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REVOLUTION IN TIME

Clocks and the Making of the Modern World

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In memory of teachers and mentors:
Arthur Harrison Cole
Donald Cope McKay
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under the Ming Dynasty in the fifteenth and sixteenth centuries, tells us that the morning audiences especially were vexatious, trying the patience of all the officials, who had to stand about in the open in bad weather as in good, but also of the emperor himself. Some remedy was found by reducing the frequency of these ceremonies; by permitting more appropriate dress on inclement days; and by allowing officials to be accompanied by umbrella bearers.[31] But all these were at best palliatives, and the whole system rested on the assumption that an official's time—all his time—belonged to the emperor, who could do with it (and waste it) as he pleased. The only way to correct this waste—which the Chinese could not even perceive as such—would have been to recognize time as private property. This was not a simple matter in a system where material possessions were also held on loan, as it were, from the emperor. The position of the mandarin was analogous to that of the apprentice: both were servants and their time was their master's. Under the circumstances, it was not easy to inculcate a sense of time as something to be tracked, measured, saved.

The K'ang-hsi emperor, who loved his Western clocks and sought to naturalize their manufacture in his palace, put the alternative very well; but then his time was his own:

> Red-capped watchmen, there's no need to announce the dawn's coming.
> My golden clock has warned me of the time.
>
> By first light I am hard at work,
> And keep on asking, "Why are the memorials late?"[32]

3 Are You Sleeping, Brother John?

IT IS ONE OF THE MISFORTUNES of scholarship that there was only one word for clock in the western Europe of the Middle Ages: *(h)orologium.* This generic term referred to every kind of timekeeper, from sundial to clepsydra to fire clock to mechanical clock. So when, in the late thirteenth century, we get an unprecedented spate of references to clocks, we cannot be sure *prima facie* what kind of device our sources are talking about. Not until the fourteenth century do we get our first unmistakable reports of mechanical clocks—namely, the tower clock with astronomical dial built by Roger Stoke for Norwich Cathedral (1321–1325); the highly complicated astronomical mechanism that Richard of Wallingford initiated at St. Albans around 1330 and that took thirty years to build; and then, completed in 1364, Giovanni de' Dondi's astronomical clock, the marvel of its time. The latter two were described by their authors in such detail that we have been able to make working copies in our own day.[1] (See Figure 7.)

The obscurity of what Needham calls "one of the most important turning-points in the history of science and technology" has been a fruitful source of legend and speculation. For some centuries it was common to attribute the clock to the canon Gerbert, who later became Pope Sylvester II (999–1003), the Pope of the

Millennium. Gerbert was indeed a savant in his generation. He had learned mathematics and astronomy in Spain, perhaps at the feet of Jewish and Muslim scientists there, and had taken away with him a fund of knowledge and technique that reemerged in the fourteenth century with the work of Richard of Wallingford and Giovanni de' Dondi. The historian and monk Richer (tenth century), who was one of Gerbert's students, tells us that his master built a globe, also an armillary sphere for the planets and another to show the motions of the stars.[2]

Gerbert, then, presumably had the knowledge and skill to build a mechanical clock. But *could* is not *did.* There is no contemporary proof of Gerbert's inventing such a device and some reason to think otherwise: if the oscillating controller and mechanical escapement were known as early as the year 1000, why do we have to wait another three hundred years to see clocks appear in the belfries and towers of city halls and churches? Surely, moreover, if so remarkable an invention had been coming slowly into use, it would have left some literary or pictorial trace, if not some physical remains. Some have suggested that if Gerbert did indeed build a mechanical clock, it must have been suppressed by the church, which might have seen it as the illicit fruit of intercourse with infidels or as the cunning product of some dark, Faustian compact. Gerbert did eventually acquire the reputation of a sorcerer and heretic—to the point where, in the sixteenth century, militant Protestants exploited his "infamy" to calumniate the papacy.[3] But this amounts to heaping speculation on speculation. Would the church have wanted to suppress a device so useful in its own management of time? Could it have? I am not a medievalist and am in no position to answer such questions. But the matter is worth investigating.

In the meantime, we are left with over two hundred fifty years of near silence, followed by a rush of ambiguous noise. The resulting uncertainty has given negative encouragement and support to a most unexpected interpretation of the invention and development of the mechanical clock. This is the thesis of Derek de Solla Price, coauthor with Joseph Needham and Wang Ling of *Heavenly Clockwork* and specialist in the history of ancient and medieval scientific instruments. Price argues that the machines of Wallingford and Dondi were the first mechanical clocks, that the

timekeeping components served simply as drives for astronomical devices of a type going back to antiquity, and that timekeeping for its own sake was an unanticipated by-product of this experiment in automation. "The escapement, which originally gave perfection to the astronomical machine, was also found useful for telling time, and as social development led to an increased social awareness and importance of time reckoning, simplified versions of this part of the astronomical device were made and became widely used as mere time-tellers."[4] Price is hard on "simplified versions" and "mere time-tellers": on another occasion he refers to "degeneration in complexity" and describes the later fourteenth century as a time when "tradition of escapement clocks continues and degenerates into simple time-keepers." To cite his by now well-known metaphor: "The mechanical clock is nought but a fallen angel from the world of astronomy!"[5]

Now, it is no doubt true that terrestrial timekeeping is less elevated than heavenly clockwork, but "degeneration" does seem a mite strong. So do Price's strictures against the other wisdom on this subject, which he finds "unsatisfying, misleading, and often false." Earlier students of horology, he warns us, were on the wrong track: "On no account must we take the easy way out which abandons the history of the clock and talks instead about the history of time-measurement. It is most unfortunate that such a term was ever coined."[6] "What did not happen was that man wanted to measure time and so devised new ways of doing it. What did happen is that in the course of following an old trend, not quite yet extinct, he developed quite sophisticated techniques, important for their technological brilliance, that gave him for the first time the possibility of doing something he had not wanted before it was readily available. This product, timekeeping, caught on, and it is due to this ancient fashion that time became a matter of the deep philosophical and scientific importance it has today."[7]

Price's thesis, if true, would imply a most intriguing paradox. Here you have two societies, Europe and China, thousands of miles apart, both of them building extraordinary machines to imitate the movements of heavenly bodies, both of them automating these planetaria/astraria by means of clock drives. In both cases, the clock is an accessory, and neither society cares much about time measurement for its own sake. Yet one society, the Eu-

ropean, abstracts the time function from its device and starts building a civilization based on pure (simple) timekeepers, whereas the other, the Chinese, does not.

Unfortunately, in both logic and evidence this is an unconvincing, indeed a most surprising thesis. (The exclamation point in Price's allusion to fallen angels is well justified.) In logic: the normal sequence of technological development runs from simple and rudimentary to complex and refined. To quote Price himself, "Historically speaking we expect that the further back we delve, the more primitive and simple the technology becomes." Any alleged deviation from this rule should put the historian on his guard.[8] And in evidence: we are as sure as we can be, short of possessing the remains of a very early machine, that there were mechanical clocks before Wallingford and Dondi, hence that simple timekeepers preceded complex, clock-driven planetaria and astraria.[9]

It is a fact that no early escapement clock seems to have survived, but then, neither has any medieval water clock. If anything, we should be less surprised by the disappearance of the former than of the latter. The first mechanical clocks were crudely fashioned and liable to break down at any time. They needed continual care, frequent overhauls, and substantial replacement every ten or twenty years. They were made of brass or iron, valuable metals at the time, and we may be sure that clockmakers who repaired them were not inclined to treat discarded parts or machines as junk to be abandoned. Rather, just as roofers today routinely keep and recycle the copper gutters and sheets they replace, so medieval clockmakers must have treated used brass and iron as valuable "perks" of the trade.

We are thus thrown back on literary evidence, ambiguous at times because of the generic character of the term *horologium,* none of it definitive in itself but collectively decisive. For one thing, there is the abrupt increase in the frequency of references to clocks toward the end of the thirteenth century. Suddenly clocks are news because clocks cost money. Cathedral chapters mention them in their accounts; itemize their repairs; pay people to watch them and keep them going; hire all manner of specialists to replace wheels, paint dials, carve wooden figures. A new profession makes its appearance, that of the clockmaker or *horologeur.*[10] There

is simply nothing like this for the earlier period. The late British scholar C. F. C. Beeson argued, I think correctly, that this in itself was indicative of a new device.[11]

For another, the new clocks and their associated bells were often sited in high places—the better to hear them. But towers are no places for a water clock: no one hauls water any higher than he has to, and lofty exposures make it very difficult to keep water from cooling and freezing. Do not imagine, either, that medieval clockmakers were placing clepsydras on ground level and using them to drive or trigger mechanisms thirty or more feet above. Such an arrangement is not inconceivable, but would have been extravagantly costly in the context of medieval metallurgy. We would have heard about it, if only about its breakdowns. The fact is that contemporary accounts make no mention of water in connection with this new generation of timepieces—no concern for freezing, no reference to leaks or evaporation, no hint of rust or corrosion—nothing. Under the circumstances, all efforts to salvage the clepsydra connection, however ingenious, must be rejected as highly improbable. Indeed, on the principle of Occam's Razor, their very ingenuity makes them suspect.

