Uncovering a masterpiece of Roman engineering: The project of Via Appia between Colle Pardo and Terracina

Giulio Magli [a], Eugenio Realini [b,*], Mirko Reguzzoni [c], Daniele Sampietro [d]

[a] Faculty of Civil Architecture, Politecnico di Milano, Milano 20133, Italy
[b] Research Institute for Sustainable Humanosphere, Kyoto University, Uji Kyoto 611-0011, Japan
[c] Department of Civil and Environmental Engineering, Politecnico di Milano, Milano 20133, Italy
[d] Geomatics Research & Development, Como 22100, Italy

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1. Research aims

Via Appia or Regina Viarum, the unequalled masterpiece of the Roman roads, is analysed for the first time with high precision GPS techniques and shown to have been planned in accordance with a sophisticated project that took into account geometry and astronomy in both a practical and a symbolic way.

2. Introduction

"*Appia longarum teritur regina viarum*", Appia is the queen among the longest roads. This famous statement, written by the Roman poet Statius, celebrates the road constructed by Appius Claudius (appointed censor in 312 BC) as an outstanding masterpiece of Roman engineering. We shall be interested here especially in the first section of Via Appia, from Rome to Terracina, which is composed by two straight segments connected by a short zigzag section aimed at crossing the Alban hills at Colle Pardo, and in the associated centuriation of the Pontine marshes. The first segment, starting from Rome, runs straight for about 26 km and the second one proceeds straight to Torre Elena, near Terracina, for as much as 61 km. A very long section of this path, about 41 km from Cisterna di Latina to Torre Elena, is covered by the modern road which has been traced along the ancient one. A few visible remains, such as Clesippo's mausoleum in Mesa, survive however here and there along the modern road, as well as scattered blocks of the ancient *crepidines* (platforms) on the west side. We present a map of the road in Fig. 1, warning the reader that all our maps (Figs. 1–4) are in Mercator projection.[1]

The builders of this road achieved almost incredible technical results, as already described in the literature (see e.g. [1,2]). However, to our knowledge, no author has ever tackled in-deep with the *project* of the road and, in particular, of its longest and spectacular segment. It is in fact known that the path proceeds with impressive straightness, but – in spite of the fact that tracing a virtually straight line for several tens of kilometres is a very difficult problem – no *quantitative* estimate of the accuracy of the project exists; actually, the azimuth of the road is usually taken to lie along the inter-cardinal north of west-south of east line, which, as we shall see, is not true.

* Corresponding author.
E-mail addresses: giulio.magli@polimi.it (G. Magli), eugenio_realini@rish.kyoto-u.ac.jp (E. Realini), mirko@geomatica.como.polimi.it (M. Reguzzoni), daniele.sampietro@g-red.eu (D. Sampietro).

[1] This projection was chosen because it represents lines with constant bearing (i.e. loxodromes) as straight segments, keeping their direction with respect to the true north unchanged. On the other hand, of course, distances (which are less interesting for this work) are altered, thus the scale bars on the figures were added just as a reference and they should not be considered exact. The digital terrain model used as a background was extracted from the elevation data provided by the Shuttle Radar Topography Mission (SRTM) by NASA [3]; contour lines were obtained from the same model, with an interval of 250 m.

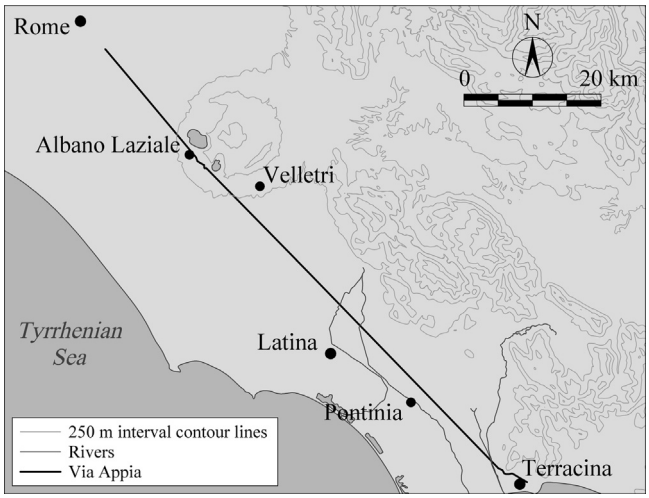

Fig. 1. The first section of Via Appia, from Rome to Terracina.

