced Chinese mariner's compass, and inspired by the novel Hindu concept of perpetual motion, in 1269 Roger Bacon's friend, the military engineer Peter of Maricourt, proposed a magnetic clock to replace all others.[10] In 1271 Robert the Englishman, talking about plans for a weight-driven clock, admitted that the problem of the escapement had not been entirely conquered, but he was confident that it would be.[11] Almost at the same moment, at the court of Alfonso el Sabio of Castile, Rabbi Isaac ben Sid of Toledo described not only new kinds of waterclocks, which he claimed to be much better than any earlier models; he also depicted as an absolute novelty a weight-driven clock with a mercury brake.[12] Indeed, this was a fairly practical solution for the escapement, as a subsequent tradition of such clocks shows.[13] Before 1313 someone invented the sandglass.[14] But

[6] For a complex example of this coherence, see an inventory of the ways, between ca. 1010 and ca. 1480, in which Western technicians utilized the velocity, resistence and pressure of air, in my "The Invention of the Parachute," *Technology and Culture* 9 (1968) 462-467, and "Medieval Uses of Air," *Scientific American* 222 (Aug. 1970) 92-100.

[7] About 1235 Villard of Honnecourt, and in 1269 Peter of Maricourt, independently inform us that many men are arguing and laboring to the point of exhaustion to produce *perpetua mobilia*; *Villard de Honnecourt: Kritische Gesamtausgabe*, ed. H. R. Hahnloser (Vienna 1935) pl. 9; Peter of Maricourt, *Epistola de magnete* in *Rara magnetica 1269-1559*, ed. Gustave Hellmann (Berlin 1896) 11.

[8] *De secretis operibus*, chap. 4, in *Opera queadam hactenus inedita*, ed. J. S. Brewer (London 1859) 533.

[9] *Chirurgia* 1.22, appended to Guy de Chauliac, *Ars chirurgica* (Venice 1546) fol. 143.

[10] See my "Tibet, India and Malaya as Sources of Western Medieval Technology," *American Historical Review* 65 (1960) 522-526.

[11] Lynn Thorndike, "Invention of the Mechanical Clock about 1271 A.D.,"*Speculum* 16 (1941) 242-243.

[12] *Libros del saber de astronomia del rey D. Alfonso de Castilla*, ed. M. Rico y Sinobas (Madrid 1866) 4.67-76.

[13] Silvio A. Bedini, "The Compartmented Cylindrical Clepsydra," *Technology and Culture* 3 (1962) 115-141.

[14] *Med. Techn.* 165-166.

technicians labored from the 1260s until the 1330s before the true mechanical clock was invented.[15]

In a sermon on repentance preached at Santa Maria Novella in Florence on 23 February 1306, the Dominican Fra Giordano of Pisa, while providing our best evidence of the invention of eyeglasses in the 1280s, incidentally sang the praises of the recent invention of invention. "Not all the arts," he said, "have been found; we shall never see an end of finding them. Every day one could discover a new art . . . indeed they are being found all the time. It is not twenty years since there was discovered the art of making spectacles which help you to see well, and which is one of the best and most necessary in the world. And that is such a short time ago that a new art, which never before existed, was invented . . . I myself saw the man who discovered and practiced it, and I talked with him."[16]

By the early fourteenth century, then, Europe showed not only an unmatched dynamism in technology: it also arrived at a technological attitude toward problem solving which was to become of inestimable importance for the human condition. The profound contrast between this aspect of the

[15] The intensity and diversity of the search is indicated by the fact that, almost simultaneously, inventors reached two related solutions: the verge and the wheel escapement; Ernst Zinner, *Die ältesten Räderuhren* (Bamberg 1939) 26. The use of geared weight-operated striking trains in clepsydras by the thirteenth century, and the assimilation of the vocabulary of the water clock to the mechanical clock, make difficult exact dating of the invention of the latter; cf. *Med. Techn.* 124. The earliest firm date is 1341 when Galvano Fiamma, *De gestis Azonis vicecomitis*, ed. L. A. Muratori, *Rerum italicarum scriptores* 12 (Milan 1728) 1038, tells of the invention in Milan of mills run neither by water nor by wind "sed per pondera contra pondera sicut fieri solet in horologiis. Et sunt ibi rotae multae, et non est opus, nisi unius pueri. . . . Nec umquam in Italia tali opus fuit adinventum, *licet per multos exquisitum*" (italics added). The middle 1330s however, seem indicated by the fact that in 1338 a party of six Venetian merchants left for India taking a clock and an automatic fountain as their most valuable merchandise. In Delhi the Muslim Sultan paid to them the fantastic sum of 200,000 bezants "tam pro rellogio quam pro fontanella et aliis rebus dicte societatis"; Robert A. Lopez, "L'extrême frontière du commerce de l'Europe médiévale," *Moyen âge* 69 (1963) 488 n. 16. To command such a price, this clock must have been a great novelty, almost certainly weight-driven and escapement-controlled, since Islam was entirely familiar with elaborate water clocks, as is shown by Eilhard Wiedemann and F. Hauser, "Über die Uhren im Bereich der islamische Kultur," *Nova acta* (Halle) 100.5 (1915) 1-272.

[16] "Non sono però trovate tutte. Di trovare arti non si verrebbe a fine mai. Ognedì se ne potrebbe trovare una dell'arti . . . e sempre se ne trovano delle nuove. Non è ancora xx anni che si trovò l'arte di fare gli occhiali, che fanno vedere bene, ch' è una delle migliori arti e delle piu necessarie che'l mondo abbia: ed è così poco che si trovò arte novella che mai non fu. . . . Io vidi colui che prima la trovò e fece, e favellagli"; Enrico Narducci, *Tre prediche inedite del b. Giordano da Rivalto* (Rome 1857) 59-60, an offprint from *Giornale arcadico di scienze, lettere ed arti* 146 (1857) 125-126. Edward Rosen, "The Invention of Eyeglasses," *Journal of the History of Medicine and Allied Sciences* 11 (1956) 13-46, 183-218, clarifies the context.

Occident and the relative passivity toward technology in the Near East is the more significant because Byzantium, Islam, and the Western world were related societies, all in great measure, but in varying proportions, built of elements found in the Greek and Semitic legacies from Antiquity. The fact that thirteenth-century theologians in Cairo, Constantinople, and Paris were all commenting on Aristotle helps us to grasp the unity of the triune Middle Ages. The fact that in the time of Saint Thomas Aquinas labor-saving machinery was little developed in the Near East and concern for invention was minimal, whereas in the West a new sort of engineering[17] was being pursued with an enthusiasm amounting to passion, helps us to understand why the Occidental third of the Middle Ages generated what we call the modern world.

II

This technological thrust of the medieval West does not yield easily to explanation. Necessity is not the mother of invention,[18] since all necessities are common to mankind living in similar natural environments. A necessity becomes historically operative only when it is felt to be a necessity, and after prior technological development makes possible a new solution. Even then, what seems needed and feasible to one culture may be a matter of indifference to another.

For example, the lands of medieval Islam were generally so arid that, even where there was enough water for agriculture, the flow of streams was too scanty or sporadic to operate many mills to grind grain. Windmills were an "obvious" solution, since dry country is notoriously windy because sparsity of vegetation helps to generate air currents. And in fact in the tenth century of our era[19] the first functional windmills appeared in eastern Iran and Afghanistan, rotating on vertical axles. Here, surely, the Muslim world had discovered an answer to its "need" for mechanical power. But did Islam feel that need with any intensity? There is no evidence that the windmill of Sejistan ever spread to the rest of Islam: claims for windmills in Muslim Spain have not been substantiated.[20] In 1185, on the other hand, the hori-

[17] The word "engineer" first appears in 1170 and is very common in the thirteenth century; see *Med. Techn.* 160.

[18] I have not been able to trace this misconception earlier than the late 1120s when Hugh of Saint Victor, *Didascalicon* 1.9, ed. Charles H. Buttimer (Washington 1939) 17, cites a proverb of which scholars have not found the source: "Ingeniosa fames omnes excuderit artes." In 6.14 (p. 130) Hugh comes closer to the modern phrasing: "propter necessitatem inventa est mechanica."

[19] For the controversy over the date see *Med. Techn.* 86 n. 7.

[20] *Ibid.* 161; *Isis* 58 (1967) 249. To judge by the distinction achieved in Yuan China by immigrant Muslim engineers (see Herbert Franke, "Westöstliche Beziehungen im Zeit-

zontal-axle windmill appeared independently in Yorkshire,[21] seemingly invented by analogy with the Vitruvian watermill, and it spread over Europe almost explosively.[22] Within seven years it had been taken to Syria by German crusaders. Yet fourteen years after that, writing at Edessa in 1206, the leading Arabic author on engineering, al-Jazarī, remarks that the notion of mills driven by the wind is nonsense: the wind is too fickle to power such a machine.[23]

Late medieval Byzantium, although ruling a dwindling area, was economically still fairly prosperous and continued to be amazingly vigorous in the arts and in religious speculation. Its resilience fills one with admiration. But, like the Muslims, the Greeks of that age were not particularly concerned to improve their technology.[24] About 1444 Cardinal Bessarion, a learned Byzantine cleric who had emigrated to Italy, wrote to the Despot of the Morea[25] urging him to strengthen himself against the Turks by sending young men to the West to learn the mechanic arts. He was impressed by improved Western glass,[26] textiles, weapons, and ships. What most amazed him, however, was the spectacle of water wheels operating both sawmills and the bellows of blast furnaces. Yet in the Occident at that time there was no novelty in these: the first lumber mill appears at Evreux in 1204, and the first water-

alter der Mongolenherrschaft," *Saeculum* 19 [1968] 99-100), Islamic technology must have been more dynamic than the present deplorable state of scholarship would indicate. The best, but inadequate, survey is that by Gaston Wiet, Vadime Elisséeff, and Philippe Wolff "L'évolution des techniques dans le monde musulman au moyen âge," *Cahiers d'histoire mondial* 6 (1960-61) 15-44.

[21] *Med. Techn.* 87.

[22] By about 1322 a monk at Saint Mary's of Pipewell in Northamptonshire complains that one of the chief reasons for deforestation is the search for long timbers for the vanes of windmills: "et quot virgae molendinorum venticorum dabantur in temporibus diversorum abbatum nemo novit nisi Deus"; W. Dugdale, *Monasticon anglicanum*, ed. 2 (London 1682) 1.816.

