FIRST DRAFT

THE INVENTION OF THE MECHANICAL CLOCK

AND THE BEGINNINGS OF MODERN EUROPEAN SOCIETY

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Abstract

There is little doubt, that the invention of the mechanical clock as one of the first inventions made in Western Europe without clear antetypes in antiquity or the Muslim world had serious consequences for thinking and behaviour even in the everyday life at the end of the 13th century. This shift exerts influence on modern Western societies that continues to today. It is therefore significant to consider, why this invention was made in Western Europe, what were the preconditions of this invention and (if it is possible), to fix the date of this invention as clear as possible.

The first question shall be answered by examining the changes in the concept and cognition of time and its relation to historical circumstances, the expectation of the Judgement Day in near future and the broader extension of the idea of purgatory. For the second question new concepts in natural sciences as the analysis of the laws of crank and pneumatic devices on the one hand, the discussion on the role and interpretation of Aristotelian philosophy in Paris between 1270 and 1277 on the other can help to clear the terms of the invention. The question for the date shall be discussed by the help of the common handbook of astronomy at medieval universities and a special addendum to it for the terminus post quem, special developments in music theory for the terminus ante quem. Finally a short outlook of the consequences of this invention will be given.

Keywords:
time – measurement – hour – clock – medieval society and thinking – Aristotle – music

(I. section title?)

Management of time – even more important than measurement of time – is one of the most fundamental tasks and challenges of every human society. From the era in which first communities settled on one place for more than one generation as in Anatolia around 10.000 years B.C. [...] observation of the sky, especially sun and moon enabled people to fix important dates for agriculture in the course of year. So it is not astonishing that thousands of years ago monumental constructions, perhaps used for religious rituals too, had been erected to celebrate solstice in summer and winter and/or monitor the different overlapping periods of the moon. These long-period observations had been conducted carefully, so it became not only an obvious fact for priests or rulers of these societies that the different cycles and repetitive events on heaven and earth do not match in a simple way. It was also clear, that complex structures for the management of time could not become reduced to one single and tangible unit for time- measurement. The result of this comprehension of time-units we can see in our calendric system today. We live with additional days to correct the difference between the duration of the solar year and a discrete number of days, whilst our months differ from the duration of moon-phases (some societies even preferring a double calendar related to the moon and sun). The interesting point for our considerations here is, that even for the construction of time-units which are based on astronomical given facts, there remain underlying determinations which are not derived from these astronomical facts but instead from religious or even abstract principles. So for instance a year, consisting of 13 months with 28 days per month – which would fit better to moon-phases and even to the Jewish order of the week – would have only a difference of a little bit more than one day to the correct solar year. This would offer a simpler and more practical solution than our current system of months and years which is based on the religious and number conceptions in the area of Mesopotamia around 3000 years ago [...]. The tension between the physical and astronomical facts and the every-day-use of time units influenced not only our practical knowledge of time, it seems that it also affects theories and understanding of time fundamentally, especially in the matters of time-structure which cannot become related to these physical and astronomical facts in an other than arbitrary way. Concepts of time and time-measurement get some spe-

> cial high-handed character. This can be seen in the concept and measurement of the hour, which links the astronomical based time-units as day, month and year with the corporal rhythms of breathing, heart beating and pulse. The duration of an hour is apparently highly arbitrary, though attempts to introduce other durations (e. g. to establish a decimal system also in time-measurement [...]) had not been successful. The reasons for this may be found in deep-rooted traditions of dividing the duration of a day; perhaps psychological or psychosomatic factors may also play a role. The crucial point, however, is, that the duration of an hour is not a fixed quantity of time until the invention of mechanical clocks.

This seems amazing, especially because the hour is the most important time-unit for every-day- life – everybody uses it day to day – and since antiquity different tools for a sufficient measurement of the duration of an hour had been invented. This could be such a rather simple (but expensive) tool like a candle, a sand-clock or much more sophisticated constructions like the so-called clepshydra (water-clock [...]). The reason for the on-going success of the "breathing" hour, an hour whose duration depends on seasonal fluctuations of the length of day-light and is measured by the help of sundials, apparent from its fit best to the organization of life in societies which depend a lot, not to say at all, from daylight. It makes no sense for a peasant to stay at home after sunrise in summer only because a clock tells him that it is not yet 6 o'clock in the morning. It's the same for a stonecutter on a building site of a cathedral; he should not get up in darkness in winter only because a clock demands this. His work – lighted by candles or even torches – cannot be done as accurate as necessary without daylight. Even in libraries work could not start before dawn and had to end at dusk – (although here questions of fire hazard may play a role too). The only relevant social class in medieval societies, which could have benefitted from an hour-measurement, based on a clear and fixed duration would have been monks. They had to organize their so-called "Hours" of singing and preaching in day and night-time: in summer they had little time to sleep, because the obligations of the Hours do not left over much time in night. In winter there was little time to work during the day for the same reason. However, the mechanical