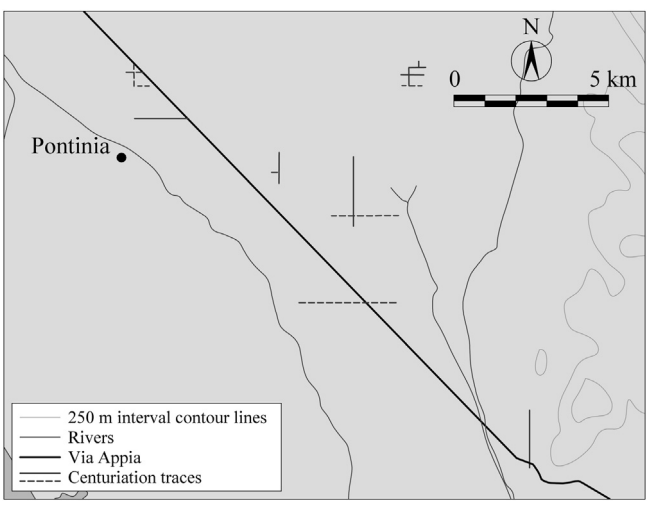

Fig. 2. The existing traces of the centuriation of the Pontine Marshes (dashed lines indicate traces found by Cancellieri and confirmed in this work; continuous lines indicate traces that were found in this work).

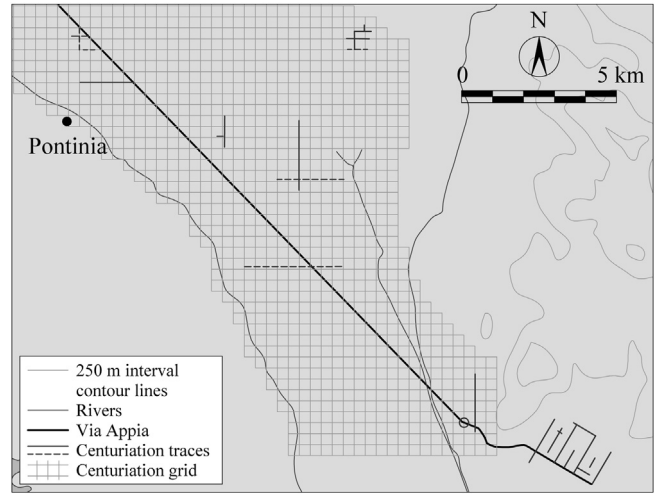

Fig. 3. Reconstruction of the centuriation of the Pontine Marshes. The small Roman centuriation near Torre Elena is also shown.

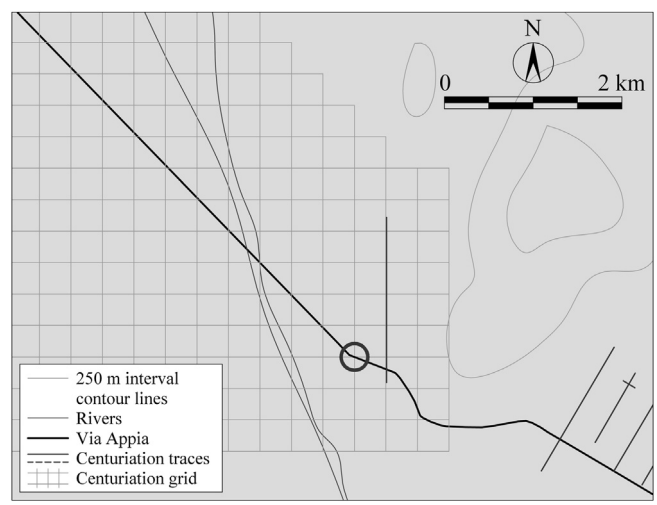

Fig. 4. The relationship between the straight path of Via Appia and the (extrapolated) centuriation grid in the area of Torre Elena. The intersection node which was likely the starting point of the project is highlighted.