[23] E. Wiedemann, "Die Konstruktion von Springbrunnen durch muslimische Gelehrte, in *Festschrift zur Feier des hundertjährigen Bestehens des Wetterauischen Gesellschaft für die gesamte Naturkunde zu Hanau*, ed. C. Lucanus (Hanau 1908) 36.

[24] K. Vogel's admirable chapter on Byzantine technology in the *Cambridge Medieval History*, ed. 2, 4.2 (1967) 299-305, and bibliography 465-470, indicates little motion after the seventh century.

[25] Alex G. Keller, "A Byzantine Admirer of 'Western' Progress: Cardinal Bessarion," *Cambridge Historical Journal* 11 (1955) 343-348.

[26] A symptom of European initiative is not only the fact that in this period Western glass was being widely exported to the Near East, but also that the Venetians, and probably the glass-masters of Barcelona likewise, were manufacturing mosque lamps for that market decorated both with Western floral designs and with pious Koranic inscriptions, sometimes garbled; R. J. Charleston, "The Import of Venetian Glass into the Near East, 15th-16th Century," in *Annales du 3e Congrès International d'étude historique du verre, Damas 1964* (Liège 1968) 158-168.

powered blast furnace in 1384 at Liège.[27] In much of Greece there were ever-running streams operating flour mills. Nor were medieval Greeks and Latins ignorant of each other. The essential fact is that they acted differently because they had differing notions on how it was important to act. In the medieval East, whether Byzantine or Islamic, technological innovation was not considered important. It involved no sense of necessity. Bessarion's letter shows that by 1444 he personally had become Latinized in more than his religion.

There have been efforts to refine the idea of necessity by relating the vitality of medieval Western technology either to the disappearance of slavery or to an alleged labor shortage that placed a premium on increasing the productivity of labor, whether agricultural or industrial.

Unfortunately the present state of scholarship in the comparative sociology of the various medieval subcultures does not permit assured generalization. For example, as regards slavery in Byzantium, one would assume that the military victories of Romanus I, Nicephorus II Phocas, and John I must have increased the supply of slaves from the ninth into the eleventh centuries. However, we do not yet know the extent to which slave labor was used in Byzantine industry[28] and consequently how it may have affected inventiveness in that area. About Antiquity we are somewhat better informed, and what we know does not confirm all modern presuppositions. In certain contexts slavery does not appear to be an obstacle to technological advance. The Hellenistic and early Imperial periods witnessed both the apogee of the ancient slave economy and the most rapid advances not only in engineering but also in basic inventions such as glass blowing.[29] In contrast, the urban artisan class both in Byzantium and in medieval Islam seems, as in the West, to have consisted largely of free men; yet the Near East, unlike Europe, did not make the transition from craftsmanship to widespread industrial production.

There is scanty but interesting evidence that in late Roman times scarcity of manpower was, in fact, an occasional stimulus to invention;[30] but it would appear that the antitechnological attitudes of the ruling class—a bent of

[27] Bradford B. Blaine, *The Application of Water-Power to Industry during the Middle Ages*, Ph. D. dissertation, University of California, Los Angeles (1966) 155, 134-135.

[28] Anne Hadjinicolaou-Marava, *Recherches sur la vie des esclaves dans le mond byzantin* (Athens 1950) 114.

[29] See the thoughtful discussion by Ludwig Edelstein, "New Interpretations of Ancient Science," *Journal of the History of Ideas* 13 (1952) 579-585: he concludes that the obstacles to the wide application even of those inventions lay less in social conditions than in "the basic values underlying ancient life." In particular, Edelstein notes, p. 584, that in Antiquity there was no sense that technological advance was approved by the gods.

[30] H. W. Pleket, "Technology and Society in the Graeco-Roman World," *Acta historica neerlandica* 2 (1967) 15-16.

mind propagated from generation to generation by an almost exclusively rhetorical education—made such proposals abortive.[31] In Europe until the late thirteenth century[32] the movement of assarting indicates that there was probably more land available than there were hands to cultivate it, and this may have been one of the stimuli to the improvement of agricultural methods which was so notable in the West. Yet over the world and throughout history many peoples faced with untapped resources have been slow in developing methods of exploiting them.

At the level of concrete facts it is difficult to interpret technological history from its social context. The emergence of the water mill, the first mechanical application of inanimate power, is an event of prime significance. It appears almost simultaneously, in the first century before Christ, in three widely separated regions: Jutland, northern Anatolia, and China.[33] Are we to assume that in early Germanic Scandinavia, in the Pontus of Mithradates, and in the Yellow River Valley of the Han dynasty, social relationships were so similar as to evoke, in a single inspired generation, the notion of replacing human muscle with the force of water? Similarly the cannon, a complex invention harnessing the expanding forces of gasses by means of a metal tube to propel a missile, is found first at Florence in 1326, in England in 1327,[34] and in China in 1332.[35] Are we to believe that in the early fourteenth century conditions in Italy and England on the one hand, and in Yuan China on the other, were so alike that a major innovation in the art of war was socially necessary, or at least appropriate? It is far simpler, and more consonant with the present state of the evidence, to hold that technology, like art, religion, or social forms themselves, enjoys a certain autonomy in its development, and that diffusion is sometimes swift among very different societies.

The history of papermaking likewise illustrates the difficulty of explaining technological growth as a function of social relations. Paper was invented in China, and, after A.D. 751, when the Caliph's armies captured some papermakers in Samarkand, it spread throughout Islam because it was cheaper than either papyrus or parchment. By about 1050 the Byzantines were using imported Muslim paper both for documents and for books. It is curious that there is no present evidence that medieval Greece ever manufactured its own paper: in the thirteenth and fourteenth centuries its source of supply

[31] Ibid. 17-24.

[32] *Med. Techn.* 67 n. 4.

[33] Ibid. 80-81.

[34] Carlo M. Cipolla, *Guns and Sails in the Early Phase of European Expansion, 1400-1700* (London 1965) 21, 32.

[35] L. C. Goodrich, "Early Cannon in China," *Isis* 55 (1964) 193-195.

shifted increasingly from Islam to Italy.[36] The first indication of paper in the Occident is a Greek charter granted in 1101-1102 by Countess Adelasia of Norman Sicily;[37] this paper was probably imported. Despite assertions to the contrary regarding Játiva in Valencia in the middle of the twelfth century,[38] there is no proof that the production of pulp for paper was ever mechanized in Islam. In startling contrast, the first paper factory known to us in the West—it was already in operation by 1276 near Fabriano—[39] was a *mill*, using water power for pulping. So likewise was the second, in 1280 at Játiva,[40] now under Aragonese rule. There is no independent evidence that labor was scarcer in Italy or in Christian Spain at that time than it was in Islam. In the present state of historical research, the ardor for advancing technology which is observed in the medieval West cannot be explained, save marginally, by social conditions, although it is clear that technological changes were occasionally a factor in social change.[41]

In the twentieth century, new technology is composed so largely of engineering applications of scientific discoveries that we tend to assume a similar relation in the past. In fact, however, until a little more than a century ago there was small connection between science, which was a theoretical effort to understand nature, and technology, which was an empirical attempt to use nature.[42] For nearly five hundred years the world's greatest scientists wrote in Arabic, yet a flourishing science contributed nothing to the slow advance of technology in Islam. By the late thirteenth century the scientific movement in the West, which had begun in the eleventh century with a wave of translations from Greek and Arabic, had seized the global primacy that it still holds. Yet while some individuals at that time, like Roger Bacon, were concerned with both science and technology, their science does not seem to have enriched technology.[43] The slight connection was the

[36] J. Irigoin, "Les premiers manuscrits grecs écrits sur papier et le problème du bombycin," *Scriptorum* 4 (1950) 194-204, and "Les débuts de l'emploi du papier à Byzance," *Byzantinische Zeitschrift* 46 (1953) 314-319.

[37] E. Caspar, *Roger II* (Innsbruck 1904) 482, 561.

[38] E. g. in *A History of Technology* ed. Charles Singer *et al.*, 3 (Oxford 1957) 412.

[39] Aurelio Zonghi, "Le antiche carte fabrianesi," in *Monumenta chartae papyraceae historiam illustrantia*, ed. E. J. Labarre, 3 (Hilversum 1960) 114. Irigoin, in *Scriptorium* 4 (1950) 197 concludes that Italian paper was already being exported to Byzantium by 1255. Whereas Islamic paper never shows watermarks, the lively entrepreneurship of Westerners is indicated by the appearance of such trademarks in Italian paper by the 1280s; Irigoin, 194.

[40] Augustin Blanchet, *Essai sur l'histoire du papier et de sa fabrication* (Paris 1900) 52-53.

[41] Cf. *Med. Techn.*, passim.

[42] See my "Pumps and Pendula: Galileo and Technology," in *Galileo Reappraised*, ed. Carlo L. Golino (Berkeley 1966) 96-110.

[43] The idea that systematic scientific research can help to advance broad areas of technology is first clearly formulated in 1450 by Nicholas of Cusa in *De staticis experimentis* which

reverse: technology was advanced by supplying instrumentation for scientists, most notably the mechanical clock as an aid to medical astrologers.[44]

Still other hypotheses may be offered to account for the permeative technological interest of the medieval West. It has been shown in detail[45] that change leads to further change. In the early Middle Ages the West was much more deeply shaken by invasions and turmoil than were the lands of the Near East. Can this trauma have made the Occident more open to change than the Orient? Perhaps; but this does not explain why the West's penchant for change should have expressed itself so early and so notably in technology rather than in other kinds of activity.

Again: I myself once toyed with the notion[46] that since under Roman rule the Celts showed themselves to be fairly inventive, the vigor of medieval technology may have been simply an amplification of a cultural condition preexistent in Gaul. Perhaps; but this merely transfers the medieval enigma to the Roman age without illuminating it.

III

Clearly, along such paths we have little chance of reaching a satisfactory historical understanding of our problem. To find an explanation for this distinctive quality in the Western Middle Ages we must try to relate it to the general cultural climate of those centuries and places.