What we do have in the contemporary sources is a clear sense of excitement and pride. These great clocks were, like computers today, the technological sensation of their time. When a poet like Dante looks to the clock and its wheel train for vivid similes, you know that he is speaking to established and conspicuous sensibilities. Thus in canto 24 of the *Paradiso* (written between 1316 and 1321):

> And like the wheels in clock works, which
> Turn, so that the first to the beholder
> Seems still, and the last, to fly.
>
> E come cerchi in tempra d'oriuoli
> si giran si che il primo, a chi pon mente,
> quieto pare, e l'ultimo, che voli.

Again, it takes excessive ingenuity to see here anything but the wheel train with reduction gearing characteristic of the mechanical escapement clock.

By the time we get to Wallingford and Dondi, then, the mechanical clock was in its third or fourth generation—at least.

Dondi himself must have learned much of what he knew about these devices from his own father, an astronomer and clockmaker. Both Wallingford and he provide us with careful descriptions of their wheelwork and gear ratios, but neither finds it necessary to say anything about the character and construction of the controller-escapement—that is, the timekeeping heart of his machine. Indeed Dondi explicitly dismisses the mechanical clock as a commonplace, the making of which "will not be discussed in such detail as the rest, because its construction is well known, and there are many varieties of them and, however it is made, the diversity of methods does not come within the scope of this work." His own clock, he says, beats at the usual two-second rate; and anyone who is not capable of making a "common clock"—"by himself and without written instructions"—should not attempt the rest.[12]

To sum up: the Wallingford and Dondi masterpieces, far from being the first mechanical clocks, made use of an already established technique. What is more, the use of falling weights as power source made it possible to impart steady drive to more complex mechanisms than could be worked by a clepsydra. It was the clock, in other words, that facilitated and thereby fostered the automated planetarium or astrarium, not the reverse. Indeed, the simple mechanical clock, by opening for the first time serious possibilities of precision timekeeping, eventually laid the basis for modern astronomical science. So much for "fallen angels"!

The clock did not create an interest in time measurement; the interest in time measurement led to the invention of the clock.

Where did this demand come from? Not from the mass of the population. Nine out of ten Europeans lived on the land. "Labor time," to quote the medievalist Jacques Le Goff, "was still the time of an economy dominated by agrarian rhythms, free of haste, careless of exactitude, unconcerned by productivity—and of a society created in the image of that economy, *sober and modest*, without enormous appetites, undemanding, and incapable of quantitative efforts."[13] Town and city life, to be sure, was different. The city dweller has no natural sequence of tasks to rhythm his day. The very uniformity of his occupation makes him time-conscious; or if he is moving about, the irregular pattern of his

contacts imparts a sense of haste and waste. But urban centers developed late in the Middle Ages, from about the eleventh century on, and already before that there was an important timekeeping constituency. That was the Christian church, in particular the Roman branch.

It is worth pausing a moment to consider this temporal discipline of Christianity, especially of Western Christianity, which distinguishes it sharply from the other monotheistic religions and has not been adequately examined in the literature on time measurement. In Judaism the worshiper is obliged to pray three times a day, but at no set times: in the morning (after daybreak), afternoon (before sunset), and evening (after dark). A pious Jew will recite his prayers as soon as possible after the permissible time; but if circumstances require, he has substantial leeway in which to perform his obligation. Today some of the starting times of worship are given on calendars to the minute, thanks to astronomical calculations. In ancient and medieval times, however, nature gave the signals. The animals woke the Jew to prayer, and the first of the morning blessings thanks God for giving the rooster the wit to distinguish between day and night.[14] The evening prayer could be recited as soon as three stars were visible; if the sky was cloudy, one waited until one could no longer distinguish between blue and black. No timepiece or alarm was needed.

Islam calls for five daily prayers: at dawn or just before sunrise, just after noon, before sunset, just after sunset, and after dark. Again, none of these requires a timepiece, with the possible exception of the noon prayer. I say "possible," because high noon is easily established in sunny climes by visual means. Besides, insofar as the local religious authorities wanted to set times for prayer and used clocks for the purpose, they could easily make do with the sundials and water clocks of the ancients. In most Islamic countries, the sun usually shines and water rarely freezes. Moreover, in Islam as in Judaism the times of prayer are bands rather than points, and local tradition determines how much the prayers may be delayed without impairment. In both religions prayer is a personal act, without clerical or congregational mediation, and worship, with some exceptions, need not be collective and simultaneous.

Christianity, especially monastic Christianity, differs from

both. The early Christians had no standard liturgy; the new faith was not yet a church. Usage varied from place to place, and prayer was as much a function of opportunity as of obligation. Insofar as the Nazarenes were still Jews, they built on the practices of the older faith, with its morning and night recitations (Deut. 6:7, "when thou liest down and when thou risest up") or its triple office (Dan. 6:11, "he kneeled upon his knees three times a day"). But then they added their own devotions, in part to give expression to those praises and supplications that had no place in the Jewish service, in part to distinguish themselves from the "obdurate" Hebrews. By the early third century, Tertullian, acknowledging the impracticality of the Pauline ideal of ceaseless prayer (1 Thess. 5:17), recommended daily prayers at set times: in addition to the morning and evening prayers prescribed by the Law, there would be devotions at the third, sixth, and ninth hours. These were the points that divided the daytime into quarters,[15] and Tertullian asserts that they were recognized as temporal punctuation marks by all nations: "they serve to fix the times of business and they are announced publicly."[16] Very convenient: that way there was no problem of knowing when to pray, since civil time signals would serve to summon the faithful.

The setting of prayer times by the clock was no small matter. It represented a first step toward a liturgy independent of the natural cycle. This tendency was much reinforced by the introduction of a night service, which apparently went back to the earliest days of Christianity, when the Jewish followers of Jesus, having celebrated the Sabbath, met again on Sunday for nocturnal devotions. The choice of hour had some precedent in scripture:

> I have remembered Thy name, O Lord, in the night . . .
> (Psalms 119:52)
>
> At midnight I will rise to give thanks unto Thee . . .
> (Psalms 119:62)
>
> I rose early at dawn and cried;
> I hoped in Thy word.
> Mine eyes forestalled the night-watches,
> That I might meditate in Thy word.
> (Psalms 119:147–148)

Scriptural precedent, though, is more often sanction than cause. The early Christians had good prudential reasons for coming together in the night while Caesar slept; also a most potent spiritual motive, namely the hope of salvation. The Gospel speaks of the Bridegroom's coming at midnight (Matt. 25:6), which led the church in Constantinople to institute a midnight office. Yet such precision was the exception, indeed was deliberately avoided. Uncertainty was preferable, because more compelling. The Lord will come, it is written, "at an hour you do not expect" (Matt. 24:42–44). "If he comes in the second watch, or if in the third," blessed are the servants who are watching and waiting (Luke 12:37–38). Nocturnal devotions, then, appropriately called vigils, were a spiritual watch for the second coming (the *parousia*) of the Lord.[17] Pliny the Younger wrote of this practice to the emperor Trajan at the beginning of the second century: "They are wont to come together before the light."[18]

For hundreds of years there were no rules, only practices. Rules came with monasticism—with the formation of a regular clergy (that is, a clergy subject to a *regula,* or rule) whose vocation it was to pray and pray often, and in so doing to save that multitude of the faithful whose worldly duties or inconstancy prevented them from devoting themselves entirely to the service of God. The innovator here was Pachomius in Upper Egypt in the early fourth century: against the prevailing eremitic individualism, his new order instituted a minute regulation of the collective praying, working, eating, and sleeping day. "It was there that for the first time we see realized the practice of an office in the strict sense, recited every day in the name of the church, *publicum officium,* at set hours."[19] Among the services: vigils, the *officium nocturnum* that was later merged with and called matins. From Egypt the practice spread to Palestine, Syria, Mesopotamia, and Europe.