The research presented here thus started with the aim of understanding how, and to what degree of accuracy, the Roman architects solved the "straightness" problem. In addition, we were interested in the motivations which led them to adhere to such a rigorous, apparently exaggerated master plan, and in the possible role of astronomy in the project. To study these problems, as we shall see, it is necessary to take into account also the ancient division of the land (centuriation) that the Romans planned in the same area. Our approach therefore considers the ancient landscape and the sky as a whole, as modern Archaeoastronomy aims to do [4–6]. As such, the methodology we develop here can be applied in the future to several other interesting cases in which ancient roads were deliberately traced along straight segments; in particular, we plan to study the case of the Roman Roads of Britain and that of the Maya sacred roads.

3. Methods

3.1. The survey of Via Appia

The use of high precision GPS survey is nowadays quite standard for obtaining precise azimuths of well-preserved monuments. For instance, one can obtain measures as precise as those of a theodolite, or better, in measuring the orientation of temples or of ancient town's axes. The problem here was, however, to measure with very high accuracy an "object" as long as several tens of kilometres. Our GPS survey has therefore been performed on the whole drivable segment. The path of the ancient road has then been further extrapolated from satellite images and local surveys along some 20 km north-west of Cisterna di Latina.

The GPS measure was made using a single-frequency receiver (u-blox AEK-4T) and the goGPS software[2] [7]. The GPS antenna was positioned on the rooftop of a car, driven from Cisterna di Latina to Torre Elena, with the receiver recording measurements at 1 Hz. The coordinates of more than 5000 points were estimated by applying the double differences method [8] using the GPS permanent station of Latina as base station, every point with an expected accuracy of less than 1 m. The direction of the line interpolating the points was estimated by applying the least-squares principle [9,10]. In order to validate the result, a second survey was performed with a dual-frequency Leica 1200 system GNSS receiver, which was used to estimate the coordinates of three points (at the ends and in the

[2] http://www.gogps-project.org.

centre of the path). Their coordinates were estimated by static surveying (lasting about 15 minutes) and also in this case the observations were elaborated by double differences using the permanent station of Latina, thus obtaining an accuracy of the order of less than 5 cm [11]. The dual-frequency GPS receiver could not be employed over the complete road segment because of the dense foliage that covers most of it, not allowing for centimetre-level positioning. On the contrary, the u-blox AEK-4T single-frequency receiver could be employed since it is a high-sensitivity receiver, its lower positioning accuracy partly compensated by goGPS Kalman filter algorithm [11,12].

Our results have a maximum estimated error of $\pm 10'$. This error arises as the sum of two terms: the GPS observation error propagated to the azimuth estimate, which however is of the order of few arc seconds, and the model error in neglecting the variability of the north direction in the map projections used for estimating the direction of the road (see the Appendix 1 for further details).

3.2. *The survey of the ancient centuriation*

In 1990, the existence of an ancient, regular division of the Pontine marshes was discovered [13,14]. This division – actually a centuriation, although the dimension of the blocks is smaller than usual, being of 10 *actus* (355 m) – is orientated to the cardinal points and it is still visible on aerial photographs (for a general introduction to centuriation and the division of lands in Roman times see references [15,16]). To study the relationship between road and centuriation we have digitized and geo-rectified the aerial photographs on which the traces were individuated in the nineties (i.e. they were rotated, warped and georeferenced by using control points), and overlaid them on satellite images. In this way, we could confirm many of the traces (although not all show internal consistency: in particular, traces reported on paper maps probably suffered by errors induced by hand drawing). Further, we have performed a careful analysis of satellite images to identify new traces; in particular, we have found three sides of a square of the original centuriation, located at Codarda (Latina) (Fig. 5; Fig. 2 on the upper right). The square, whose "authenticity" is beyond any doubt since the side is precisely ten *actus*, breaks the regularity of the 19th century grid and probably had been privately drained before the reclaim of the Pontine marshes. Finally, we performed a computer reconstruction of the centuriation grid and a computerised viewshed analysis of the corresponding inter-visibility areas. The reconstruction of the grid has been based on all the fragments we have been able to re-locate, plus the new ones for a total of more than 15 km of traces (Fig. 3). Our computer reconstruction is freely available in a companion webpage[3] so that, if further traces are discovered by anyone, they can be easily added to the database to improve the simulation. The accuracy of the grid can be estimated by considering the empirical standard deviation of the difference between the reconstructed grid itself and the fragments (in computing the statistics each fragment has to be weighted according to its own length). It turns out that the grid is able to fit the known fragments with an accuracy of 9 m.