Unfortunately the scholarly discovery of the significance of technological advance in medieval life is so recent that it has not yet been assimilated to our normal image of the period. Moreover historians, like most humanists except archaeologists and art historians, are word-bound and therefore find it hard to appraise an activity like technology which has not usually left its traces in writing. In literate societies like those of the Middle Ages which place a high value on ancient texts, contemporary actualities are often obscured by words that are a prized ornamental veneer drawn from obsolete

is Bk. 4 of *Idiota*, ed. Ludwig Baur (Leipzig 1937); a complete French translation is available in Maurice de Gandillac, *Œuvres choisies de Nicolaus de Cues* (Paris 1942) 328-354, who notes (328 n. 166) that in the Vitruvius Strasbourg editions of 1543 and 1550, to which this dialogue is appended, the two participants, named Orator and Profanus in the original, are renamed Philosophus and Mechanicus. Throughout the conversation Mechanicus generally holds the initiative in proposing scientific experiments that might have useful applications in medicine, pharmacy, metallurgy, gem polishing, materials analysis, forecasting the weather, making bells and organ pipes, and perfecting ships and military engines.

[44] *Technology and Culture* 10 (1969) 439-441.

[45] Margaret Hodgen, *Change and History: A Study of Dated Distributions of Technological Innovations in England, A.D. 1000-1899* (New York 1952).

[46] "What Accelerated Technological Progress." (n. 2 above) 280-282.

but revered tradition. Historians trying to understand the cultural climate of an epoch recognize that the degree and style of an era's respect for written tradition is a major element in its climate. The extent, however, to which the verbal repertory of each age may have been self-deceptive, or else inadequate for expressing reality, is not always pondered.

As compared with words, nonsymbolic actions are usually functional rather than decorative. Since many such actions are related to the state and trend of a society's technology, technologies and changes in them offer a useful means of judging how far written records reveal or distort the true state of a cultural climate. There is thus a feedback between our understanding of technology and our interpretation of the general context to which technology is integral.

Items borrowed by a culture offer simpler case studies than those originated within it since they involve no internal genetic problems.

The quality of life in central Java contemporary with Charlemagne may be judged by one of the world's most evocative monuments, Barabuḍur. The enormous Buddhist stupa presents a panorama of bas-reliefs[47] illustrating a world of much elegance, but one remarkably restricted in its technical methods. Only the ships that gave contact with India, whence most of old Indonesian civilization was derived, were in any way advanced, and these vessels were presumably built on Indian models. It may be significant of cultural values that the sole technical novelty that seems traceable to Java at that time is in the arts: the fiddle bow.[48]

Despite this innovation, instrumental music in the East Indies has continued to be primarily percussive. Carried westward on the currents of the spice trade, however, the musical bow, still with a very curved stick, reached Europe about 980[49] where it spread and developed speedily. In order to equalized tensions along the entire length of the bowstring and thus produce a uniform and smooth tone, the stick in Europe was progressively flattened. In early twelfth-century France the first form of the "frog" appeared as a link between the lower part of the stick and the bowstring, thus greatly im-

[47] Nicolaas J. Krom, *Barabudur: Archaeological Description*, 2 vols. of text, 3 of plates (The Hague 1927-1931).

[48] Mantle Hood, "The Effect of Medieval Technology on Musical Style in the Orient," *Selected Reports* of the Institute of Ethnomusicology, University of California, Los Angeles, 1 (1970) 147-170. The evidence is not conclusive but is strong: the *surendro*, a type of five-tone gamelan orchestra which distinctively includes a bowed lute, was known in eighth-century Java. Francis W. Galpin, "The Violin Bow," in *The Legacy of India*, ed. G. T. Garratt (Oxford 1937), 331-334, provides no early dating from India. Bowed instruments were introduced to China perhaps as late as the Yuan dynasty; cf. H. G. Farmer, "Reciprocal Influences in Music 'twixt the Far and Middle East," *Journal of the Royal Asiatic Society* (1934) 327-342.

[49] Curt Sachs, *History of Musical Istruments* (New York 1940) 275.

proving the musical possibilities of bowed instruments.[50] By the later Middle Ages the bow, probably Javanese and certainly Asian in origin, had acquired the dominance of Western instrumental music which it retains today.

No medieval text documents with explicit words the amazing openness of the medieval European mind to borrowings from alien cultures,[51] or shows contemporary awareness of Europe's capacity to exploit and elaborate such borrowings far beyond the level achieved in the lands that generated them. The Indic concept of perpetual motion which in India was doubtless a symbol of karma, and which in Islam was a curiosity, fostered in the Occident a generalized concept of a cosmos full of forces waiting to be used mechanically by man.[52] What Europe did to Chinese paper manufacturing has already been mentioned. India originated the stirrup and China developed it, but Charles Martel's army was the first to realize its full implication for warfare[53]. Gunpowder was Chinese, but the Near East, India, and ultimately Japan received artillery and firearms not from China but from the West.[54] Let us consider one example of such a borrowing, and its consequences, in more detail.

There has long been discussion, among architectural historians, of possible Asian contributions to the genesis of Gothic architecture. The idea generally has been rejected, particularly among the French.[55] The still dominant view that gothic architecture was spontaneously born of the efforts of medieval engineers to cope with the structural necessities of romanesque vaulting shows, however, misunderstanding of the nature of diffusion and of the not infrequent ability of a fairly simple item borrowed from an alien culture to "trigger" much more elaborate creations in the borrowing culture, especially if the intrusive idea answers a felt need.

In the late tenth and eleventh centuries, for reasons that are far from clear, the height of Europe's new churches was steadily increased. The lateral

[50] Hans Heinz Dräger, *Die Entwicklung des Streichbogens und seine Anwendung in Europa* (Berlin 1935) 25-26.

[51] I attempt a brief inventory of such items, only a minority of which were technological, in "Medieval Borrowings from Further Asia," *Medieval and Renaissance Studies* 5: *Proceedings of the Southeastern Institute for Medieval and Renaissance Studies, Summer 1969*, ed. O. B. Hardison, Jr. (Chapel Hill 1971) 3-26.

[52] See n. 10 above. The earliest repudiation of the feasibility of perpetual motion appears on the first page of Leonardo's unfinished treatise on machine design: see Ladislao Reti, "The Two Unpublished Manuscripts of Leonardo da Vinci in the Biblioteca Nacional of Madrid", *Burlington Magazine* 110 (1968) 17.

[53] *Med. Techn.* 1-28.

[54] *Ibid.* 163-164; also Delmer M. Brown, "The Impact of Firearms on Japanese Warfare," *Far Eastern Quarterly* 7 (1948) 238-253.

[55] E.g., André Godard's discussion of "l'origine de l'architecture française du moyen-âge" in "Voûtes iraniennes," *Āṯhār-é Īrān: Annales du service archéologique de l'Iran* 4 (1949) 239-256, and *Art de l'Iran* (Paris 1962) 266ff.

thrust of semicircular vaults demanded massive walls and buttresses; the loftier the vaults, the thicker the lower masonry that was required. In those days all quarrying and stone cutting was manual, and land transport was fearfully expensive, although less so than in Roman times.[56] What could be done to reduce the quantity of masonry needed for a church of the desired height? Moreover, the ground plans of great churches were becoming more elaborate with ambulatories, radial chapels, and the like. Semicircular vaulting could not easily be tailored to cover such irregular areas. Fortunately, to solve such problems a new idea came out of the East at the moment when Europe's architects most needed it.

The ogival arch, sometimes combined with pointed vaulting, is first found in Buddhist India about the second century after Christ.[57] It was used by the Sasanians, whose influence apparently brought it to Syria by A.D. 561.[58] The pointed arch, with vaults, appears at Ramla in Palestine in 789[59] and by the later ninth century was common in Muslim Egypt.[60] Thence it moved by about 1000 to Amalfi, a city intimately connected with Fatimite Egypt,[61]

[56] *Med. Techn.* 66.

[57] Although the present state of Indic studies does not permit definite statements about the priority of pointed arches among various sites, a growing opinion is expressed by Dietrich Brandenburg, *Islamische Baukunst in Ägypten* (Berlin 1966) 49, that the ogive began "in der frühesten buddhistischen Kunst Indiens, kam von dort nach dem zentralen Hochasien und von da nach dem Irak und Ägypten." This type of arch probably originated as a purely decorative form for gable ends in wooden structures; cf. a Kushan relief of the second century after Christ at Mathurā in John Rosenfield, *The Dynastic Arts of the Kushans* (Berkeley 1967) fig. 29. Small masonry pointed arches appear about the same time at Kauśambi; G. R. Sharma, "Kuṣāṅa Architecture with Special Reference to Kauśāmbi (India)," in *Kuṣāṅa Studies*, ed. G. R. Sharma (Allahabad 1968) 18-19, fig. 4 (3). Also of the second century is a pointed vaulted niche at the Buddhist monastery of Takht-i-Bāhi; Benjamin Rowland, *The Art and Architecture of India*, ed. 3, (Baltimore 1967) pl 42a. Alexander Cunningham, *Mahābodhi* (London 1892) 85, believed that the spectacular pointed arches and vaulting at this greatest of Buddhist shrines are later than the original Kushan (second century) construction; the evidence, as indicated by Rowland 98, 291, pl. 52b, is ambiguous. In any case the Gupta Hindu temple of the fifth century at Bhītārgāoṅ (Rowland fig. 20) with pointed vaulting antedates any known Iranian evidence of such construction; Rowland fig. 20 and J. P. Vogel, "The Temple of Bhītārgāoṅ, "*Archaeological Survey of India, Annual Report* (1908-1909) 5-16, pl. 3, 4.

[58] Arthur U. Pope, "Possible Iranian Contributions to the Beginning of Gothic Architecture," in *Beiträge zur Kunstgeschichte Asiens in Memoriam Ernst Diez* (Istanbul 1960) 20.

[59] Brandenburg (n. 57 above) 49.

[60] One of the earliest appearances in Egypt is in the shaft of the Nilometer (A.D. 866 or 861) built by an architect from Fergana; Pope (n. 58 above) 20.

[61] Cf. A. O. Citarella, "The Relations of Amalfi with the Arab World before the Crusades," *Speculum* 42 (1967) 299-312. Evidence of the pointed arch in Amalfi about 1000 has been available for more than three decades in the very dilatory restoration of the Old Cathedral, but has not been published. I myself saw some of the earliest discoveries in 1933.

and by 1071 a porch with pointed arches and pointed vaults graced Abbot Desiderius's new church at Monte Cassino.[62] Considering that the most remarkable monk there under Desiderius's abbacy was Constantine the African (died 1087), a native of North Africa who was the first great translator of Arabic science into Latin[63] and who dedicated his version of the *Pantegni* of 'Alī ibn 'Abbās (died 994) to Desiderius,[64] there is nothing surprising in the appearance of an architectural borrowing from Islam at that time and place.