Still, rules varied—"they were still feeling their way."[20] Temporal prescriptions, for example, may have been looser in the Eastern churches, where the natural diurnal cues continued to play an important role.[21] It was in the West, in the Rule of Saint Benedict, that the new order of the offices found its first complete and detailed realization: six (later seven) daytime services (lauds, prime, tierce, sext, none, vespers, and compline) and one at night (vigils, later matins). As the very names indicate, most of these were designated and set in terms of clock hours. Hence the very term "canonical hour," which eventually became synonymous with the office itself: one "recited the hours."[22]

This was around 530. In the centuries that followed, the Benedictine rule was adopted by other orders, including the great houses grouped around the Vatican and Lateran basilicas, thereby ensuring the eventual normalization of the canonical hours throughout Western Christendom. Progress in this direction was uneven owing to the physical insecurity of a violent age; in many parts of Europe, monastic life was disrupted for long periods by recurrent invasions and internecine strife. Besides, each house had its own interpretation of the Rule: we are talking here about customs (*consuetudines*), and there is nothing so idiosyncratic as custom.

Beginning in the tenth century external pressures eased, and the foundation of the Cluniac order (910), with its almost exclusive devotion to prayer, was the first sign of a general monastic revival. Cluny was followed by others, in particular the Cistercians (beginning of the twelfth century), under whom work regained the place it had held alongside prayer in the original Benedictine discipline. The very nature of these foundations, as expressed by the idea of an order, pressed them toward uniformity of practice and observance, and their reformism found expression not in the latitudinarianism often associated with the idea of reform today, but in the restoration of discipline. Discipline in turn had at its center a temporal definition and ordering of the spiritual life: *omnia horis competentibus compleantur*—all things should be taken care of at the proper time.

To be sure, one should not interpret the new discipline to mean an absolute uniformity of practice. We are still dealing here with uses and customs, and some of the confusion and contradiction among accounts and analyses of the monastic *horarium* is no doubt due to these conventual, regional, and national variations. Within each house, though, time discipline was taken seriously, and the abbot himself or his representative was personally responsible for its accuracy and enforcement. "Nothing, therefore, shall be put before the Divine Office," says the Rule.[23] Nothing was so important as the round of punctual, collective prayer.

Why was punctuality so important? One reason was that lateness—"God forbid!"—might make it necessary to abridge an office, in particular matins: "Let great care be taken that this shall not happen."[24] Another, I think, was that simultaneity was

thought to enhance the potency of prayer. That would also explain the requirement that devotions be chanted aloud: to sing along is to sing together. That indeed was the point of community: the whole was greater than the sum of the parts.

Multiplication of simultaneous devotions—this was the way of salvation for all. Indeed, there were those who would have revived the Pauline ideal of continuous prayer (in relays presumably): thus Benedict of Aniane in the early ninth century and, even more, the monastery at Cluny in the tenth. (The latent purpose—or, if you will, the objective consequence—was, in conjunction with ascetic diet, to promote a state of light-headedness conducive to enthusiasm and hallucinations, or, euphemistically, to illumination and visions.)

The performance of such a demanding sequence, in particular the recitation of the nocturnal office after a period of sleep, imposed a new and special kind of temporal servitude. Unless some member of the congregation were ready to stay awake through the night and watch the clock—a precarious resort, as anyone who has stood sentry duty knows—it was only too easy to oversleep. In Roman times, some sympathetic or coreligionist member of the night watch may have served as waker; but with the fall of the empire, urban services broke down and watches became only a memory. To replace them, the medieval church would learn to make alarm mechanisms. Otherwise no one would ever have gotten any sleep, for fear of failing in his duty and jeopardizing not only his own salvation but that of others. Hence the instructions of one of the Villers Abbey fragments (1267–1268): "You must do the same when you set [the clock] after compline, so that you may sleep soundly."[25]

This religious concern for punctuality may seem foolish to rationalists of the twentieth century, but it was no small matter to a monk of the Middle Ages. We know, for one thing, that time and the calendar were just about the only aspect of medieval science that moved ahead in this period. In every other domain, these centuries saw a drastic regression from the knowledge of the ancients, much of it lost, the rest preserved in manuscripts that no one consulted. Much of this knowledge was not recovered until reimported hundreds of years later via the Arabs and the Jews in Spain or, still later, from Byzantium. But time measurement was

a subject of active inquiry even in the darkest of the so-called dark ages. One has only to compare Isidore of Seville's rudimentary notions of time in his *De Temporibus* (615) with Bede's enormously popular textbook, the *De Temporum Ratione* (725)—written in the peripheral, tribal battleground that was Anglo-Saxon England—to realize the progress made in this field.

In large part this progress reflects the church's continuing concern to solve and systematize the dating of Easter and the other so-called movable feasts. These dates were established in accordance with the lunar as well as the solar calendar—like the Jewish calendar, but different. The principles of calculation, the science known as the *computus,* were sufficiently complex to give rise to multiple solutions, which came eventually to divide different Christian rites from one another. The task of extrapolating these dates into the future was particularly difficult, so much so that a thousand years later even so brilliant a mathematician as Carl Friedrich Gauss was not able to reduce the calculation to a comprehensive algorithm.[26]

It was in this area that Bede made his greatest contribution, and the rapid diffusion of his work on the continent testifies to its superiority and interest. Certain monasteries became centers of training and calculation (thus Sankt Gallen and Auxerre) and produced a substantial literature on the subject that was avidly copied elsewhere. The great volume of tables, charts, discussion, and diagrams that can be found today in any major manuscript collection testifies to the vigor and creativity of this effort.[27]

Most of this literature deals with dating, but calendrical concerns invariably spilled over into the area of time measurement, and vice versa. Indeed, I would argue that it was precisely this that made European astronomy and the computus so different: the practitioners were interested not only in the moon and the seasons, but in the day and its divisions. In particular, these same monks wanted to know the division of the day into light and darkness, the better to set the hours of the liturgy. The best of them, Gerbert for example, were quite aware that day (and night) did not grow and diminish at an equal rate from week to week, and they worked out the schedule of changing proportions (what they called a *horologium*) by measuring day and night at the solstices and adjusting from there. Gerbert offers one correspondent

advice on how to take this measure: use a clepsydra, he says, and collect the water separately for night and day; then pour them together, and if the sum makes twenty-four (equinoctial) hours, you know you have it right.[28]

This combination of measure and calculation made possible the construction of *horologia* giving night and day for every day in the year. We have one tenth-century table, for example, which gives the division not only by hours (*horae*), but by points (*puncta,* five to the hour) and *ostenta* (twelve to the *punct*). That made each *ost* equal to one of our minutes, and the clocks of the day could not measure that accurately; so the figures in the table were given to the nearest third of a *punct,* that is, four *osts.*[29]

Time mattered to such experts as Gerbert, but it also mattered to the ordinary monk, for whom getting up in the dark of the night was perhaps the hardest aspect of monastic discipline. Indeed, the practical meaning of "reforming" a house meant first and foremost the imposition (reimposition) of this duty. The sleepyheads were prodded out of bed and urged to the office; also prodded during service lest they fail in their obligations. Where the flesh was weak, temptation lurked. Raoul Glaber (early eleventh century) tells the tale of a demon who successfully seduced a monk by holding out the lure of sweet sleep: "As for you, I wonder why you so scrupulously jump out of bed as soon as you hear the bell, when you could stay resting even unto the third bell . . . but know that every year Christ empties hell of sinners and brings them to heaven, so without worry you can give yourself to all the voluptuousness of the flesh."[30]

The same Glaber confesses to two occasions when he himself woke late and saw a demon, "come to do business with the laggards."[31] And Peter the Venerable, Abbot of Cluny in the twelfth century, tells the story of Brother Alger, who woke thinking he had heard the bell ring for nocturns. Looking around, he thought he saw the other beds empty, so he drew on his sandals, threw on his cloak, and hastened to the chapel. There he was puzzled not to hear the sound of voices lifted in prayer. He hurried back to the dormitory. There he found all the other monks fast asleep. And then he understood: this was all a temptation of the devil, who had awakened him at the wrong time, so that when the bell for nocturns really rang, he would sleep through it.[32]

These, I suggest, are what we now know as anxiety dreams. They clearly reflect the degree to which time-consciousness and discipline had become internalized. Missing matins was a serious matter, so serious that it has been immortalized for us by perhaps the best known of children's songs:

> Frère Jacques, Frère Jacques,
> Dormez-vous? dormez-vous?
> Sonnez les matines, sonnez les matines,
> Ding, ding, dong; ding, ding, dong.[33]

4 The Greatest Necessity for Every Rank of Men

"IDLENESS," WROTE BENEDICT, "is an enemy of the soul."[1] The fixing of a daily schedule of prayer was only part of a larger ordering of all monachal activity, worldly as well as religious. Indeed, for monks there was no distinction between worldly and religious: *laborare est orare*—to work *was* to pray. Hence, there were rules setting aside times for work, study, eating, and sleeping; rules prescribing penalties and penance for latecomers; rules providing explicitly for the maintenance of the clock and its nightly adjustment, so that it would wake the sacristan at the proper time. Note that at this stage, it was not the clock that worked the big bells. As "Frère Jacques" tells us, the clock merely rang loudly enough to get the bell ringer out of bed.