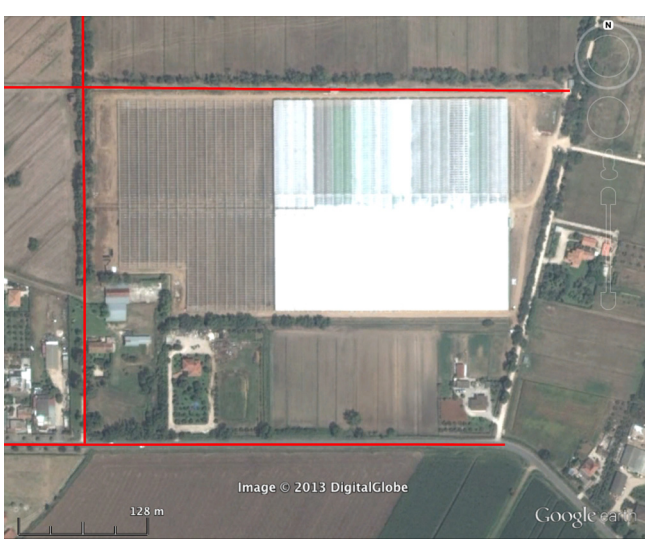

Fig. 5. The traces located in Codarda (Latina), forming a square with a side length of 10 *actus* (screenshot courtesy Google Earth).

4. Results

It is given for granted in many works that the segment of Via Appia crossing the Pontine marshes runs with azimuth 135°, i.e., that it was projected along the inter-cardinal north-west/south-east direction. Such a feature – if true – would have clearly simplified the project of the road, since astronomy could be used to determine the north celestial pole (due to precession, there was no "pole star" in Roman times) and then the Roman *groma* could be employed first to find the meridian on the ground and then to bisect two times. However, our results show that the azimuth of the road is *not* inter-cardinal: it is $135^\circ\ 57' \pm 10'$ (using satellite images this result can be validated – with a slightly lower accuracy – also for the remaining part of the road).

Our result means that, *if* the Roman *mensores* wanted to orientate the road along the inter-cardinal direction, *then* they committed an error around one degree, and certainly not less than 47′. We strongly believe that this error is too much to be acceptable (in a while we shall see that there is actually no doubt on this point). Therefore, whatever strange it may seem, we *must* conclude that Via Appia was deliberately orientated along an azimuth very close to 136°. Clearly, there are two problems to be solved: how was this azimuth maintained with such a high accuracy, and why was this azimuth chosen. The latter question is connected with the interpretation of the road, and will be deferred to the Discussion section. Here instead we discuss the first problem. The solution comes analysing the relationship between the road and the centuriation. In fact, it is clear that the grid cannot postdate the road (if this were the case, then every – admittedly not crazy – *mensor* would have traced an axis along the existing road, as indeed was made during the modern drainage). Cancellieri proposed to predate the grid to a distribution of lands occurred in 340 BC [13]. This is a sensible possibility, but again, every *mensor* would in this case have traced the road along the diagonal of the existing grid. We sustain rather the idea that the road and the grid are contemporary, and thus belong to a global project aimed at modelling the landscape of the Pontine Marshes in Appius' times. The reason is that, superimposing the grid on the satellite map of Via Appia, we were able to search for intersections at grid nodes (recall that Appia, bearing an azimuth close to 136°, does not run along a diagonal of the grid). To our surprise, we discovered that they intersect at a node very close to the beginning of the straight segment at Torre Elena (Fig. 4).[4] It is, therefore, very likely – if not certain – that the road was traced starting from this node used as the main survey point and, therefore, with the key help furnished by the contextual tracing of the centuriation grid. Since indeed the latter was

[3] http://geomatica.como.polimi.it/elab/via_appia/.