clock was not invented in a monastery in the late 13th century, as is commonly supposed [...]. Be that as it may, the fact, that this mechanism was not only successful but also widely adopted in Western Europe immediately after its invention, needs a convincing explanation. But another point also needs such an explanation. The mechanical clock driven by a weight and possibly by the help of a balance wheel is certainly a smart invention; compared with mechanic constructions and automata like the famous mechanism of Antikythera [...], the astronomical clocks build in Muslim territories like al-Jazaris automata (especially his so called "Elephant Clock") and the connected considerations of al-Ghazali [...] or described in the Libros del saber de astronomia from Spain [...] it is rather simple. To make matters even worse: Muslim astronomical research and science had such a high level, that's not possible to suppose that the lack of a clear and fixed time-unit for the hour should for them felt less uncomfortable for the further processing of the observation data than Robertus Anglicus expressed in 1271 [see below].

> For me the only possible explanation for both questions is: the concept and the perception of time had changed in Western Europe in the 13th century so much and in such a way, that a stable, calculable and countable unit was not only useful, it became necessary. This shift is clearly connected to Western Europe, so it must have reasons, which appear in Western Europe only or in a special way.

I see two different but syndetic reasons for this shift. Both lie in the religious sector and are related to special, but in the consequence fundamental transformations of the interpretation of Christian doctrine. The first one is strongly related to a phenomenon, which appears consistently in the history of church and more or less Christian societies. Christ has promised his Parousia, so his believers want to be prepared for his second coming. Special external influences like cruelties, wars or epidemic events, special years (as the year 1000 P.C.) could let grow more or less nebulous apocalyptic feelings and phenomena or give rise to chiliastic and apocalyptic movements. As in other eras (such as the 16th century) this role could be

played by calculations, which are done by the help of the very dark and unclear relations to the prophecy of the end of all days with numbers, which could be found in the Bible. Such calculations are done in small circles, but their ideas could penetrate larger groups in the society especially if the special historical situation let emerge some resonance for the expectation that the end of time is near. It is clear, then, why people want to have a clear and countable unit of time to calculate this end. But why was this end expected in the second half of the 13th century? On the one hand the end of the gospel of Matthew [...] there Jesus assigned his disciples to bring his message to all people until the end of the world, was seen as prophecy of the end. In the moment all nations, the whole mankind had heard the Christian message, Jesus should not have any reason to hesitate to come again. This situation at the end of the 13th century seems not any more an expectation far away. On the other hand, the influence, even the existence of churches outside the roman- catholic tradition disappeared after the 4th crusade nearly totally. Concurrent religious movements could be seen as heretics, who are not able to hinder the coming of Christ but may be part of apocalyptic struggles and wars. In this situation, a (later banned) Jewish rabbi from Spain, Abraham Aboulafia [...] started hidden activities based on his cabalist readings of the Scripture, the so called Sepher Jezira and other texts, to prepare for the end of the present aeon he expected in the nineties of the century. It's highly astonishing, that he was strongly supported by Christian monks and followers of Joachim of Fiore, who had speculated one hundred years ago about a new order of the world, he called regnum tertium. They even helped Aboulafia to realize his – at the end, failed – plan to convince the Pope to become a Jew [...]. In a situation in which Christians and Jews work together to prepare the end of all times, the time itself shifts from a given structure of every-day-life which takes place in the natural order and rhythms of days, weeks, months, seasons and years, and to a "time that is left", to years, months, days even hours which not only have to be calculated to be prepared but to be used as a "last chance" before no chance is left.

This leads directly to the second point: as much as the time "here on earth" becomes "time

that is left", a last chance, the time in the expected world after death also gains a clear time-structure. Hence in the early church sometimes a "third place" between heaven and hell was reflected, the idea of purgatory became more and more popular and influential in Western Europe after the nonappearance of Christ in the year 1000. Hence this doctrine became dogma in the roman- catholic church not before 1439 [...] the general acceptance and influence of the idea, that every person – in normal cases – will be punished for a fixed time in purgatory before this person can ascend to paradise. This can be seen in Dante`s Divina Comedia, where the descriptions of the "third place" take a whole part of the book. But if the punishment in purgatory and its duration is clearly connected with special misbehaviour or special sins, then it should be clear, how the calculation of this duration of punishment works. Though this duration normally is seen as a number of years and not of months, days or even hours – in comparison to eternity even years are a "short time" – when time becomes a real currency in front of heaven's gate, then it should be clear how this currency is counted and how the calculation works. The duration of the fixed unit of time here is not as much a question how long or short it is. Importantly, only a fixed unit can be counted and can be related to other currencies: prayers, pilgrimages, acts of mercy and – as to be expected – at the end: money. It's not a surprise that, if time in the after-world can be paid, then time also on earth can be paid, can be bought or sold. For this a tool like the mechanical clock is absolute necessary.