These were not necessarily clocks in our sense of the term. Many of them did not indicate the time or run continuously. Rather, they were what we now know as timers and associate with three-minute eggs or film developing. But these were timers that ran for hours. They were set to run during the night and served only to trip the alarm; to use the medieval terminology, they were *horologia nocturna* or *horologia excitatoria.* It is now generally agreed, moreover, that some of them made use of an escapement-type

mechanism to produce a to-and-fro motion of the hammer(s) beating on the bell, and that this mechanism was often weight-driven.

It is this mechanism, probably, that was the forerunner of the clock escapement.[2] We have already met the device: the wheel train ends in a *scape wheel* (also called the *crown wheel,* after the shape of the teeth), whose rotation is alternately blocked and released by pallets on a staff (the *verge*) pivoting to and fro.[3] In the alarm version, one puts a knocker on the end of the verge, and this oscillating knob strikes a bell. In the timekeeping version, the verge is T-crossed by a rod that swings back and forth with it (called the *foliot,* perhaps because of its "mad" motion). This foliot is an inertial controller: by moving weights along it, one can change its moment and thus the beat of the mechanism. (See Figures 5 and A.1.) The action, in other words, is the same in both versions, and it would not have taken much to go from one to the other.

Etymology makes clear what was happening. Before the invention of the weight-driven mechanical clock, remember, the clepsydra and sundial were both known as *horologia,* and this generic term was subsequently applied in the vernacular to the new machine as well. Thus we get French *horloge,* Italian *orologio,* Spanish *reloj.* But new things often call for new names: the English called the new device a clock; the Dutch and Flemings, a *klokke.* And what is a clock, but a bell? (Compare medieval Dutch *clokke,* German *Glocke.*) Even the French, who stayed with the old name, changed their word for bell at about this time, from *sein* or *sain* (from the Latin *signum*) to *cloche.*[4] Something new had come on the scene. Seen ontologically and functionally, these timekeeping machines began as automated bells.

Bells, bells, bells. Big bells and small. Monasteries were beehives of varied activity, the largest productive enterprises of medieval Europe. Brothers, lay brothers, and servants were busy everywhere—in the chapel, the library, the writing room (scriptorium), in the fields, the mill, the mines, the workshops, the laundry, the kitchen. They lived and worked to bells. The big bells tolled the canonical hours and the major changes, and their peal carried far and wide, not only within the convent domain but as far as the wind could take it. And the little bells tinkled insistently throughout the offices and meals, calling the participants to attention and signaling the start of a new prayer, ceremony, or activity. All of this was part of a larger process of depersonalization, deindividuation. Monastic space was closed space—areas and corridors of collective occupancy and movement—so arranged that everyone could be seen at all times. So with time: there was "only one time, that of the group, that of the community. Time of rest, of prayer, of work, of meditation, of reading: signaled by the bell, measured and kept by the sacristan, excluding individual and autonomous time."[5] Time, in other words, was of the essence because it belonged to the community and to God; and the bells saw to it that this precious, inextensible resource was not wasted.

The bells, in short, were drivers—goads to effective, productive labor. It is this larger role, going far beyond reveille, that may account for the higher standard of punctuality enforced by the new monastic orders of the eleventh and twelfth centuries. The Cistercians in particular were as much an economic as a spiritual enterprise (they would not have recognized a difference). Their agriculture was the most advanced in Europe; their factories and mines, the most efficient. They made extensive use of hired labor, and their concern for costs made them turn wherever possible to labor-saving devices. Their Rule enjoined them, for example, to build near rivers, so as to have access to water power; and they learned to use this in multifunctional, staged installations designed to exploit power capacity to the maximum. For such an undertaking, timekeeper and bells were an indispensable instrument of organization and control; and it may be that it was the proliferation of this order throughout Europe and the expansion of its productive activities that stimulated the interest in finding a superior timekeeper and precipitated the invention of the mechanical clock. The Cistercian abbeys of central Europe must have had their hands full getting satisfactory performance from clepsydras.[6]

Whatever the inspiration, it seems clear that in the century or two preceding the appearance of the mechanical clock, there was a substantial advance in the technique of hydraulic timekeeping and a concomitant diffusion of the new methods and devices. For the first time we see the temporal discipline of the cloister explicitly linked to the *horologium:* thus the instructions of William, abbot of Hirsau in the eleventh century, on the duty of setting the clock each night (to take account of the unequal temporal hours);

and the several provisions of the Cistercian Rule (early twelfth century) on the care of clocks and bells. From these and similar references, still occasional but too frequent to be dismissed as exceptional, we may infer that the bell-ringing clepsydra became in this period a feature of the "well-tempered" monastery. The strongest corroboration, in my opinion, is the language of Robertus Anglicus in the passage cited earlier (p. 10) on the search for a mechanical clock. "Clockmakers," he tells us—*artifices horologiorum*—are trying to make a wheel that will make one turn in a day. Who were these *artifices* if not technicians (mechanics) who had made a specialty of the clepsydra, in particular the bell-ringing clepsydra, and were led by their experience of wheelwork to experiment with new kinds of timekeepers? I am not one of those who give credence to the existence of a guild and street of clockmakers (presumably water-clock makers) in Cologne in the late twelfth and early thirteenth centuries—after all, why Cologne? But I do think that Robert's designation of horological specialists, *artifices horologiorum,* is unconscious testimony to the presence, if not of a trade, at least of an established group of producers and, by implication, of a corresponding market.[7]

The monastic clergy may have provided the primary market for timekeepers and the principal stimulus to technical advances in this domain, but the church alone cannot account for the popularity and development of the new device, which for all its limitations rapidly drove the clepsydra from the scene. For one thing, clerical demand by itself was probably insufficient to sustain what rapidly became a major craft. For another, the nature of time measurement as practiced by the church was incompatible with the technological possibilities and characteristics of the new instrument.

Consider the new sources of demand. These consisted of, first, the numerous courts—royal, princely, ducal, and episcopal; and second, the rapidly growing urban centers with their active, ambitious bourgeois patriciates. At the very beginning, in the thirteenth and early fourteenth centuries, princes and courtiers may well have accounted for the greater part of secular demand for timekeepers. Typically they were the wealthiest members of society, the more given to luxury expenditure because they did not earn their income. (It is always easier to spend other people's money.) The preceding centuries, moreover, had been an era of sustained increase in wealth and power: population was growing, and with it the area under cultivation; trade also, and with it the yield of duties and taxes. These new resources nourished central authority and enabled it to enforce that condition of order that is in itself the best encouragement to productive activity. (One should not exaggerate, of course. Europe was still a perilous place by today's standards, but security had immensely improved over what it had been when Northmen, Magyars, and Saracens were raiding everywhere with impunity and the law of the strongest and most violent prevailed.) One can well understand, then, how after centuries of reconstruction and growth the rulers of Europe seized upon and delighted in the new bell-ringing clocks, these wondrously ingenious instruments, costly to build and maintain, but well worth it for their plangent ubiquity—the ideal, quotidian reminder of and symbol of high authority.

In the long run, though, the future of the infant clock industry lay with the bourgeoisie—originally and literally the residents of the *bourgs* (in colloquial American English, the *burgs*). Along with the crown, indeed in alliance with it, the town was the great beneficiary of the agricultural and commercial expansion of the high Middle Ages (eleventh to fourteenth centuries). Sleepy villages were becoming busy marketplaces; administrative centers and points of transshipment and exchange were growing into nodes of wholesale and retail trade and craft industry. The more successful residents of these new cities quickly came to constitute a new elite, an urban patriciate possessed of great wealth and a sense of power and self-esteem that rivaled that of the older landed elite. They were able, further, by shrewd cooperation with the crown and the construction of an urban military base, to win substantial autonomy for their municipalities, which were organized by collective agreement among the residents and by contractual arrangement with or concession from higher authority into self-administering communes. These had their own fiscal resources, so that when mechanical clocks appeared on the scene, the cities of western and Mediterranean Europe could afford to build them as complements to or successors to the cathedrals—a symbol of a new secular dignity and power and a contribution to the general welfare.

Why the general welfare? Because, just like the monastery, the

city needed to know the time even before the mechanical clock became available. Here, too, necessity was the mother of invention.