Structurally the Monte Cassino porch was no more adventurous than its Near Eastern prototypes: it was, in Kenneth Conant's happy phrase, "a bit of chic."[65] The great technological advance involving the pointed arch occurred not in Italy but in Burgundy. In 1080 Abbot Hugh of Cluny visited Monte Cassino, and there either he or his engineers,[66] then working on the design of an enormous new church being planned for Cluny, realized that pointed arches and pointed vaults offered the key to solving the chief problems with which romanesque architects had been contending. As a result of their insight, the church at Cluny, begun in 1088 and effectively finished in 1120, contained 196 pointed arches with more in the high vault.[67] The new Cluny was the most conspicuous church of northern Europe. In 1130 Abbot Suger of the French royal abbey of Saint-Denis visited it. Between 1135 and 1144 he and his engineers produced at Saint-Denis what is usually regarded as the first true gothic church. In doing so they realized the full possibilities inherent in the novel Cluniac development of oriental architectural ideas.

Nothing is more characteristically and superbly medieval than Saint-Denis, and no monument of the twelfth century has been more often cited by historical meteorologists studying the cultural climate of that age. Yet an

[62] Kenneth J. Conant, *Carolingian and Romanesque Architecture, 800 to 1200* (Baltimore 1959) 223 and pl. 8 A, corrects and amplifies an earlier drawing published in conjunction with Henry M. Willard in *Speculum* 10 (1935) 144-146, pl. 1; see their article, below 203-209.

[63] See Paul O. Kristeller, "The School of Salerno," *Bulletin of the History of Medicine* 17 (1954) 151-153.

[64] The text of the dedication is best found in Constantine the African, *L'arte universale della medicina* (*Pantegni*) 1.1, ed. Marco T. Malatto and Umberto de Martini (Rome 1961) 37.

[65] Kenneth J. Conant, *A Brief Commentary on Early Medieval Church Architecture* (Baltimore 1942) 8.

[66] Jacques Stennon, "Hézelon de Liège, architecte de Cluny III," in *Mélanges offerts à René Crozet*, ed. P. Gallois and Y. J. Riou (Poitiers 1966) 1.345-358 fails to prove his thesis: the extant evidence indicates that Hezelo may have been the major fund-raiser, not the architect, of the great church at Cluny.

[67] Kenneth J. Conant, "The Pointed Arch: Orient to Occident," *Palaeologia* (Osaka) 7 (1959) 36.

essential quality of its achievement has been overlooked: that in creating this glorious synthesis of engineering and esthetics, the black-robed Benedictines of Saint-Denis were the vigorous heirs of russet-garbed Buddhist monks in India a millennium earlier.[68]

Apart from students of folklore—which of all the humanistic disciplines has the broadest geographic and sociological horizons—medievalists have been reluctant to recognize cultural connections over such distances. On its slow journey from India, however, the ogive travelled in much company. Since the middle of the eleventh century, shortly before Desiderius built his porch, a Christianized life of Buddha, transmitted from Sanskrit to Arabic, perhaps through a Manichean Turkic version, and thence through Georgian and Greek into Latin, had been circulating widely in the West, with the result that Buddha, slightly masked[69] as the ascetic Indian prince Josaphat (that is, Boddhisatva), was increasingly revered as a saint whose festival is on 27 November.[70] About 1110, as Cluny was approaching completion, the Arabic-speaking Jewish convert Petrus Alfonsi included in his very popular *Disciplina clericalis* many of the animal fables of the *Pañcatantra* which had made their way from Sanskrit through Pahlavi and Syriac into Arabic.[71] In 1138, while Saint-Denis was rising, Indic numerals appeared for the first time in the West on a coin of Roger II of Sicily.[72] In 1149, five years after Saint-Denis was finished, Robert of Chester, revising some Arabic astronomical tables to the coordinates of London, introduced into Latin

[68] So far as I can discover, no one in the Middle Ages spoke of gothic engineering as providing economies in construction. The proof that many were in fact aware of this virtue of the new style—which was quickly lost in the immense new elaboration of gothic carving, clustered pillars and the like—is that the austere order of Cistercians who hotly denounced the extravagances of Cluniac churches and permitted no towers or ornaments of any sort on their own (see François Bucher, "Cistercian Architectural Purism," *Comparative Studies in Society and History*, 3 [1960] 89-105) after an intial hesitation seized upon the gothic way of building and spread it over Europe. Hanno Hahn, *Die frühe Kirchenbaukunst der Zisterzienser* (Berlin 1957) 254-258, who holds that the usual image of the Cistercians as "missionaries of the gothic" is overdrawn, fails to distinguish gothic structure from gothic embellishment. The early Cistercian gothic churches achieved the stark beauty of pure functionalism in a period when the dominant trend of gothic towards lavish ornament was developing, as Hahn correctly indicates, in the cathedrals of northern France.

[69] The first Western suspicion that Josaphat was Buddha appears in a gloss inserted into a text of Marco Polo about 1446; cf. A. C. Moule and P. Pelliot, *Marco Polo: Description of the World* (London 1938) 1.410.

[70] See David M. Lang's introduction to [St. John Damascene] *Barlaam and Joasaph* (Cambridge, Mass. 1967).

[71] *Disciplina clericalis*, ed. Alfons Hilka and Werner Söderhjelm (*Acta Societatis scientiarum fennicae* 38.4, Helsingfors 1911); Haim Schwarzbaum, "International Folklore Motifs in Petrus Alfonsi's *Disciplina clericalis*," *Sefarad* 21 (1961) 267-299; 22 (1962) 17-59, 321-344; 23 (1963) 54-73.

[72] Lynn Thorndike, "The Relation between Byzantine and Western Science and Pseudo-Science before 1350," *Janus* 51 (1964) 18.

the Indian trigonometric concept of the sine function (in Latin *sinus*),[73] which word, by a series of mistranslations and transliterations, is derived from the Sanskrit term for sine.[74] In 1154, a decade after the completion of Saint-Denis, a Cistercian monk of Clairvaux named Lawrence who was returning from Rome, with the aid of two boys and many saints drove a herd of ten Indic buffaloes—creatures never before seen in northern parts—across the Alps to Clairvaux where they promptly propagated and spread "ex eo loco per multas jam provincias."[75] The inspired engineering of the new gothic architecture was part of a larger pattern of Eurasian relationships which was far more than technological and which we have scarcely begun to understand.

Medieval Europe's capacity for gathering and expanding insights and elements drawn from the most distant and unexpected sources is a major characteristic of its culture which, on the one hand, is underscored by the study of technology and which, on the other hand, helps to explain the vigor of that technology. Despite difficulties of travel and communication, medieval European technicians had autennae delicately adjusted to catch the vibrations of every promising novelty, however distant. If since 1500 global technology has become increasingly that of the Occident, the reason is not only the inventiveness of medieval Europe but also the fact that by 1498, when Vasco da Gama reached Calicut, Europe had already absorbed and adapted to its use a great part of the other technologies of Eurasia. The culture of the medieval West was unique in the receptivity of its climate to transplants, although the verbal statements of medieval men would not lead us to such an estimate of their mentality.

What a society does about technology is influenced by casual borrowings from other cultures, although the extent and uses of these borrowings are reciprocally affected by attitudes towards technological change. Fundamentally, however, such attitudes depend upon what people in a society think about their personal relation to nature, their destiny, and how it is good to act. These are religious questions.

IV

The most thoughtful analysis of the presuppositions of Western technology has been provided by a medieval historian, Ernst Benz[76] of the University of Marburg. Study of Buddhism and personal experience of it in Japan

[73] Charles H. Haskins, *Studies in the History of Mediaeval Science*, ed. 2 (Cambridge, Mass. 1927) 123.

[74] H. Hankel, *Zur Geschichte der Mathematik in Altertum und Mittelalter*, ed. 2 (Hildesheim 1965) 280-281.

[75] Herbertus, *De miraculis* 2.30, PL 185.1341.

[76] "Fondamenti cristiani della tecnica occidentale," in *Technica e casistica*, ed. Enrico Castelli (Rome 1964) 241-263. A more popular presentation of his thesis is contained in the chapter, "The Christian Expectation of the End of Time and the Idea of Technical

—especially of the anti-technological impulses in Zen[77]—led him to find the genesis of Europe's technological advance in Christian beliefs and attitudes. The Christian Creator God, the architect of the cosmos and the potter who shaped man from clay in his own image, commands man to rule the world and to help to fulfill the divine will in it as a creative cooperator with him. History, far from being cyclical as it is in most religions, in Christianity is unique and unilinear; it is accelarating toward a spiritual goal; there is no time to lose; therefore, work, including manual work, is an essential and pressing form of worship. Moreover, matter was created for a spiritual purpose and it is neither to be transcended nor despised: the dogmas of the incarnation and of the resurrection of the flesh vouch for this. The sense that intelligent craftsmanship is shown in the world's design, and that we participate in the divine by being ourselves good artisans; the conviction that we follow God's example when we use substance for righteous ends, that time must be saved because every moment is a unique psychic opportunity: these are characteristics of the Judeo-Christian view of reality and of destiny. They are alien to all the other major religions except Islam, which belongs to the same spiritual phylum, and possibly Zoroastranism, a related species. Since in Hellenistic times and in China there were notable and sometimes rapid advances in engineering, Christianity obviously is not essential to technological dynamism. What Benz suggests, nevertheless, is that Christianity provided, historically in Europe, a set of assumptions, a cultural climate, unusually favorable to technological advance.

One may expand Benz's thesis somewhat. In 1956 Robert Forbes[78] of Leyden and Samuel Sambursky[79] of Jerusalem simultaneously pointed out

Progress," in his *Evolution and Christain Hope: Man's Concept of the Future from the Early Fathers to Teilhard de Chardin* (Garden City 1966) 121-142.