(II section title?)

When we look now to the preconditions for the invention of mechanical clock in the practice of natural sciences we find comparable ideas to the "third place" in religious thinking and believing. Based upon the research of air/gas in antiquity [...] and special considerations in Muslim science since 9th century Western scientists in the 12th century such as Richard de Fournival in his Excerpta de libro Heronis de specialibus ingeniis [...] found out, that it is necessary to suppose something "third" as property in constructions like pneumatic ma-

chines, what cannot assigned neither to "real/natural" nor to a spiritual sphere or the area of imagination. Iordanus Nemorarius [...] discusses in his work De ponderibus [...] the fact that the power, which is necessary to lift up heavy objects, depends on the length of a crank. The same person, who is not normally able to lift something, can do this by the help of a construction, which adds the power is necessary. But where does this power comes from? Is this power "real" in a natural sense? It's clear, that one cannot suppose that some angels or demons reside in the crank. Rather, a virtual reality must be accepted, which is not "potentia" in an Aristotelian sense; it's a real property of a mechanical device, which unfold effects again and again. It seems that this idea does not really correlate to the situation we find in the construction of the mechanical clock. The weight must wind up – but this is the result that the rope of the weight has a special length. The power that makes the clock work is the well-known force of attraction of earth, not some mysterious virtual property of the construction. But as much as we can suppose, that the ideas of Iordanus helped to construct the balance-wheel, we see that it is much more the idea of time itself, which departs form the dichotomy of the opposition of "natural" and "supernatural" or "natural = in reality" and "conceited = in soul". This seems more than a more or less metaphoric assumption we can learn from the dispute between the archbishop of Paris Etienne Tempier [...] and his consultants with the proponents of Paris University concerning the proper way of interpretating the work and ideas of Aristotle [...]. An ardent debate took place not only in Christian theology and philosophy but also in the Jewish community [...]. Tempier accused his opponents of teaching an interpretation, which follows the Arabic tradition, especially that of Averroes; with the result that one must suppose a "double truth". A truth based on theological considerations and another truth is based on reason, natural sciences and/or philosophy. In 1270 and again in 1277 Tempier succeeded in the damnation of this idea of "double truth"[...]. This debate and its result are important for our question in a double sense. In general this damnation – as fatal it was for theology as science – paradoxically for the natural sciences even philosophy and their practice was something like a lucky chance. In this case the practice resigns the claim of absolute truth, then it could be done in free-

dom. This maintained the fast development of scientific thinking and research in Western Europe. On the other hand under these conditions the practice created something what was later called German Weltbild [...]. Scientific work takes place as construction of something, which not only can become modified; it can be changed or even replaced. The virtuality discovered as property of mechanical devices becomes the characteristic of scientific research at all. In respect to the question of time and its measurement the debate gives us an important clue: One of the advisers of the Paris archbishop was the well-known Henry of Ghent [...]. He wrote a treatise in the question of time [...], especially to find out, if the ideas of St. Augustine [...] could be connected or even unified with the teachings of Aristotle [...]. He had to discuss the question of how "time" can be real, if the past is gone and the future not yet happened, but he has to try to avoid the proposition, that "time" is only "conceited" (in soul). He used some different statements of Aristotle in his Physics [...] to go from the traditional imaginatio (imagination)whichfollowsPlotin[..."τὸνχρόνονεἰργάσμεθα"–We haveinventedtime]to the conceptus which is in theory some similar idea as "third place" as in mechanics the virtuality [...].

So we see, that in the years after 1270 in the scientific discussion an idea of time was developed, which could save the "existence" of time as well as its freedom from astronomic or corporal facts in a virtual concept which was flexible enough to state an arbitrary unit as fundamental and fixed element of a construction of time in which every duration can be connected and calculated by help of this unit.

(III subtitle?)