We have already noted the contrast between the "natural" day of the peasant, marked and punctuated by the given sequence of agricultural tasks, and the man-made day of the townsman. The former is defined by the sun. The latter is bounded by artificial time signals and the technology of illumination and is devoted to the same task or to an array of tasks in no given sequence. The spatial compactness of the city, moreover, is an invitation to serial engagements: with careful planning (that is, timing), one can multiply oneself. To be sure, the medieval town long remained half-rural. Everybody who could, kept a *basse-cour* of chickens, roosters, rabbits, and other useful livestock; so that some of the natural time signals heard in the countryside were heard in the city as well. Still, it is one thing to receive or perceive the time; another thing to track and use it. The two environments differed radically in their temporal consciousness.

This difference was growing. (It was not to contract until the nineteenth century, with the coming of the railroad and the penetration of the country by the rhythms and servitudes of the city.) As commerce developed and industry expanded, the complexity of life and work required an ever larger array of time signals. These were given, as in the monasteries, by bells: the urban commune in this sense was the heir and imitator of the religious community. Bells sounded for start of work, meal breaks, end of work, closing of gates, start of market, close of market, assembly, emergencies, council meetings, end of drink service, time for street cleaning, curfew, and so on through an extraordinary variety of special peals in individual towns and cities.

The pressure for time signals was especially strong in those cities that were engaged in textile manufacture, the first and greatest of medieval industries. There the definition of working time was crucial to the profitability of enterprise and the prosperity of the commune. The textile industry was the first to engage in large-scale production for export, and hence the first to overflow the traditional workshop and engage a dispersed work force. Some of these workers were true proletarians, owning none of the instruments of production, selling only their labor power. They streamed early every morning into the dye shops and fulling mills,

where the high consumption of energy for heating the vats and driving the hammers encouraged concentration in large units. These workers—called *ciompi* in Florence, "blue nails" (stained by dye) in Flanders—were poorly paid, overworked, potentially troublesome and mobilizable. Other branches of the manufacture could be conducted in the rooms and cottages of the workers. Employers liked this so-called putting out because it shifted much of the burden of overhead costs to the employee, who was paid by the piece rather than by time; and the workers preferred it to the time discipline and supervision of the large shops. They could in principle start and stop work at will, for who was to tell them what to do in their own home?

The bells would tell them. Where there was textile manufacture, there were work bells. Artisans in other places might work the traditional day from sunup to sundown, but Brussels had its *joufvrouwenclocke* at dawn, another work clock (called the *werckclocke*) a little later, a *drabclocke* in the evening for weavers and twisters, among others, and a *lesteclocke* for tapestry workers, cobblers, and whitesmiths. Sometimes these bells were public, installed by the municipal authorities in a church tower, perhaps rented, or in a belfry erected for the purpose. This was the case in Amiens in 1335, where the king granted the request of mayor and aldermen "that they might be permitted to issue an ordinance concerning the time when the workers of the said city and its suburbs should go each morning to work, when they should eat, and when return to work after eating; and also, in the evening, when they should quit work for the day, and that by the issue of said ordinance, they might ring a bell which has been installed in the Belfry of the said city, which differs from the other bells." Sometimes the bells were private, the property of the employer. In Ghent in 1324 the abbot of St.-Pierre authorized the fullers "to install a bell in the workhouse newly founded by them near the Hoipoorte."[8]

These work bells inevitably gave rise to conflict. Part of the problem, no doubt, was implicit in the effort to impose time discipline on home workers. In principle, payment by the piece should have taken care of the matter, with workers responding to wage incentives. In fact, the home workers were content to earn what they felt they needed, and in time of keen demand, employers found it impossible to get them to do more, for higher pay only

reduced the amount of work required to satisfy these needs. The effort to bring the constraints of the manufactory into the rooms and cottages of spinners and weavers made the very use of bells a focus of resentment.

Meanwhile in the fulling mills and dye shops the bells posed a different kind of problem, especially when they were controlled by the employer. Consider the nature of the wage contract: the worker was paid by the day, and the day was bounded by these time signals. The employer had an interest in getting a full day's work for the wages he paid, and the worker in giving no more time than he was paid for. The question inevitably arose: How did, indeed how could, the worker know whether bell time was honest time? How could he trust even the municipal bells when the town council was dominated by representatives of the employers?

Under the circumstances, workers in some places sought to silence the *werckclocke*. At Thérouanne in 1367 the dean and chapter promised "workers, fullers, and other mechanics" to silence "forever the workers' bell in order that no scandal or conflict be born in city and church as a result of the ringing of a bell of this type."[9] But few places gave in so completely, and the years after the Black Death of 1347–1350 saw repeated trouble on this score. The plague had sharply reduced the population of the cities and towns, some of them by well over half, and a skeleton labor force was exploiting its enhanced bargaining power to demand concessions from employers and authorities. Among other things, they turned the very bells that bound them into tocsins of revolt. The decrees of these years make it clear what was at stake: the heaviest penalties were reserved for such *lèse-majesté*. At Commines the fine was sixty pounds (an enormous sum) for anyone ringing the bell as a call to assembly; and for sounding a call to revolt, the punishment was death.

Such efforts to eliminate the work bells never achieved success: as soon suppress the system of wage labor. Besides, once the workday was defined in temporal rather than natural terms, workers as well as employers had an interest in defining and somehow signaling the boundaries. Time measurement here was a two-edged sword: it gave the employer bounds to fill and the worker bounds to work. The alternative was the open-ended working day:

We'll always be weaving cloth of silk,
And shan't be better dressed for it.
We'll always be poor and bare
Always hungry and thirsty.
We'll never be able to earn enough
To eat better.
Bread, we have to share,
A little in the morning and in the evening less.
And we are in great misery,
But the man we work for
Gets rich on our wages.
We're up a good part of the night
And work all day to make our way . . .[10]

It was not the work bells as such, then, that were resented and mistrusted, but the people who controlled them; and it is here that the chiming tower clock made its greatest contribution. It provided regular signals—at first on the hour, later on at the halves or quarters—which necessarily limited the opportunities for abuse. Of course, with the appearance of the dial (from the word for day), it was possible for all interested parties to verify the time on a continuous basis.

This was not the end of the matter. As new clocks were built, discrepant time signals gave rise to new issues of discord: Why are we obliged to start work earlier than they? Or to stay later? Perhaps it was with this kind of conflict in mind that Charles V of France decreed in 1370 that all clocks in the city should be regulated on the one he was installing in his palace on the Ile de la Cité. He thereby affirmed the primacy of royal power, but such decrees could not solve the problem. The early tower clocks were far too crude and inaccurate to synchronize, even approximately: "C'est l'horloge du palais; / Elle va comme il lui plaît." Almost two hundred years later, another Charles V, Holy Roman Emperor, was to spend the last years of his life trying among other things to make his clocks sound together. He was still trying when he died.

This change in the technique of time measurement and signaling was associated with an equally drastic change in the units of measurement. The church, remember, kept temporal hours that changed with the season, and as the church kept time, so did the

rest of society. The punctuation marks were, in addition to the natural diurnal events (sunrise, sunset), the liturgical offices. Thus, the Parlement of Paris met at the hour of the first mass in Sainte-Chapelle and remained until the bell for none. In Bruges court cases ran until noon, and appeals until vespers.[11] In Liège a citizen condemned for a debt had to pay or give security by sunset. The millers of Paris ceased work on Sunday from the announcement of the holy water in the chapel of St-Leufroy to the ringing of vespers. Spinsters of silk quit work in the summer when the bell of Ste-Marie-des-Champs called to alms, and carpenters stopped on Saturday when the big bell of Notre Dame sounded none. In summer (defined as from Easter to Saint Rémy's day) the tanners of Paris worked from sunrise to sunset. But what about wintertime, when the sky was often cloudy and the sun obscured? They worked as long as it was light enough to tell two similar coins apart, the *livre tournois* and the *livre parisis*. Another regulation provided that work would begin as soon as it was light enough to recognize someone in the street.[12]

These are obviously nonclock standards. Whether, as some historians have believed, they are also preclock—that is, whether they are evidence that as yet no clockwork turned in Paris or clock bells chimed—is another story. Nothing was so conservative in the Middle Ages as hours of business and terms of labor. Any change in these was sure to injure some vested interest, while the hazards, costs, and limitations of artificial illumination made employers and workers alike reluctant to work days of fixed length. The fact that earlier usages persisted well into a new timekeeping era is testimony to the difficulty of changing so fundamental a way of thinking about and ordering life and work.

In the long run, however, change was implicit in the new mode of measurement. Whereas variable (temporal) hours were easily measured by the clepsydra, they were incompatible with mechanical turret clocks. Not that the flow of a water clock can easily be made to vary with the season; but the reading is easily adjusted to the calendar. All that is required is a series of scales, either marked on the clepsydra itself or on measuring rods, for the different times of year. (The ancient Egyptians learned to use a similar system with their shadow sticks and vertical gnomons.)