[77] More research is needed on the relations of Buddhism to technology: the former is divided into many sects, which may have different influences. In the sixteenth century the Japanese were eager and metallurgically equipped to adopt European types of firearms from the Dutch and Portugese; see Brown's article, n. 54 above. In sharp contrast to the Chinese, in the nineteenth century they rapidly absorbed Western technology. Both in the sixteenth and the nineteenth centuries Buddhism would seem to have played a greater psychic role in Japan than in China. The considerable literature on the differential reactions of China and Japan towards Western technology (see particularly the thoughtful essay of Marion J. Levy, Jr., "Contrasting Factors in the Modernization of China and Japan," *Economic Development and Cultural Change* 2 [1953] 236-253) generally concludes that the essence of the divergence lies in the mentality of the aggressive feudal aristocracy of Japan as compared to that of the Confucian bureaucracy of China. Confucianism, however, cannot be considered inherently anti-technological: the Sung dunasty, the great age of Neo-Confucianism, produced achievements in engineering in which Confucian scholars participated; cf. Joseph Needham, Wang Ling, and Derek J. Price, *Heavenly Clockwork: The Great Astronomical Clocks of Medieval China* (Cambridge, Eng. 1960) esp. 129-130.

[78] "Power," in *History of Technology*, ed. Charles Singer et al. (Oxford 1956) 2.606.

[79] *The Physical World of the Greeks* (New York 1956) 241. As is emphasized by W. J.

that Christianity, by destroying classical animism, brought about a basic change in the attitude toward natural objects and opened the way for their rational and unabashed use for human ends. Saints, angels and demons were very real to the Christian, but the *genius loci*, the spirit inherent in a place or object, was no longer present to be placated if disturbed.

Undoubtedly also, there has been an element of Christian compassion motivating the development of power machinery and labor-saving devices: as early as the sixth century an abbot in Gaul, troubled by the sight of his monks grinding grain in querns, built a water mill, "hoc opere laborem monachorum relevans."[80] Pity, however, is not exclusively a Christian virtue: Antipater's pagan poem, which is our second document for the existence of water mills in the ancient Mediterranean, celebrates the new machine as harnessing the water nymphs to save the aching backs of slave women.[81]

Benz has pointed a direction by which historians can make intelligible the technological dynamism of the Middle Ages. His hypothesis, however, is defective because he fails to recognized that the Greek church held the fundamentals of the Christian faith as ardently as did the Latin, yet after Kallinikos's invention of Greek fire just before 673[82] the highly civilized regions dominated by Eastern Orthodoxy were unadventurous in technology. If, as Benz believes, the vigor of Western medieval technology is an expression of religion, the sources of that dynamism must be found less in the broader aspects of Christianity than in the distinctive qualities and moods that differentiate Occidental from Byzantine Christian piety.

It may seem ludicrous to claim that the distillation of alcohol,[83] the trebuchet,[84] the functional button,[85] the suction pump,[86] the wire-drawing

Verdenius, "Science grecque et science moderne," *Revue philosophique* 152 (1962) 329-331, lower-class animism was sophisticated into a deification of the cosmos among the educated which made intellectuals as reluctant as artisans to use mechanics to compel nature to submit to human wishes.

[80] Gregory of Tours, *Vitae patrum* 18.2, ed. B. Krusch, MGH *Script. rer. merov.* 1 (Hanover 1885) 735.

[81] *Anthologia palatina graeca*, 9.418, ed. H. Stadtmueller (Leipzig 1906) 3.402-403.

[82] M. Mercier, *Le feu grégois* (Paris 1952) 14.

[83] Ca. 1150, in Italy; cf. Robert J. Forbes, *A Short History of the Art of Distillation* (Leyden 1948) 87-89.

[84] Ca. 1199; *Med. Techn.* 102 n. 5.

[85] Some buttons were used in Central Asia, Iran, and Greece in Antiquity for ornament, but apparently not for warmth. The functional button, fastening overlapping edges of cloth, is first found ca. 1235 on the "Adamspforte" of Bamberg cathedral, and in 1239 on a closely related relief at Bassenheim; cf. Erwin Panofsky, *Deutsche Plastik des 11. bis 13 Jahrhundert* (Munich 1924) pl. 74; H. Schnitzler, "Ein unbekanntes Reiterrelief aus dem Kreise des Naumburger Meisters," *Zeitschrift des Deutschen Vereins für Kunstwissenschaft* 1 (1935) 413 fig. 13.

[86] Ca. 1440, in Italy; Sheldon Shapiro, "The Origin of the Suction Pump," *Technology and Culture* 5 (1964) 566-574.

mill,[87] and the myriad other medieval inventions are ultimately *gesta Christi* where Christ was worshiped with a Latin accent. Nevertheless, the processes of the human mind are so curious that our judgment of the forces that produced Western technology must be based upon what appear to be the relevant facts even when the result contains elements of irony. Since people are often comic, so also history may be.

Historians of spirituality have long been aware of a basic contrast of tonality between the two great segments of Christendom which surely affected the development of their respective technologies. The Greeks have generally held that sin is ignorance and that salvation comes by illumination. The Latins have asserted that sin is vice, and that rebirth comes by disciplining the will to do good works. The Greek saint is normally a contemplative; the Western saint, an activist.

This difference, largely subliminal, emerges clearly in the iconography of the Creator God. During the first Christian millennium, in both East and West, God at the moment of creation is represented in passive majesty, actualizing the cosmos by pure power of thought, Platonically. Then, shortly after the year 1000, a Gospel book was produced at Winchester which made a great innovation: inspired by Wisdom 11.20, "Omnia in mensura et numero et pondere disposuisti," the monastic illuminator showed the hand of God—now the master craftsman—holding scales, a carpenter's square, and a pair of compasses.[88] This new representation spread and, probably under the influence of Proverbs 8.27, "certe lege et gyro vallabat abyssus," the scales and square were eliminated leaving only the compasses—the normal medieval and renaissance symbol of the engineer—held in God's hand. This tradition, which culminated in William Blake's "Ancient of Days,"[89] was never adopted in the Eastern Church. It was the perfect expression of Western voluntarism, but it violated Greek intellectualist sensibilities about God's nature.

As medieval machine design became more intricate, God the builder developed into God the mechanic. The term "machina mundi" is at least as old as Lucretius, but was rejected on religious grounds by Arnobius Afer. By the thirteenth century, however, it was commonly used by Latin clerical scientists and had strongly affirmative overtones.[90] The first to foreshadow the Deist concept of the clockmaker God was Nicole Oresme who died as

[87] The first secure evidence is a drawing, 1489-1494, by Dürer; Friedrich Lippmann, *Zeichnungen von Albrecht Dürer* 1 (Berlin 1873) pl. 4.

[88] Erwin Panofsky and Fritz Saxl, *Dürer's "Melencolia I"* (Leipzig 1923) 67 n. 3.

[89] A. Blunt, "Blake's 'Ancient Days': The Symbolism of the Compass," *Journal of the Warburg Institute* 2 (1938-39) 53-63.

[90] *Med. Techn.* 174.

bishop of Lisieux in 1382. He proposed that, to prevent the celestial spheres from accelerating as they turned, the Creator had provided the equivalent of a clock's escapement mechanism to keep them rotating at a constant speed.[91] The subsequent success of the simile indicates the direction of Europe's thought about God, nature and man.

Students of the history of scriptural exegesis are as helpful as art historians in laying bare structures of values that lie so deep that they are not often verbalized explicitly. For our purposes the varying treatments of Luke 10.38-42, the Mary-Martha episode, are full of meaning. Since the time of Origen at least, the Greek East has invariably assumed that Martha represents the active and Mary the contemplative life, and that Christ's rebuke to Martha validates the superiority of the contemplative over the active.[92] In the West, however, a quite different style of exegesis emerges early. Saint Ambrose, once himself a Roman official and now a bishop, feels that the sisters of Bethany are symbols of *actio* and *intentio*: both are essential, and one cannot rightly be considered better than the other.[93] Then Saint Augustine, a revolutionary in so many ways, entirely subverts the Greek exegesis, the structure of values inherent in it, and, one must add, the literal meaning of Christ's words. To him, Mary and Martha represent two stages in the perfect life: Martha, the life of the soul in time and space; Mary, in eternity. "In Martha erat imago praesentium, in Maria futurorum. Quod agebat Martha, ibi sumus; quod agebat Maria, hoc speramus."[94] Yet, since we mortals dwell in time and not eternity, we must be Marthas, troubled about many things, rather than Marys.

The Middle Ages grew increasingly restless over this pericope. In the middle of the twelfth century Richard of Saint Victor, while acquiescing in Christ's praise of Mary's choice on the Augustinian ground that contemplation anticipates our heavenly condition, nevertheless shows by his phrasing where

[91] "Excepté la violence, c'est aucunement semblable quant un homme a fait un horloge et il le lesse aler et estre meu par soi. Ainsi lessa Dieu les cielz estr meuz continuellment"; Nicole Oresme, *Le livre du ciel et du monde* 2.2, ed. Albert D. Menut and Alexander L. Denomy (Madison 1968) 288.

[92] T. Camelot, "Action et contemplation dans la tradition chrétienne," *La vie spirituelle* 78 (1948) 275. That the cultural climate of Semitic Christianity was in this particular closer to that of the West than of the Greek world is indicated by the fact that Saint Ephraem Syrus, writing in Syriac and almost uninfluenced by Platonic prejudices, adopts elaborate stratagems to avoid valuing Martha's activism below Mary's contemplation: see I. Hausherr, "Utrum sanctus Ephraem Mariam plus aequo anteposuerit," *Orientalia christiana* 30 (1933) 153-163.

[93] D. A. Csànyi, "Otima pars," *Studia monastica* 2 (1960) 56-57.

[94] Saint Augustine, *Sermo* 104.4, cited by A. M. de la Bonnardière," Marthe et Marie, figures de l'église d'après saint Augustin. " *La vie spirituelle* 86 (1952) 425.

his own sympathies lie: "Intenta erat Maria quomodo pasceretur a Domino; intenta erat Martha quomodo pasceret Dominum. Haec convivium parat Domino; in convivio Domini illa jam delectatur."[95] Two hundred years later the European affirmation of the primacy of action reaches almost absurd heights in one of Meister Eckhart's vernacular sermons on this text.[96] Martha, the older and wiser sister, fears lest the adolescent Mary may become so ecstatic in contemplation that she will not mature spiritually by realizing that action is essential to holiness. Christ's apparent rebuke to Martha and praise for Mary are, in Eckhart's opinion, the exact reverse: they are his way of telling the perceptive Martha not to be troubled by Mary's sentimental condition; she will grow out of it. The Greek Church could not have produced, much less tolerated, such a sermon. The mood of activism which Eckhart reflects surely fostered technological growth in the West.