[4] To be precise, the best fit is at present obtained at a node which is 3 cells (about 1500 m) to the north-west of the node which is likely the south-easternmost one, being located as close as possible to the "corner" of Mount S. Elena where the Appia turns towards Terracina. The deviation is however minimal, as the latter node anyway falls within 25 m from Via Appia.

orientated to the cardinal points, it allowed for a precise determination and collimation of the *desired* azimuth of the road, section after section, keeping the error to a minimum. To further confirm this, we have estimated also the accuracy of the centuriation using *a priori* (before interpolation) single lines measured on satellite images, and it turns out to be very good, the grid being orientated about 10′ east of north. Clearly it is very probable that the construction of the road proceeded with a *single* building site (instead of two at the two ends or even more than two distributed along the path) the one that started at the south easternmost node. This assertion is further confirmed by the inter-visibility analysis. A first approach to this analysis can be performed using the "horizon" formula which states that an object of height h in metres can be seen from a distance roughly equal to the square root of 13 h kilometres. The Pontine lowlands are enclosed by the Albani hills to the north and by the corner of Monte S. Elena to the south-east. The maximal height of the Albani exceeds 900 m; however the corner of Colle Pardo which is near the end course of the straight Appia segment does not exceed 400–450 m. This would actually give a *theoretical* visibility near to 70 km, barely sufficient to trace the road in that direction, but with an horizon height of the sighted point which is equal to zero under any practical means and only assuming optimal weather conditions which are (and were, due to the marshes) seldom to be expected in the area. This analysis is confirmed by the viewshed algorithm (we used the "r.viewshed" function[5] provided in the open source GIS software GRASS[6]), which takes into account also atmospheric refraction. The Albani hills become much more visible if a sight point on Monte Leano to the south is taken, but in this case it becomes difficult to use two elevated sight points from the plain where the road has actually to be constructed, while again, pointing to the Monte Leano hill from the far plain has to be excluded. So, we can conclude that the presence of the Albani hills to the north-west and of Monte Leano to the south-east – although being certainly very important landmarks for the surveyors – could not account for the astonishing accuracy with which the road was constructed for as long as 61 km.

5. Discussion

To summarize, our results show that the centuriation of the Pontine marshes and the Via Appia were very likely conceived and carried on together, following a single direction of progression towards Rome. However, a problem remains: why the road does not run along the diagonal of the grid? It should be noted that no topographical explanation can be found: since the road and the diagonal differ of only one degree in azimuth, the deviation that Appia accumulates with respect to the diagonal is of less than 1.5 km at the *end* of the segment.

A first thing to be considered is that Roman projects based on a cardinally orientated grid have already been documented in centuriations [17], town planning [18], and roads [19]. In these examples the straight segments were traced with the help of rational fraction tangents, that is, using angles whose tangent is the ratio m/n between two integer numbers, counted on the grid. Therefore, we tested Via Appia in such a context. Actually, we found that the *first* straight segment was probably realized in this way; in fact the topography of the area (along the solidified lava plateau called Capo di Bove) clearly invites to use the Aventine Hill as a distant foresight [2], but after having fixed the general setting, a rational fraction of 6/5 was very probably adopted; our estimate for the azimuth of the first straight segment is in fact 140° 8'; subtracting 90° gives 50° 8′, which is extremely close to 50° 12′, the arc whose tangent is 6/5. The use of this method for the main segment is, instead, very unlikely. To obtain an angle close to 45° 57′, one should in fact use a ratio like 31/30.[7] Clearly, this would have been pretty illogical, having at full disposal the simplest ratio of all, 1/1. The solution must therefore be elsewhere, and effectively there is another, striking possibility. Analysing the sky at the time of construction, it can be seen that, looking at azimuth 315° 57′ (that is, from Terracina to Colle Pardo along the direction of the road) in the years around 312 BC, the bright star Castor, the brightest star of the constellation Gemini, was seen to set (at an altitude of one degree – appropriate for a first magnitude star; recall that the horizon is practically flat). Castor's setting was visible approximately from the first days of January to the first days of June (proleptic Julian dates).

6. Conclusions

The original project of Via Appia thus arose from a complex interplay of geometrical and astronomical techniques, not unlikely other spectacular projects of later Roman architecture, such as Augustus' *Campus Martius* and Hadrian's Pantheon [20,21]. Can the astronomical alignment to Castor be framed in such a scenario, or should we regard it as a mere coincidence?