The mechanical clock is ill-adapted to such use. Its beat is regular and it marks its beat. To be sure, one can allow for variable

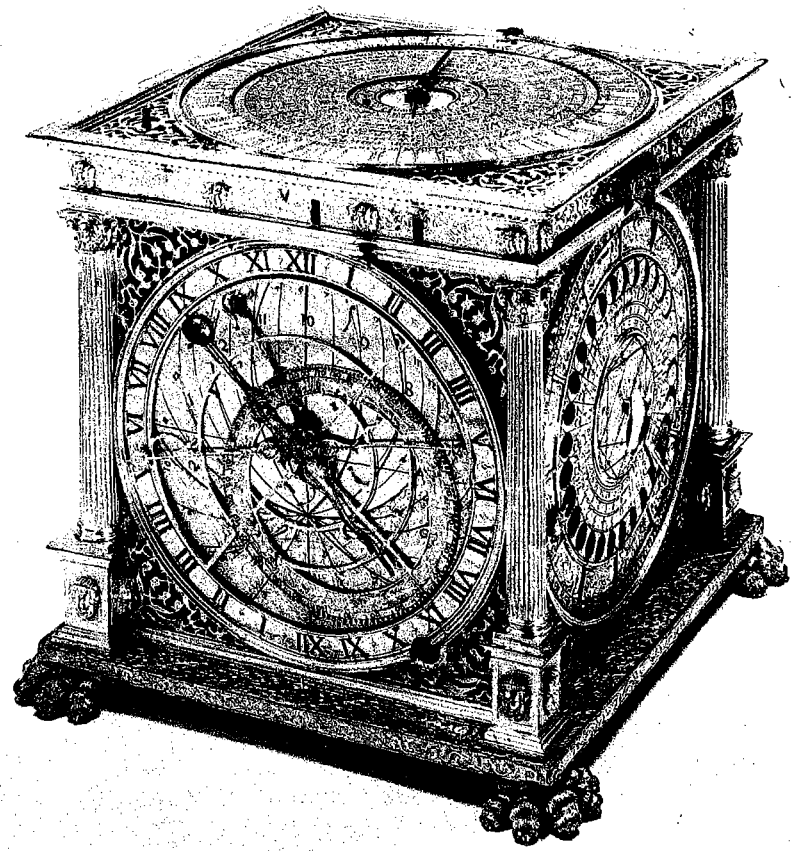

Plate I. Table clock by Steffen Brenner, Copenhagen, 1558. Height 21 cm. The movement is made of iron; the case of bronze, gilt brass, and silver. *Sonnerie* hours and quarters, plus alarm. Five dials. On the four sides: (1) astrolabe dial, sun hand, dragon hand with rotating moon (showing phases) at tip; number rings for temporal (unequal) hours, 2 × 12, and the astrological houses, 1–12; (2) age of moon, moon phases, duration of moonlight in hours and minutes; position of sun in zodiac; (3) length of day and night; correction dial in center; (4) days of the week, with associated planets; alarm dial in center. On top: Calendar and holy days; year-to-year dominical letters, movable feasts, golden number; minute hand.

A word about the very rare dragon hand: its function is to show the position of the moon's nodes (the points on the celestial sphere, 180 degrees apart, where the moon's path intersects the sun's). Used in conjunction with the sun hand, which tracks through the year along the ecliptic, such a dragon hand makes it possible to predict eclipses. Since the line of nodes retrogrades relative to the stars, the dragon hand turns counterclockwise, sweeping the calendar and zodiac scales and completing its revolution in some 18.6 years.

Brenner was court clockmaker to Frederick II of Denmark. This table clock is surely one of the most beautiful and mechanically ingenious astronomical clocks ever made—in its architecture, far ahead of its time.

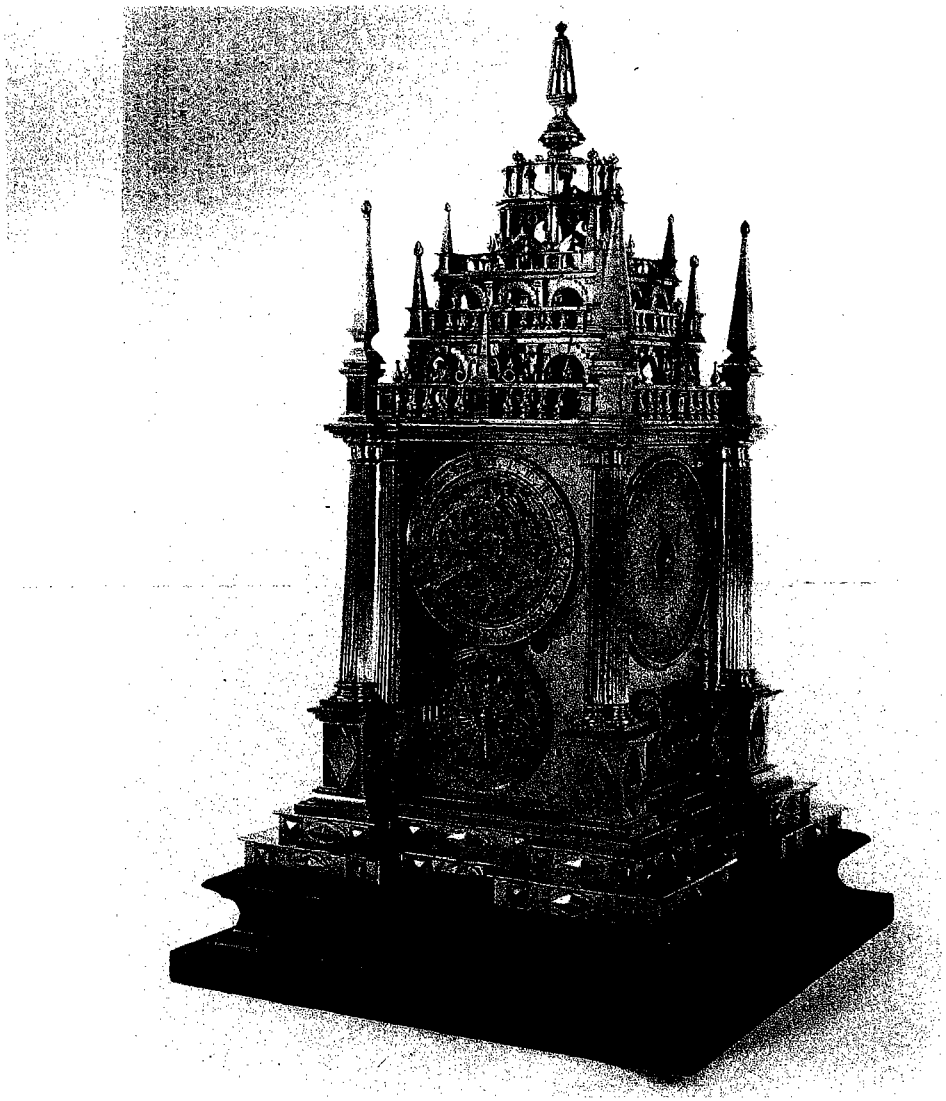

Plate II. Table "tabernacle" clock, Augsburg, 1600, no signature. Height 52 cm. Hour and quarter striking; also alarm. Movement is of brass, except for epicyclic gearing (iron). Case is of gilt bronze, brass, silver. Dials are of silver, partially enameled. Astrolabe dial has dragon, sun, and moon hands, age and phases of moon; dial below gives days of week and associated planets. Opposite side: hours and minutes, sectors for length of day and night; below, dial with hand for adjusting length of day and night. On sides: two calendar dials, each covering half a year, giving saints' days, dominical letters, the golden number, the epact (age of the moon on January 1, used in fixing the date of Easter), and the date of Easter for the years 1600–1687. Below, two small dials for regulating the striking and going rates and setting the alarm. A typical, high-quality astronomical clock, multiplying functions and information at the price of reliability and accuracy.

Plate III. Clock in the form of a Turkish vessel. Augsburg, c. 1585. Height 45 cm. The movement is made of iron; the case is of gilt bronze and copper. *Sonnerie* hours and quarters. Clock in center. The eyes of the Turk on top are linked to the going train and move from side to side. On the hours, he lifts his arm, which probably held a sword originally; at the same time, the two oarsmen make rowing movements. On the quarters, the monkey on the prow moves and the front oarsman turns his head back and forth. This is a clockwork toy, perhaps made for the Turkish tribute.

Plate IV. Table automaton clock, by Nikolaus Schmidt, Augsburg, c. 1580. Height 43 cm. The movement is made of iron; the case is of gilt bronze and copper. The eyes of the elephant move with the clock balance; the legs are soldered in position. (Did the raised leg move at one time?)