Some degree of respect for manual labor is, along with activism, integral to massive technological development. It was generally lacking, at least among the literate classes, in the Greco-Roman world.[97] The Jews, however, considered God's command to labor six days of the week to be as binding as that to rest on the seventh.[98] In the late third century, massive conversions of pagans to Christianity around the eastern Mediterranean threatened to corrupt the Church, and quite naturally a few zealots tried to purify it by returning to its primitive, that is Jewish, tradition. One result was monasticism, which from the beginning asserted the originally Jewish thesis that work is worhip, indeed, that it is an essential kind of worship. With considerable constancy the monks of both East and West continued through the Middle Ages to work with their hands.[99] Many of them likewise were

[95] Richard of Saint Victor, *Liber exceptionum* 2.14.5, ed. Jean Chatillon (Paris 1958) 504.

[96] *Deutsche Predigten und Traktate*, ed. and trans. Josef Quint (Munich 1955) 280-289.

[97] Cf. Moses I. Finley, "Technical Innovation and Economic Progress in the Ancient World," *Economic History Review* 18 (1965) 44. Before the impact of the monastic ethic was fully felt, moral aversion to hard work was still found in the Christian West; see my "The Iconography of *Temperantia* and the Virtuousness of Technology" in *Action and Conviction in Early Modern Europe: Essays in Memory of E. H. Harbison*, ed. T. K. Rabb and J. E. Seigel (Princeton 1969) 198-199.

[98] S. Kalischer, "Die Wertschätzung der Arbeit in Bibel und Talmud," in *Judaica: Festschrift zu Hermann Cohens siebzigstem Geburtstage* (Berlin 1912) 583.

[99] The Greek ascetics may, in fact, have been even more steadily devoted to manual labor than the Latin: see P. McNulty and B. Hamilton, "Orientale lumen et magistra latinitas: Greek Influences on Western Monasticism (900-1100)," in *Le millénaire du Mont Athos, 963-1963* (Chevetogne 1963) esp. 187, 192, 212. One reason for this was that monastic reform movements in the West, combating what was regarded as corruption arising from worldly entanglements, elaborated Benedictine liturgies from the ninth century onward to the point where there was little time left for labor; cf. P. Schmitz, "L'influence de saint Benoît d'Aniane dans l'histoire de l'Ordre de saint Benoît," *Settimane di studio*

well read; indeed, for centuries monks were the most learned men of the West. This combination of education with pratical work would seem theoretically, by joining head and hand, to provide communities in the monasteries where technological innovation would thrive. Yet the contrast in this respect between the sons of Saint Basil and those of Saint Benedict is notable.

One voice of dissent in the West may illuminate the basic situation. The sole instance in Christian monasticism of an antipathy toward the mechanic arts appears in *Scholica graecarum glossarum* by Martin of Laon (died 875) who derives *mechanicus* not from μηχανικός but from μοικός "adulterer": "Moechus est adulter alterius thorum furtim polluens. Inde a maecho dicitur mechanica ars, ingeniosa atque subtilissima et paene quomodo facta vel administrata sit invisibilis in tantum, ut etiam visum conspicientium quodam modo furetur, dum non facile penetratur eius ingeniositas."[100] Martin was an immigrant Irish monk. The rule of Saint Columba is the only monastic code of East or West in which manual labor is regarded as pure penance for sin, unconnected with prayer and praise.[101] Moreover this etymology offered by Martin is the only Western occurence of the Heronic concept of technology as primarily producing machines to deceive and awe the populace: one among several indications of connections between early Christian Ireland and the Greek culture of Alexandria.[102] Yet this Irish mediation

del Centro Italiano di Studi sull'Alto Medioevo 5: *Il monachesimo* (Spoleto 1957) 401-415. The result was the development of *conversi*, lay brothers designated primarily for manual labor and distinguished from the choir monks whose prime duty was *opus Dei*. K. Hallinger, "Woher kammen die Laienbruder?", *Analecta sacri ordinis cisterciensis* 12 (1956) 38, shows that such *conversi* were found in many Western abbeys in the eleventh century, but not at Cluny before 1100. Greek monasticism never developed such specialized worker monks; cf. P. de Meester, *De monachico statu iuxta disciplinam byzantinam* (Vatican 1942) 93-95.

[100] Max L. W. Laistner, "Notes on Greek from the Lectures of a Ninth-Century Monastery Teacher," *Bulletin of the John Rylands Library* 7 (1922-1923) 439. Martin's etymology was remembered by Hugh of Saint Victor, *Epitome Dindimi in philosophiam*, ed. Roger Baron, *Traditio* 11 (1955) 112, who speaks of *mechanica* as "adulterina" but notes (p. 111) that "de interpretationibus vero nominum pauca deducimus."

[101] E. Delaruelle, "Le travail dans les règles monastiques occidentales du IVe au IXe siècle," *Journal de psychologie normale et pathologique* 41 (1948) 61.

[102] Early in the seventh century an Alexandrian merchant took a ship loaded with grain to Christian Celtic Cornwall and returned to Egypt with a cargo of tin: Leontius, *Vita sancti Joannis Eleemosynarii* (d. 616), PG 93.1624-1625. About 800 the *Martyrology of Oengus the Culdee*, ed. Whitley Stokes (London 1905) 86, 80, remembers an Egyptian monk, who from the context seems to have died in Ireland. A litany of the tenth-eleventh century remembers seven Egyptian monks buried at Disert Uilaig; Charles Plummer, *Irish Litanies* (London 1925) 64. These were presumably part of the massive emigration of the Greek Orthodox elite from Egypt resulting from the Persian and Muslim conquests in the early seventh century, on which see my *Latin Monasticism in Norman Sicily* (Cambridge, Mass.

of Greek secular alienation from labor and technology was to have small influence in the West.

Part of the reason for this differential development between Latin and Greek monasticism lies in the fact that in the Byzantine world a literate laity continued to preserve the worldly aspects of high culture, with the result that Greek monks felt able to devote themselves more exclusively to sacred studies. In the West, the level of civilization for a time sank so disastrously that the monks assumed almost sole responsibility for preserving and encouraging all aspects of culture, profane as well as churchly.[103] Thus in the Occident monks tended to be more deeply involved in secular matters than in the East. The Slavic and Germanic regions into which the missionary monks of each Church penetrated were equally primitive. The Greek evangelists were very theological in their emphasis, and their labors were almost entirely religious. The Benedictines, however, concerned themselves less with doctrine than with ethics, and carried with them not merely a new religion but also new practical arts.[104]

1938, repr. 1968) 16-26. Most commentators on Egyptian influence in Ireland have supposed that it was transmitted at second hand through abbeys in southern Gaul. However, Margaret Schlauch, "On Conall Corc and the Relations of Old Ireland with the Orient," *Journal of Celtic Studies* 1 (1950) 152-166, has collected literary materials known from Coptic, Ethiopic, and Christian Arabic sources, but resting on vanished Greek writings, which appear in Ireland long before they are found elsewhere in Europe. Miss Schlauch misunderstands the nature of the seventh-century migration from Egypt: it consisted not of Monophysite Copts, who would have found the West inhospitable, but of Melchite Greeks fleeing Coptic hatred.

[103] Benedictine libraries often contained a considerable group of secular works; cf. C L. W. Laistner, *Thought and Letters in Western Europe, A.D. 500 to 900* (Ithaca 1957) 228-235. The only regional survey of Greek monastic libraries known to me—that made in 1457 of the seventy-eight foundations in Calabria before there is any indication that their holdings were being looted by neo-Hellenic enthusiasts from the North—lists some sixteen hundred MSS of which only five are secular: two Homers (one a fragment), the *Hecuba* of Euripides, a part of Aristophanes, and Galen's treaise on medications; moreover, of these the four literary MSS are found in two abbeys, Seminara and Mesiano, which were no more than twenty miles apart; see *Le "Liber visitationis" d'Athanase Chalkeopoulos (1457-1458)*, ed. M. H. Laurent and A. Guillou, Studi e testi 206 (Vatican 1960) 47, 107, 111.

[104] See the provocative essay of Richard E. Sullivan, "Early Medieval Missionary Activity: A Comparative Study of Eastern and Western Methods," *Church History* 22 (1954) 17-35. Byzantine lack of interest in technological advance infected the waters with which their Slavic converts were baptized. Novgorod, for example, was a great and free republic of merchants in constant commerce with the west; one might expect, on sociological grounds, technological movement there. Yet, on the basis of recent excavations in the city, Michael W. Thompson, *Novgorod the Great* (London 1967) xvii, remarks that "In the tenth century there was perhaps little to choose between the two, but already in the twelfth century Russian and western societies were widely separated, because the former avoided innovation and the latter welcomed it. We do not appreciate how innovating western medi-

This monastic technical tradition finds its greatest written expression in *De diversis artibus* produced by a theologically sophisticated and technologically learned German Benedictine, Theophilus, in 1122-1123.[105] It is a religiously motivated codification of all the skills available for the embellishment of a church, from the enameling of chalices and the painting of shrines to the making of organ pipes and the casting of great bells for the tower. In Theophilus's mechanisms the first flywheels appear; he is the first to record a new and cheaper way of making glass, which largely accounts for the expansion of glazed windows in his time; he is the first to mention a wire-drawing plate and likewise the first to describe the tinning of iron by immersion,[106] a technique that continued in use until the Japanese capture of Malaya in 1941 caused such a scarcity of tin elsewhere that the electrolytic process was developed.

Theophilus was not exceptional in his interests. In his contemporary life of Saint Bernard, Abbot Arnold of Bonneval pictures the rebuilding of Clairvaux in 1136 without mentioning the church but with a delighted account of all the abbey's waterpowered machines for milling, fulling, tanning, blacksmithing, and other industries.[107] Another quite independent monastic

eval society was until we can put it beside a part of Europe which was virtually static." The judgement is just in relation to technology, but Novgorod proved itself very original in painting and the forms, as distinct from the structural methods, of architecture.