The life of Appius is relatively well known. He became censor in 312 BC, after the defeat of the Romans by the Samnites at Lautulae. During his consulates, the Romans reverted the sorts of the war, up to the peace of 304 BC. In 295 BC, Appius served as praetor in Etruria, playing probably a relevant role in the events leading to the fundamental battle of Sentinum, a victory which would eventually lead to the final end of the Samnite wars in 290 BC. As an old and revered blind man, Appius is mentioned once again for his speeches against Pyrrhus in 279 BC. It is usually said that he conceived the road as a main route (with final destination Capua) for military supplies. However, connection with Capua was already assured by the Via Latina, running along the Lepini mountains, and a careful analysis via satellite images shows that the difference in length is seldom appreciable. Thus, saving of time does not explain *per se* the construction of the road. As a consequence, some authors tried to frame Via Appia in the more general cultural horizon of the Hellenistic influxes on Rome [22], viewing it as a "Hellenistic road", celebrating the successes of its builder. Clear connections between astronomical events and Hellenistic monumental architecture have been recently found in the orientation of the urban plan of Alexandria [23,24] and in the funerary monument of Antiochos I at Mount Nemrud [25]. In both cases the main alignment points to the rising sun on the day of birth of Alexander the Great, an alignment which also closely matches the rising of "king's star" Regulus at the time of construction. In such a context, it seems reasonable to think that the "ideology" connected to the construction of the Appia road was strengthened by an astronomical orientation related with the military environment within which the project was conceived. Indeed the cult of the divine twins Castor and Pollux filtered into Italy already in the sixth century BC [26], and soon acquired the role of protectors of the Roman army (Fig. 6). According to the Roman historians, the twins even fought together with the Romans at the Battle of Lake Regillus, at the beginning of the fifth century. As a consequence of the victory, a temple to the Castores was erected in the Roman Forum. Interestingly enough, Lake Regillus (today dried and not identified with certainty) was located in the short strip of Albani hills which overlooks the Pontine marshes [27]. Therefore, the road was running from Terracina in the direction of the setting

[5] http://grass.fbk.eu/manuals/html70_user/r.viewshed.html.
[6] http://grass.osgeo.org/.

[7] As a consequence, the road passes very close to the nodes of coordinates (28,29) and (58,60) of the (projected) centuriation grid if the origin of the axes is taken at the south-east intersection.

Fig. 6. A Roman coin of the second half of the second century BC. On the left, helmeted head of Rome, on the right the riding Dioscures, each one surmounted by his own star.

of Castor and *also* towards the place of the appearance of the divine twins as allies of the Romans.

To conclude, in view of the above results, the huge, seemingly exaggerated engineering project entertained by the Romans for the construction of Via Appia can be now better understood. The road served as a military connection during the Samnite wars, but represents also a synthesis between the Roman "practical" mentality and a system of religious symbols and beliefs which were of mandatory importance for the temper of the army during a key moment of the Roman history.

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Appendix 1.

In order to obtain a reliable result, the azimuth estimation was performed by applying different methods. Let us recall that the coordinates observed using GPS receivers are given in the WGS84 global Cartesian reference frame [28]. Therefore, in order to estimate the azimuth of the straight path, the point coordinates derived from the u-blox receiver have been rotated and translated into a local Cartesian reference frame centred in the middle surveyed point of Via Appia (41° 26′ 13.29″ N, 13° 2′ 3.86″ E) and with the axis pointing toward north, east and up [29]. After that, the best straight line interpolating the points has been computed according to a least-squares principle and finally the azimuth has been estimated by computing the angle between the straight line and the north direction at the centre point of Via Appia. The result is 135° 57′ 10.73″.

The method has been assessed by an alternative solution, consisting of applying a UTM projection [30] to the same GPS coordinates, directly estimating the straight line in UTM and then correcting the output by the meridian convergence. In this case, the obtained result is 135° 56′ 9.24″. A further check has been performed by applying the first method also to the GPS point coordinates derived from the dual-frequency receiver, thus obtaining an azimuth of 135° 57′ 12.87″. The good consistency when using different estimation methods make us confident on the reliability of our azimuth estimate.

Note that, in all these methods, the north direction was considered as a fixed direction (in particular as the direction toward the north at the centre point of Via Appia). This is the main approximation used in the computation, because for both the UTM projection and the local Cartesian reference frame the north direction depends on the longitude of the considered point. However, in our study, this problem can be neglected since the distance along the parallel between the centre of the survey and the farthest point is less than 15 km, thus entailing a change in the north direction of less than 10′ [29,30].

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