After this it seems rather remarkable that the notice we owe the knowledge about the terminus post quem of the invention of the mechanical clock explicitly the fixed unit of time

relates to astronomical facts. In 1271 a commentarius of a certain Robertus Anglicus [...] to the most influential and widespread manual of astronomy at medieval universities, the De sphera by Johannes Sacrobosco [...], appeared. In this commentarius this "English Robert" asserts (much to his regret), that there is no trustworthy tool yet, that would make it possible to divide the time from sunrise to sundown on the day of solstice in such a way, that 12 equal units evolve and that these units – hours – could be repeated again and again in exactly the same duration. He even proposes himself a technical solution for this problem: he describes a great wheel, which, connected with a weight of lead, should be able to rotate exactly one time from sunrise to sunrise on the day of solstice. The aberration of 1 degree per day, Robertus proposed to correct by means of an astrolabe. It's clear that this solution cannot work: even if the problem of a perfect wheel bearing were solved, the speed of the wheel would increase. Also the solution of Peter de Maricourt [...], to organize the construction by the help of magnetism like a "swimming compass needle", may sound theoretical interesting but is far away from being really built. However we learn from these suggestions to solve the problem of the fixation of the "astronomical hour" [...]. In the seventies of the 13th century many people made efforts to construct a technical tool for exact measurement of time. If the "English Robert" of the commentarius is in fact the same person as the known scholar in Montpellier in the second half of the 13th century, then we can be sure, that the mechanical clock was not invented before 1271. A scholar in Montpellier would have known something about such an invention, especially because it is widely accepted that this invention was made in northern Italy or southern France. The fact, that the ideas of the scholars we know by name are rather far away from practical use, let the hypothesis seen probably, that we owe this invention a gifted "artifex".

While the situation concerning the terminus post quem is clear, it remains problematic to give an answer about to the question of the terminus ante quem. We know that the mechanical clock was a great success. In the decades after 1300 nearly everywhere churches,

> town halls, gates, bridges were furnished with clocks. Between 1321 - 1325 Roger Stoke constructed an astronomical mechanism for the Norwich cathedral, and by around 1330 Richard of Wallingford constructed his famous and highly sophisticated astronomical clock for the abbey of St. Albans [...]. Since the treatise of Richard [...] raises more questions (especially regarding the crucial balance wheel) than would be good and the list of clocks in Italy from the beginning of the 14th century are not clear enough, most investigators of this question agree to see the terminus ante quem not much before 1330. [...]

Ultimately, a perfect answer to the question cannot be given until new clear sources appear or an artefact, a mechanical clock, that can confidently be dated, is found. Though I cannot present such a source concerning the construction of mechanical clocks or such an artefact, I want to propose the hypothesis, that this invention was made earlier, even before 1300. The proof may seem weak at first glance; but my impression is, that if we can fix a fundamental shift in the dealing with time in an art like music, which is strongly connected with time, then it can be justified to use these important texts and their relation to musical practice as resources to bring our question closer to an answer.

(IV subtitle: e.g. The management of musical time?)

After the beginning of what we call part music today a little bit more than 1000 years ago, the question of coordination of the different voices in codification and in practice arises for musicians. The important questions (especially for music theory) of possible pitches, scales and intervals, and the question of tuning can be set aside here. The crucial point in codification and in practice at hand is the organization and the management of time. It is quite impressive how soon and how convincing the first graphical solutions of these problems in the 9th century are. We see diagrams in which the voices are arranged like in a Cartesian coordinate

> system. It is seen very clearly, what happens together and which pitch-combination succeeds its precursor. This works quite well so long as both or more voices change the pitch mostly in the same moment and longer melodic fragments, "melismata" do not appear. From the 11th and much more 12th century, however, this constraint was no longer effective (if it ever was in real musical practice). In writing and singing rules had to be established. These made it possible to coordinate and connect the voices in a more or less calculable way. The graphic solution – to use graphical characteristics, which had widely lost their original meaning in Gregorian chant – seemed convincing, but we learn from the different theoretical treatises [...], which deal with the problem of time-structures, that this solution, better to say, these solutions are less appropriate to practical questions and purposes than thought. If one does not suppose – what is possible – that the several deficiencies in the system of writing and its interpretation would be used as invitation for a more free way to realize the music (today we might call it "improvisation"), then a better and clearer system for time-management in part music should be found.