Animal clocks were very popular at the time, especially those showing exotic beasts (lions, camels, and mythical birds, as well as elephants). But this one resembles nothing so much as a rook (castle) in an Indian chess set.

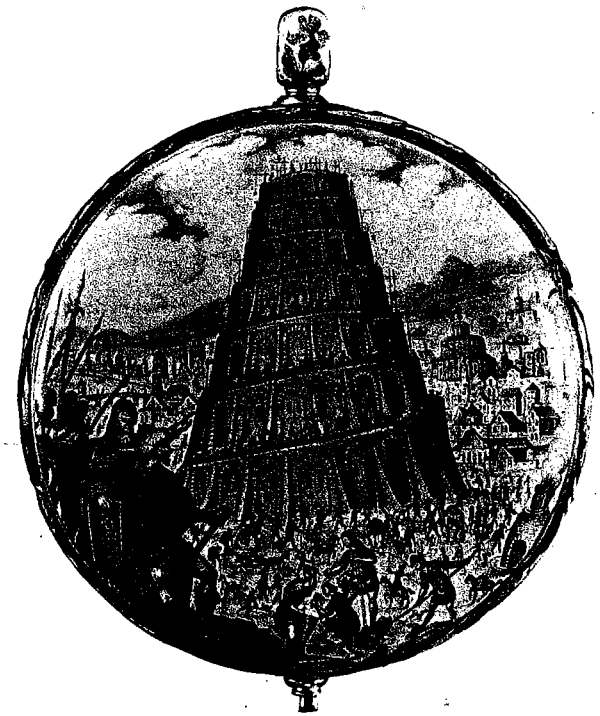

Plate V. The Tower of Babel: a "Blois enamel" watch. Movement by Matthis Wentzel, Strasbourg, 1636; case attributed to Jean Toutin, inventor of the technique of painting on enamel. Diameter 47 mm. A superb example of a vitreous polychrome miniature. The case is painted back and side, inside and out. The dial is also painted. Pre–balance spring; one hand.

Plate VI. A miniature copy of the Velasquez portrait of Philip IV of Spain (1621–1665): a "Blois enamel" watch with movement by Edme Burnot, Brussels, c. 1650; case unsigned. Diameter 62 mm. A very rare combination of polychrome painting and floral enamel in relief. On the reverse a comparable copy of the Velasquez portrait of Maria Anna of Austria, Philip's wife. Philip spent much of his reign and the resources of his kingdom trying to assert Spanish dominion over the Low Countries—in particular, over Protestant Holland; hence the link to a watch made in Brussels.

Plate VII. The Holy Family: a "Blois enamel" watch by Salomon Pairas (Payras) of Blois, c. 1650. Painting unsigned. Characteristic *bassine* case, painted all sides, in and out. The choice of a religious subject was common and signaled, I think, to others the loyalties and style of the wearer. Another favorite theme was Greek mythology, which conveyed a different message.

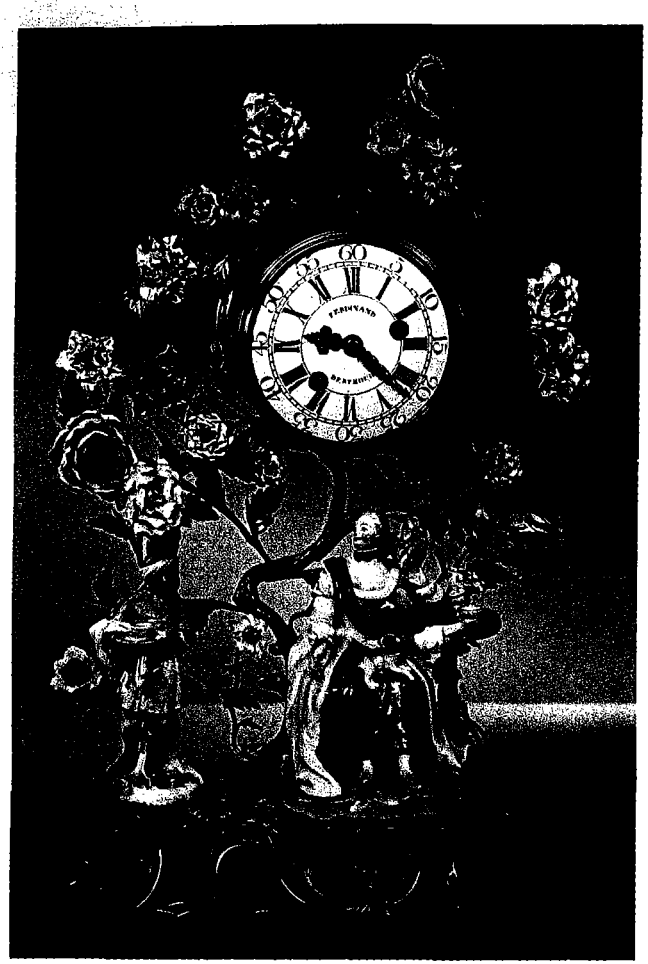

Plate VIII. The high-fashion clock of the mid-eighteenth century: all packaging and presentation. The case here is Meissen porcelain; the clock itself, by the distinguished Ferdinand Berthoud, is incidental. The secret of making hard-paste porcelain, reserved to China for a thousand years, had been discovered at Meissen in the early years of the century, and now polychrome porcelain figures were all the rage. It goes without saying that a clock like this was almost untouchable. Even the winding called for the utmost care, and dusting or moving was just about out of the question. The wonder is that a fair number of these have survived, though almost never without some damage, however slight.

hours by either changing the rate or the reading. The clock will beat faster or slower as the weights on the foliot are closer or farther from the center of oscillation. In principle, then, a mechanical clock could be adjusted as necessary to take account of the changing and different lengths of day and night hours. Such adjustments, though, are at best approximate even with small, easily accessible chamber clocks. They would have been far more difficult with the large tower clocks that marked the passage of time for the general public.

Changing to a variable reading was even harder. It can be done. The Japanese, who retained their variable hours (in every way comparable to the temporal hours of ancient and medieval Europe) even after learning of and adopting the mechanical clock in the sixteenth century, resorted eventually to the ingenious device of movable numerals on the dial of their timekeepers. But they were adjusting these numerals (moving them closer together or farther apart) on chamber clocks; and even so, the results cannot have been very accurate, if only because the changes were made only about once a fortnight.[13] (See Figure 8.)

Medieval Europe did not have this recourse. Remember that many of these early clocks were public, deliberately sited in towers and spires, tens of feet above ground. They usually had no dial, hence no numbers to move about—hardly an option in any case. Instead, as we have seen, these were automated bells. Since there was no practicable way to render the *detent* (release) for the bell train independent of the regular beat of the time train, these clocks perforce marked equal hours; and as they marked, so increasingly did the urban society that depended on them. Perhaps the earliest recorded example of the new, secular time standard comes to us from Sarum, England, where a regulation of 1306 stated that "before the clock of the Cathedral had struck one no person was to purchase or cause to be purchased flesh, fish or other victuals."[14]

The introduction of equal hours and the habituation of urban populations to public time announcements had profound consequences for the European mentality. Medieval man, it has been observed, was innumerate as well as illiterate. How much reckoning could he do in a world that knew no uniformity of measurement? Units of distance were linked to physical characteristics that varied as people do (the English *foot,* for instance, and the

French inch, called a *pouce,* which means thumb); while weights typically were converted to volume standards (a *bushel* of grain) that inevitably varied from place to place and mill to mill. Even the learned were not accustomed to using numbers. The calculation of the calendar, for example—a crucial aspect of liturgical discipline—was confined to specialist computists. The schools offered little if any training in arithmetic, and the very persistence of roman numerals was both symptom and cause of calculational paralysis.

All of this began to change in the twelfth and thirteenth centuries—just as one would expect. This was a period of growing trade, and he who trades must reckon. So must clerks and functionaries who count taxes and expenditures, and these were years of rapid development of royal power and government apparatus. It was no accident that arabic numerals came in at this time, or that books that had once resorted to metaphor now gave numbers, however erroneous, of armies, treasures, buildings, and the like.[15]

It was the urban, commercial population that seems to have been quickest to learn the new language and techniques. Arithmetic was the province above all of the unlettered speakers of the vernacular (as opposed to Latin). Many of these learned arithmetic in the shop or on the road, but even before they entered trade, they learned to count by the bells of the clock. Not by the old church bells ringing the canonical hours; these did not mark equal units and hence did not lend themselves to addition and subtraction. But the new bells and the calculations they made possible (how long until? how long since?) were a school for all who listened and began to organize their lives around them.[16] Meanwhile the church clung to old ways and, so doing, yielded the rhythm of life and work to the lay authorities and the bourgeoisie. Equal hours announced the victory of a new cultural and economic order. Here indeed was an unintended consequence: the monks had wrought too well.