[105] *De diuersis artibus*, ed. C. R. Dodwell (London 1961). Cyril Stanley Smith and John G. Hawthorne, *On Divers Arts: The Treatise of Theophilus* (Chicago 1963) have provided an excellent English translation and learned notes on the basis of Dodwell's revised text. For the date, see my "Theophilus redivivus," *Technology and Culture* 5 (1964) 226-230. Benoît Lacroix, "Travailleurs manuels du moyen âge roman: leur spiritualité," in *Mélanges Crozet*, (n. 66 above) 1.523-529, believes that in the twelfth century the Benedictine sense of religious dedication in labor—at least in the building of churches—spread to the laity. There is danger of exaggeration: there is exhilaration simply from participating in great works. A quatrain of 1110-1120 inscribed on the sarcophagus of Buschetto, architect of the new cathedral at Pisa (which was as much a product of civic pride as of faith) indicates that Buschetto was admired more for his engineering skill than for his pious construction or its beauty:

Quod vix mille boum possent iuga iuncta movere,
Et quod vix potuit per mare ferre ratis,
Busketi nisu quod erat mirabile visu,
Dena puellarum turba levabit onus.

Cited by Craig B. Fisher, "The Pisan Clergy and the Awakening of Historical Interest in a Medieval Commune," *Studies in Medieval and Renaissance History* 3 (1966) 177 n. 92.

[106] Ernest S. Hedges, *Tin in Social and Economic History* (New York 1964) 107, 161.

[107] *S. Bernardi vita prima* 2.5.31, PL 185:285. "Abundantibus sumptibus, conductis festinanter operariis, ipse fratres per omnia incumbebant operibus. Alii cadebant ligna, alii lapides conquadrabant, alii muros struebant, alii diffusis limitibus partiebantur fluvium, et extollebant saltus aquarum ad molas. Sed et fullones, et pistores, et coriarii, et fabri, aliique artifices, congruas aptabant suis operibus machinas, ut scaturiret et prodiret, ubicumque opportunum esset, in omni domo subterraneis canalibus deductus rivus ultro ebulliens."

description of Clairvaux in the same period shows the same enthusiasms: the author is particularly taken by an automatic flour sifter attached to the flourmill; he makes a little monkish joke, saying that the stamps of the fulling mill have remitted the penalty for the sins of the fullers; then he thanks God that such machines can alleviate the oppressive labors of both man and beast; and at last he offers a picture of the abstract power of water flowing through the abbey seeking every task: "coquendis, cribrandis, vertendis, terendis, rigandis, lavandis, molendis, molliendis, suum sine contradictione praestans obsequium."[108]

Nor was the commitment of Western ascetics to holy labor confined to crafts and mechanized industry: it extended to major engineering. In 1248, for example, while giving the decayed abbey of Lorsch to a community of Premonstratensian canons, the archbishop of Mainz says of them: "Invenimus viros iuxta cor nostrum. . . . Hii etenim non tantum religionis immaculate et vite habent testimonium sancte sed eciam in viis parandis, aqueductibus extruendis, paludibus exsiccandis, quibus monasterium in illa vicina nimium pergravatur, et generaliter in arte mechanica exercitati sunt non modicum et periti."[109] Thus far no similar documents have been produced from the entire Orthodox Church.

The 1120s, in which Theophilius produced his *De diversis artibus*, witnessed a moment of change in Europe's attitude towards manual labor and technology. Theophilus himself was concerned solely with the dignity of the technical arts in the life of a monk. Some of his ascetic contemporaries made labor the prime act of religion: Abbot Rupert of Deutz (died 1130) rebukes fanatics who spurn liturgical worship and "qui in opere manuum fere totam spem suam ponunt."[110] But at that time the concept of "religion" was broadening and spreading from the monastic to the lay life, particularly through channels provided by the newly vitalized groups of regular canons.[111] It was spiritually essential to transfer dignity explicitly from monastic labor to labor in the world outside the cloister.

[108] *Descriptio positionis seu situationis monasterii Claravallensis*, PL 185.570-571. The fulling mill "pedes ligneos (nam hoc nomen saltuoso fullonum negotio magis videtur congruere) alternatim elevans atque deponens, gravi labore fullones absolvit: et si joculare quidpiam licet interserere seriis, peccati eorum poenas absolvit. Deus bone, quanta pauperibus tuis procuras solatia, ne abundantiore tristitia absorbeantur! Quanta poenitentibus poenae alleviamenta dispensas, ne laboris violentia nonnumquam fortassis opprimantur! Nam quot equorum dorsa frangeret, quot hominum fatigaret brachia labor, a quo nos sine labore amnis ille gratiosus absolvit?"

[109] *Acta imperii inedita*, ed. E. Winkelmann, 2 (Innsbruck 1885) 724 no. 1041.

[110] *In s. Benedicti regulam* 3.10, PL 170:517.

[111] See M. D. Chenu, "Moines, clercs, laïcs au carrefour de la vie évangélique (XII^e siècle)," *Revue d'histoire ecclésiastique* 49 (1954) 59-89.

This task was undertaken by the Victorines in Paris.[112] At the end of *De civitate Dei*, Saint Augustine discusses technology in a mood of complete ambivalence: he exclaims over the ingenuity and variety of the arts, but considers many of them "superfluas, immo et periculosas perniciosasque"; medicaments and skills of healing are cancelled by "tot genera venenorum, tot armorum, tot machinamentorum."[113] In the face of Augustine's vast authority, Hugh of Saint Victor, one of the most original minds of the Middle Ages and, like Theophilus, a German, very deliberately developed a new and affirmative attitude toward technology.

His first effort was made in the early 1120s in the form of a curious dialogue on the nature and scope of philosophy in which Hugh's alter ego is none other than Dindimus, the leader of the Indian Brahmins who had long been regarded in the West as "instinctive" Christians, living saintly lives without the grace of revelation.[114] His intent is clear: to provide a secular schematization of all human knowledge which, for the first time, includes the mechanic arts. On Hugh's behalf Dindimus argues vehemently against the purists who would narrow the concept of philosophy to exclude not only mechanics but also grammar and logic: "conati sunt scindere et lacerare corpus universum [philosophie] ne membra sibi coherent, quia pulchritudinem totius non viderunt."[115] The unity of philosophy arises from its function of remedying man's three basic defects: ignorance, vice, and physical weakness. Speculation provides truth; ethics aids virtue; technology supports our bodily needs; recently logic or semantics (including grammar) has been added to philosophy to give it clarity and elegance of expression.[116] Of these, *mechanica* is the least in dignity; yet it is integral to philosophy not as regards its practice but because of the wisdom inherent in it.[117]

In the later 1120s Hugh expanded and elaborated his concept of the nature and elements of philosophy in his influential *Didascalicon*: at least 88 manuscripts of it are extant, of which not fewer than 50 are of the twelfth and

[112] Peter Sternagel, *Die artes mechanicae im Mittelalter: Begriffs- und Bedeutungsgeschichte bis zum Ende des 13. Jahrhunderts* (Regensburg 1966). In disagreement with Benz, Maurice de Gandillac, "Place et signification de la technique dans le monde médiéval," in *Tecnica e casistica*, ed. Enrico Castelli (Rome 1964) 273 n. 7, correctly asserts the contrast between Saint Augustine's and the Victorines' positions toward technology.

[113] Augustini, *De civ. Dei* 22.24, *Corpus christianorum, series latina* 48 (Turnholt 1955) 848-849.

[114] Cf. George Boas, *Essays in Primitivism and Related Ideas in the Middle Ages* (Baltimore 1947) 140-151.

[115] Hugh of Saint Victor, ed. Baron (n. 100 above) 113, 115-116. It is significant that Dindimus is likewise Hugh's spokesman in his *De grammatica* (*ibid.* 92).

[116] *Ibid.* 110.

[117] *Ibid.* 111.

thirteenth centuries.[118] Between 1153 and 1162 Richard of Saint Victor, probably a Scot, in his widely read *Liber exceptionum*, repeated and reinforced Hugh's fourfold division of the intellectual life.[119] Naturally both Hugh and Richard recongnized that, in the hierarchical society of their day, inclusion of the mechanic arts in a total scheme of knowledge might not be cordially received, so they disclaimed any revolutionary intent. Things like architecture and agriculture are proper topics for theorizing by a philosopher, but the doing of them is different: "agriculturae ratio philosophi est, administratio rustici."[120] Nevertheless, by giving an unprecendented psychic dignity and speculative interest to the mechanic arts, the Victorines provided one of the theses for an egalitarian movement which, centuries later, spread eastward to destroy a great part of the less flexible Orthodox Church.

A development akin to the Benedictine and Victorine sense of the significance of technology was the increasing Western acceptance of mechanisms as aids to the spiritual life. The Church Fathers, both Greek and Latin, had passionately opposed the use of all musical instruments, including the organ.[121] While in Byzantium organs habitually graced secular ceremonies, the Greek Church forbade them in its liturgies, insisting that only the unaccompanied human voice can worthily praise God.[122] Yet in the later tenth century, in the cathedral at Winchester where, about the same time, the iconography of the Creator God holding scales, square, and compasses appeared, Benedictines installed the first giant organ: 70 men pumped 26 bellows supplying 400 pipes.[123] Before the invention of the mechanical clock the organ was the most complex machine. In sharp contrast to the East, great organs became integral in the West first to processions, interludes, and the like, but, by the middle of the twelfth century, they were admitted to the central act of divine service, the Mass.[124] A hundred years later, in the mystery plays

[118] Ed. Buttimer (n. 18 above) viii. For the study of this text the annotations by Jerome Taylor in his translation (New York 1961) are fundamental.

[119] Richard of Saint Victor (n. 95 above) 105-106.

[120] Hugh of Saint Victor, *Didascalicon* 1.4 (n. 18 above) 11; cf. Richard of Saint Victor, *Liber exceptionum* 4.23 (n. 95 above) 111.

[121] James McKinnon, "The Meaning of the Patristic Polemic against Musical Instruments," *Current Musicology* (1965) 69-82.

[122] Egon Wellesz, *History of Byzantine Music and Hymnography*, ed. 2 (Oxford 1961) 105-108; 366; cf. Jean Perrot, *L'orgue de ses origines hellénistiques à la fin du XIII^e siècle* (Paris 1965) 211 n. 5, 215.

[123] *Frithegodi monachi Breviloquium vitae beati Wilfredi, et Wulfstani cantoris Narratio metrica de sancto Swithuno* ed. Alistair Campbell (Zurich 1950) 69-70, lines 141-170.