Though theoretical treatises used the term "measure" in their title, the problem of exact measurement proves to be the obstacle in solving the problem. "Musica mensurata" ("measured music") normally means part music, not in our sense "music, that is measured". The reason for this problem is, that theoretical authors tried to use rhythmic meters, derived from the well- known metrical feet of poetry in antiquity, as means to measure time in music. This may give music a common rhythmic "drive", but rather sophisticated structures and parts cannot be solved in this way. It's a familiar phenomenon for every musician who plays medieval music originated before the second half of the 13th century, that it is nearly impossible rewrite the medieval music in modern standards without at least slight "adoptions" (or more roughly said: cheating). Even in the treatise of Johannes de Garlandia, De mensurabili musica [...] we find a phenomenon called organum purum, which require such operations.1 What Willi Apel in his Die Notation der polyphonen Musik 60 years ago stated [...], is not disputed, it is common sense until now: the system, Franco in his treatise established, makes

for the first time music measurable in a strict sense of the word. From rhythmic structures inspired by antique poetry we now have constructions of time units, which can be measured, counted and combined. To call the music of this era "musica mensurata" is true in a strict sense only after Franco's treatise. My assumption is, that this fundamental shift was possible not only because the idea of a fixed time-unit was "in air" in the late 13th century, but it was also possible because this time-unit was invented. I do not know how and how much Franco could know about such a new device of time measurement. In the inspiring and international atmosphere of the university of Cologne, where some of the most influential thinkers of this time had been teachers and published their works the knowledge of new developments and tools can be supposed earlier than somewhere else.

> If my hypothesis is correct, then music and its practice became the first area, in which the new conception of time had an impact that changed this field of human activities for more than 100 years. We know that the ideas of Franco became influential very soon and affected musical notation and practice until the 16th century. [...] This would be much easier to understand (as the success of the mechanical clock) if we suppose, that the mechanical clock did not only accompanied this success, but gave the visible (and audible) time-structure what made the time- unit based music after Franco's revolutionary ideas possible.

At the beginning of the 14th century the amazing success of the mechanical clock human societies, even human existence brings back to the very beginning of European scientific thinking: one of the first conveyed fragments of philosophy is attributed to Anaximander, who said: "Whence things have their origin, there they must also pass away according to necessity; for they must pay penalty and be judged for their injustice, according to the ordinance of time" [...]. The difference between the time of the 6th century B.C. and the high middle age is, that a small mechanical device replaces the "ordinance of time" as universal, common system of the whole cosmos. As before the old Christian time-structure, which

was determined by the expectation of the second coming of Christ, changed to a time-management in which >time< is the price label at heaven's gate. This time-management is expanded to the every-day-world and merciless ruled by the mechanical clock. The new fixed hour can be sold and bought, the working day becomes expanded – first in sectors, where daylight is not necessary as in mining or less important as in the textile mills of Flanders [...], then everywhere. At last – as the adage goes: "Time is money!" at all. Money now reigns the world by the help by an automatically driven time. In a way Max Weber may be right in his thesis that the "spirit" of capitalism is a result of theological considerations. [...] But much more than John Calvin's theory of predestination capitalism is the fruit of the possibility to convert everything in a monetary commodity, even time. The peculiar and troubling aspect of this fact is not only, that this structure works in societies until now and forms a nearly worldwide effective system of working and living. The real disturbing fact is, that this system is ruled by a small ticking machine, that produces a fiction.

(oder: V postscript?)

It seems a remarkable and instructive fact that differences between Western European and the Muslim societies can be shown by the use of three mechanical devices: the organ, the printing process, and the clock. Muslim societies knew organs very well from the Byzantine Empire. They even built impressive and highly sophisticated instruments, but they used them like toy boxes or prestige goods. [...] In Western Europe the organ with its keyboard – even more its successor, the piano – became the signifier of all music, because it rules the possible pitches. [...] Similarly, in Muslim countries where the printing press was used, it was mostly a failure in contrast to Western Europe. Arabic writing, with its many connections between letters and a deep-rooted tradition of calligraphy largely prevented the success of printing. [...] Even the mechanical clock had not the same influence to Muslim societies

as in Western Europe. As can be seen in the rules of Ramadan (as well as in the rules of the Jewish Sabbath), these societies resisted the totality of a mechanical device, which reduce all durations and rhythms of life to a simple and countable unit. In all three examples we see the same: the success of mechanical devices in Western Europe, which can be simple, because they reduce the diversity and multiplicity of life and thinking to scales of discrete pitches, a small quantity of discrete letters and a unit of time, which can be used independently from corporal and natural existence. Should we be astonished that this reduction to the set of natural numbers at the end brings the Western societies under nearly total rule of black and white, of "zero" and "one"?

[1] Here is not the place to discuss the rather difficult and, in a way, dark background and identity of this medieval author – he even appears in the 17th century(!) as "hermetic writer"; the important point is, that this work shows us, how important the shift to the treatise "Ars cantus mensurabilis" by Franco of Cologne [...] is, which appears around 1280.

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