THE EARLY TURRET CLOCKS were very expensive, even when simple. Wrought iron and brass needed repeated hammering, hence much labor and much fuel. The casting of the bells was a precarious operation. The placement of the mechanism usually

entailed major structural alterations. We shall see later that the construction and installation of a tower clock might take months, if not years; that teams of craftsmen and laborers had to be assembled on the site and there lodged and boarded; and that the task of subsequent maintenance required the permanent attendance of a resident technician, repeated visits by specialized artists, and an endless flow of replacement parts. Constructing a clock was not the same as building a cathedral, a project so costly that it engaged the surplus resources of an entire community, to the point of extenuation.[17] But it did entail a substantial and continuing commitment, usually by the public authority, in the name of the common weal.

These costs increased substantially as soon as one went beyond simple timekeepers to astronomical clocks and automata. The medieval accounts show this process clearly: the sums paid to painters and woodcarvers bear witness to the growing importance of the clock as spectacle as well as time signal. The hourly parade of saints and patriarchs; the ponderous strokes of the hammer-wielding jacks, the angel turning with the sun, the rooster crowing at sunrise; the lunar disk waxing and waning with the moon—all these movements and sounds offered lessons in theology and astronomy to the up-gazing multitude that gathered to watch and wonder. The clock as pageant was an imitation of divine creation, a miniaturization of heaven and earth. As such it was a source of immense pride to the kings and communes that built it, a challenge to all kingdoms and cities around. The show clock was to the new secular, urbanizing world of the later Middle Ages what the cathedrals had been to the still worshipful world of the high Middle Ages: a combination of sacrifice and affirmation, the embodiment of the highest skills and artistry, a symbol of prowess and source of pride. When Philip the Bold of Burgundy defeated the Flemish burghers at Rosebecke in 1382 and wanted to punish those proud and troublesome clothiers, he could do no worse (or better) than seize the belfry clock at Courtrai and take it off to his capital at Dijon.

This symbolic (totemic) role of the clock goes far to account for the rapid diffusion of these instruments in western and central Europe. A show clock was a matter of prestige, an edifying spectacle for residents and visitors alike. In this sense, clocks were the secular analogue to the religious relics that had long been the

most potent attraction to pilgrims and travelers. Cost was a secondary consideration, and the multiplicity of autonomous chartered communes with substantial tax revenues of their own provided a ready demand. (Such communes, be it noted, were a uniquely European phenomenon, not to be found in Islam or East Asia.)

These public clocks, moreover, were only the top of the market. They are the ones that history knows best, but we know only a fraction of what was made. In this regard, the records are misleading: they have preserved the memory of a spotty, biased selection and largely omitted the smaller domestic clocks made to private order. As a result, it was long thought that the first mechanical clocks were turret clocks and that the smaller domestic models were the much later product of advances in miniaturization. Yet there was no technical impediment to making chamber clocks once the verge escapement had been invented. Indeed, Antonio Simoni has persuasively argued that since the mechanical clock was a development of the timer alarm, itself made to chamber size, small clocks must have preceded the big turret machines.[18]

Whichever came first, the one logically implied the other, so that we may fairly assume that both types of clock were known and made from the start. It so happens that the first literary allusion we have to a mechanical clock refers to domestic timepieces. This goes back to the late thirteenth century, in Jean de Meung's additional verses to *Le roman de la rose.* Jean, a romantic poet of curiously worldly interest, attributes to his Pygmalion a fair array of chamber clocks:

> Et puis faire sonner ses orloges
> Par ses salles et par ses loges
> A roes trop subtillement
> De pardurable mouvement.
>
> And then through halls and chambers,
> Made his clocks chime
> By wheels of such cunning
> Ever turning through time.[19]

From the middle of the fourteenth century, chamber clocks show up in inventories and accounts. Chancellery records of Aragon, recording clock purchases by the royal family, mention more

than half a dozen master clockmakers, producing simple and complicated timepieces, transportable (from the middle of the century) as well as fixed.[20] And the inventory of the personal possessions of Charles V after his death in 1380 mentions among other things a clock all in silver "without iron," with two silver weights filled with lead, apparently made toward the beginning of the century for his ancestor Philip the Fair (died 1314).[21]

These were, of course, the furnishings of kings, which have a way of being remembered. There were many more clocks, surely, that were made, went out of order, were cast aside, and disappeared unnoticed. We may reasonably infer this from the numerous references to clockmakers. The clock lists show pieces in some very small and unexpected places, no clocks in some important cities, and only a handful of clocks in the greatest centers. A handful of clocks in London and Paris? There must have been ten times that many and more by 1400. If a clockmaker could make one, he could make many, and there were probably dozens of clockmakers active in Europe by the end of the fourteenth century.

This rapid emergence of a new profession was at once a strong force for improvement in quality and reduction in costs, hence a stimulus to demand, and the best sign of the popularity of the new device. Few inventions in history have ever made their way with such ease. Everyone seems to have welcomed the clock, even those workers who toiled to its rules, for they much preferred it to arbitrary bells. Indeed, one of the themes of contemporary observers was the usefulness of the clock to people of all walks of life: *summe necessarium pro omni statu hominum* was the way Galvano Fiamma, chronicler of Milan, put it, when he proudly marked the restoration in 1333 (?) of a clock that not only struck the hours but signaled each one by the number of peals.[22] And this in turn recalls an earlier inscription on a clock installed in 1314 on the bridge at Caen: "Je ferai les heures ouir / Pour le commun peuple rejouir" "I shall give the hours voice / To make the common folk rejoice").[23]

Even the poets liked the new clocks. That is the most astonishing aspect of these early years of mechanical horology, for no group is by instinct and sensibility so suspicious of technical innovation. Here, moreover, was an invention that carried with it the seeds of control, order, self-restraint—all virtues (or vices) inimi-

cal to the free, spontaneous imagination and contemplation so prized by creative artists. Yet it would be anachronistic to impute these ideals to the thirteenth and fourteenth centuries; they came much later. The medieval ideal was one of sobriety and control, along with due respect for worthy models. Besides, it was surely too soon to understand the potential of the new device for forming the persona as well as for dictating the terms of life and work. Instead, the availability of this new knowledge gave all a sense of power, of enhanced efficiency and potential, of ownership of a new and valuable asset; whereas we, living by the clock, see ignorance of or indifference to time as a release from constraint and a gain in freedom. When we go on vacation, we want to be able to put our watch in the drawer and not look at it until we return to the "real" world: that is the essence of what the American armed forces call R & R (rest and recreation). Everything depends, I suppose, on where one is coming from.

In any event, the early celebrators of the clock were no mere poetasters. The great Dante Alighieri praised the "glorious wheel" moving and returning "voice to voice in timbre and sweetness"—*tin tin sonando con si dolce nota* (almost surely a reference to a chamber clock, unless Dante had a tin ear)—therein echoing the pleasure that Jean de Meung's Pygmalion took in his chiming clocks a generation earlier.[24] And a half-century later Jean Froissart, poet but more famous as historian, composer of "love ditties," sang in his *L'horloge amoureuse* (1369) a love song to the new machine:

> The clock is, when you think about it,
> A very beautiful and remarkable instrument,
> And it's also pleasant and useful,
> Because night and day it tells us the hours
> By the subtlety of its mechanism
> Even when there is no sun.
> Hence all the more reason to prize one's machine,
> Because other instruments can't do this
> However artfully and precisely they may be made.
> Hence do we hold him for valiant and wise
> Who first invented this device
> And with his knowledge undertook and made
> A thing so noble and of such great price.[25]

II KEEPING TIME

The mechanical clock began as a crude, imprecise, unreliable instrument. It took four hundred years to turn it into an accurate timepiece.

It proved much easier to do what seems at first thought a harder task—that is, adapt the principles of clockwork to complex mechanisms for tracking the heavenly bodies or driving ingenious automata. Within less than a century after the invention of the mechanical clock, we have the masterpieces of Richard of Wallingford and Giovanni de' Dondi; more important, we have a rapidly growing array of show clocks—the legendary Strasbourg cathedral tower clock is a spectacular example—combining fanciful astronomical and temporal indications with a pageant of moving figures, historical, mythical, and symbolic. These mechanisms called for esoteric mathematical calculations, clever and sometimes original mechanical arrangements, and extraordinary craft skills. Even so, the essential problem, that of linking different rates of circular (hence angular) motion by appropriate systems of gearing, was an old one and had been solved as far back as ancient Greece.[1] By using the right ratios of wheel teeth and pinion leaves, along with a mix of round and not-so-round wheels, one could track the sun through the zodiac (easy), reproduce