[124] Edmund A. Bowles, "The Organ in the Medieval Liturgical Service" *Revue belge de musicologie* 16 (1962) 13-29. Even in the West no instrument save the organ was admitted to the Mass until the fifteenth century when trumpets began to announce the elevation of the Host; *idem*, "Were Musical Instruments Used in the Liturgical Service during the Middle Ages?", *Galpin Society Journal* 10 (1957) 40-56. This would indicate that, to the West, a higher degree of mechanization involved higher spirituality.

that by that time were presented outside the churches, an organ was the indispensable accompaniment of any representation of Paradise;[125] indeed, it became almost a symbol of Heaven.

In a separate building outside Hagia Sophia, Justinian placed a clepsydra and sundials, [126] but clocks were never permitted within or on Eastern churches: to place them there would have contaminated eternity with time. As soon, however, as the mechanical clock was invented in the West, it quickly spread not only to the towers of Latin churches but also to their interiors, often as astronomical planetaria designed to demonstrate visually the godly order of the cosmos.[127] Clearly, by the later Middle Ages, Western men felt psychically compatible with machines.

And not simply in religious contexts: the *Mittelalterliche Hausbuch*, a German manuscript of *circa* 1480, shows a garden enclosed in which garlanded youths and maidens are sporting about a fountain, while at the right, quite unobscured, appears the waterpowered force-pump that operates the fountain.[128] To the Middle Ages all the arts, including the mechanic arts, were a part of the good life—*teste* Leonardo. Modern suspicion of technology is a reversion to the ambivalence of Saint Augustine.

The earliest indication that men thought advancing technology to be an aspect of Christian virtue appears in the Utrecht *Psalter*, illuminated near Rheims *circa* 830, almost certainly by a Benedictine monk. The illustration of Psalm 63 (64) shows an armed confrontation between a small body of the Righteous, led by King David himself, and a distressingly larger host of the Ungodly. In each camp a sword is being sharpened conspicuously. The Evildoers are content to use an old-fashioned whetstone. The Godly, however, are employing the first crank recorded outside China to rotate the first grindstone known anywhere.[129] Obviously the artist is telling us that technological advance is God's will.

[125] Henri Lavoix, "La musique au siècle de Saint Louis," in Gaston Raynaud, *Recueil de motets français des XII^e et XIII^e siècles* (Paris 1883) 2.351.

[126] E. H. Swift, *Hagia Sophia* (New York 1940) 180.

[127] *Med. Techn.* 124-125.

[128] *Das Mittelalterliche Hausbuch*, ed. H. T. Bossert and W. F. Storck (Leipzig 1912) pl. 31-32. Edgar Wind, *Pagan Mysteries in the Renaissance* (London 1958) 96, notes that renaissance emblem books place "next to the classical columns and sirens, diamonds and laurels, salamanders, porcupines and unicorns . . . the new waterwheels, bellows, catapults, rockets, bombards and barbacanes. . . . Nature is man writ large; hence if forces in nature produce miraculous effects when they are harnessed, collected and propitiously released, they can set an example for the forces in man."

[129] *The Utrecht Psalter*, ed. Ernest DeWald (Princeton, 1932) pl. 58. I am grateful to Bruce Spiegelberg of Colby College for introducing me in 1966 to the total implication of this miniature, although as early as *Speculum* 15 (1940) 153 I had noted its purely mechanical novelties.

About 1450 European intellectuals began to become aware of technological progress not as a project (as indicated above, this came in the late thirteenth century) but as an historic and happy fact, when Giovanni Tortelli, a humanist at the papal court, composed an essay listing, and rejoicing over, new inventions unknown to the ancients.[130] At almost that moment the artists of Burgundy reaffirmed the thesis of the illuminator of the Utrecht *Psalter* that an advancing technology is morally salutary: they clothed Temperance, who had displaced Charity as the chief Virtue, with major symbols of late medieval inventiveness. On her head she wore a mechanical clock, produced some 120 years earlier; in her right hand she held eyeglasses, invented, as we have noted (above, 174) in the 1280s as the greatest boon to the mature and presbyopic intellectual; she stood on a tower windmill, which first appeared in the 1390s and which was the most spectacular power machine of that era.[131] To the artists who painted those pictures, and to their patrons —clerical, aristocratic and burgher—it was axiomatic that man was serving God by serving himself in the technological mastery of nature. Because medieval men believed this, they devoted themselves in great numbers and with enthusiasm to the process of invention.

Probably there were forces other than the religious which stimulated technological progress during the Middle Ages. The tradition of illustrated calendars has been secular. Their usual pattern from Roman times until the ninth century showed the months as static personifications holding symbolic attributes. This convention continued unbroken in Byzantium. Among the Franks, however, by 830 a new form appeared which set the style for the rest of the Middle Ages in the West. The pictures now show active scenes: plowing, haying, the harvesting of grain, wood chopping, men knocking acorns from oaks so that pigs can eat them, pig slaughtering.[132] The new illustrations breathe a coerciveness towards nature which is, indeed, consonant with Christianity but which may have arisen independently. Man and nature are two things, and man is master. Technological aggression, rather than reverent coexistence, is now man's posture toward nature.

Such aggression is the normal Western Christian attitude toward nature.[133] It may be that the emergence of this stance in the Carolingian age can be

[130] Alex G. Keller, "A Renaissance Humanist Looks at 'New' Inventions: the Article 'Horologium' in Giovanni Tortelli's *De orthographia*," *Technology and Culture* 11 (1970) 345-365.

[131] See my "Iconography of *Temperantia*" (n. 97 above).

[132] Henri Stern, *Le calendrier de 354* (Paris 1953) 356-357, and his "Poésies et représentations carolingiens et byzantins des mois," *Revue archéologique* 46 (1955) 164-166.

[133] The brief effort of Saint Francis to institute a democracy of all creatures was quickly terminated; cf. my "The Historical Roots of Our Ecologic Crisis," *Science* 155 (1967) 1203-1207, reprinted in my *Machina ex Deo: Essays in the Dynamism of Western Culture* (Cambridge, Mass. 1968).

explained apart from religion. Slightly before that time a basic change in agricultural methods had occurred in Northern Europe,[134] especially between the Loire and the Rhine, the heartland of the Frankish Empire. As early as the sixth century a new heavy plow began to spread from the Slavic East. It was far more efficient than the earlier light plow, but in place of a pair of oxen it normally required as many as eight, at least in newly cleared or sticky soil. No peasant owned eight oxen. The only way to power such a plow was to organize several peasants to pool their oxen, and to distribute plowed strips to them in proportion to their contribution. Previously land had been parceled to peasants in allotments sufficient to support a family equipped with two oxen and a light plow. The assumption was subsistence farming, plus enough surplus to pay rent. Now, however, with the heavy plow and the pooling of oxen the standard of land division was not human need but rather the capacity of a new power machine to till the soil. No more profound reversal of the peasant's relation to the land can be imagined. Formerly he had been part of nature; now he became an exploiter of nature. This alteration of attitudes might be guessed from the heavy plow itself. The iconography of the new calendars confirms the change. Neither the heavy plow nor the new style of calendar was known in Byzantium. In historical analysis, even of a very religious era, we cannot credit to religion, any more than to social relations or to any other single element in culture, absolute sovereignty over every aspect of life.

Nevertheless, it can scarcely be coincidence that the miniature in the Utrecht *Psalter* (816-834) which announces the morality of technological advance appeared simultaneously with, and in the same region as, the new style of calendar illustration (shortly before 830). It can scarcely be coincidence that in 826 Louis the Pious, who, as a contemporary remarks, was always eager to introduce to his realm "illa quae ante se inusitata erant,"[135] commissioned a Venetian priest named George, who had learned his skills presumably in Byzantium, to construct the first organ built in the medieval West for secular use in his palace,[136] and that from Aachen organs spread so quickly among the churches of South Germany that in 873 Pope John VIII wrote to Freising to secure both an organ and an organist.[137] Many forces shaped the Middle Ages, but of these the most powerful was religion.

The Semitization of the Greco-Roman *oikoumene*, which was accomplished in the fourth century by the victory of Christianity, marks the most drastic change of world view, both among intellectuals and among the common people, that, before our own time, has ever been experienced by a major

[134] *Med. Techn.* 39-78.

[135] *Vita Hludovici imperatoris* 40, ed. G. H. Pertz in MGH Script. 2.629.

[136] Perrot (n. 122 above) 276 seq.

[137] *Epp. Johannis VIII*, ed. E. Caspar in MGH Epistolae Karolini aevi 5.287.

culture. In China the indigenous Confucian-Taoist symbiosis was supplemented, not displaced, by Indic Buddhism. In India itself, Vedic Brahmanism slowly broadened and diversified to engulf all rivals except the Islamic intrusion that was totally unassimilable and which produced two societies in tragic confrontation. The Muslim annexation of the southern shores of the Mediterranean had no such result because, as Dante rightly saw (*Inferno* 28.22-31), Muhammad was a Judeo-Christian schismatic, not the founder of a new religion. In the regions thus overrun, the faith of the *Koran* confirmed basic Jewish views of the nature of time, the cosmos, and destiny which had already been spread at all levels of society by Christianity, Judaism's daughter.

The historians' habit of terminating what we call ancient history with the chaos of the third and early fourth centuries in which Christianity rose to dominance is not arbitrary: it recognizes a major alteration in the cultural climate of classical civilization. During the Middle Ages, both Eastern and Western, this new religion was the essential novelty and stimulus to innovation as well as to the decay of some forms of creativity which had thrived in the Greco-Roman world. It is, therefore, not surprising that so many religious and parareligious phenomena illuminate both the high rate of technological advance in the West, and, by contrast, its slow pace in the Byzantine world.

No great religion is an entirely uniform species. As Christianity spread it accommodated to local circumstances but it likewise developed spontaneous genetic mutations which as yet cannot be explained by Lamarckian adaptation to preexisting cultural climates: to an extraordinary degree, medieval religion created the climate of its environment. Part of the fascination of the Middle Ages lies in the observation, within an essential unity extending from Greenland to the Jaxartes, of the variety of cultural subclimates that can often be interpreted according to regional variants in the temper of religion. The slight but significant differences between Greek and Latin piety in this period help not only to make historically intelligible the accomplishment of the medieval West in technology but likewise to expose the psychic foundations of our modern technology which rests on that achievement.

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