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The Solar System in a Salad Bowl

A Novel Design for an Orrery

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I recently spent ages designing and constructing a Ptolemaic orrery. After this, I felt entitled to make a simple Copernican orrery for relaxation – but to a novel design to make it interesting.[1,2,3]

The usual arrangement is to have the wheel trains for each planet stacked one above the other, each driving one of the concentric cylindrical arbors of a multiple cannon pinion (a salvo pinion?). This makes for a rather deep movement, which does not lend itself readily to a clock or watch dial. In the standard arrangement, the central arbor is static and is topped by a bead representing the Sun. Each of the other arbors is fitted with an L-shaped hand; the feet of each L correspond to distance from the Sun and the vertical parts bring the planet-beads which top them to a common horizontal plane with the Sun at the centre. Conventionally, the view is from far above the North Pole, with the planets orbiting anti-clockwise. All the orbits are circular and are equally spaced. The only nod to quantitative astronomy is to give the planetary orbits the correct relative periods; e.g. the Earth orbits the Sun about 12 times faster than Jupiter does. The actual orbital periods in Earth-years are given in the first column of **Table 1**. Some such orreries go beyond what was known to Copernicus by including planets further out than Saturn, or even asteroids and moons (he knew about our own Moon, of course), though for decoration rather than as part of the mechanism.

Here, I go back to Copernicus by ignoring post-1540 frippery, and perhaps even earlier by including only the traditional 'seven stars in the sky', except that I have substituted the Earth for the Moon (on the scale of the solar system their places are indistinguishable). Following Copernicus, the orbits are circular and, since he had little idea of the scale, I have stuck to the convention of equally-spaced orbits. The main novelties

	Period (Years)	Teeth on Torus	Teeth on Driving Wheel	Periods on Orrery (7 turns=1year)
Mercury	0.241	64	38	0.241
Venus	0.615	112	26	0.615
Earth	1.000	196	28	1.000
Mars	1.881	237	18	1.881
Jupiter	11.86	332	48	11.86
Saturn	29.46	378	22	29.45

Table 1. Planetary and gearing data.

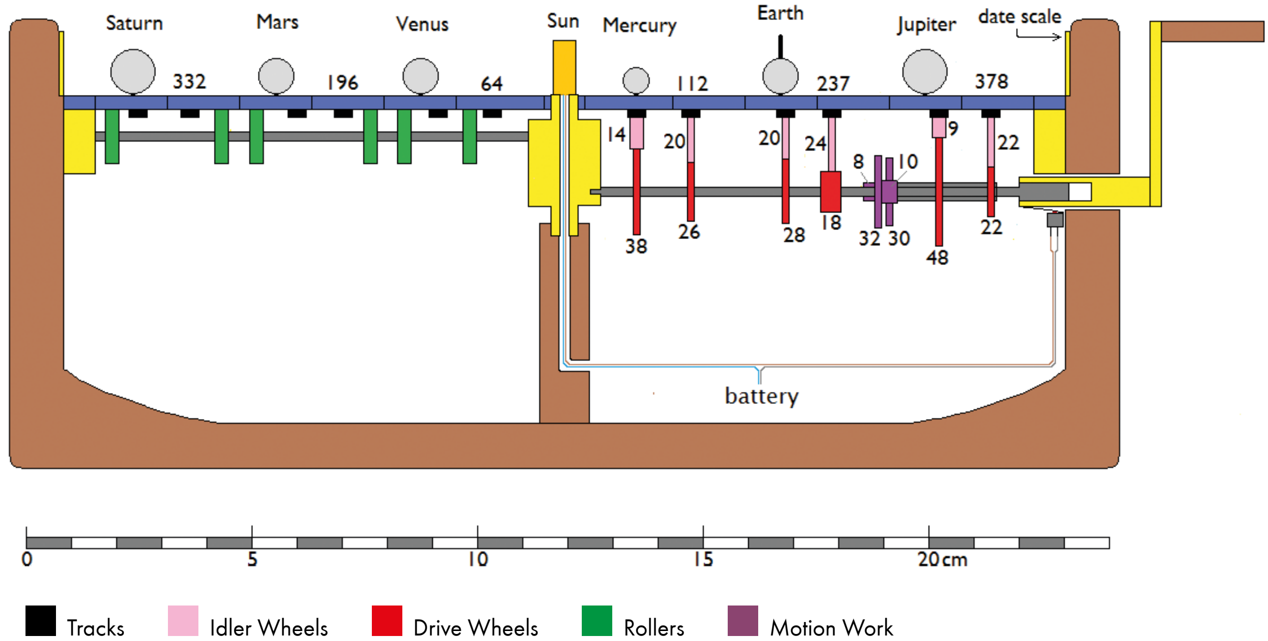


Figure 1. Side view of the gearing and supports, with tooth counts.

Figure 2. The wheel train.

Figure 3. Orrery works installed in a salad bowl.

are in the gearing and in having the cannon pinion pancaked into a series of concentric tori (not a nice word, but that is what the Oxford English Dictionary gives as the plural of torus). As well as making the orrery much shallower and more dial-friendly, each torus effectively becomes a contrate wheel, by having a toothed track on its underside. Obviously, the larger the diameter of the torus, the greater the number of teeth, so a standard-size driving wheel would automatically turn a larger torus more slowly. This goes halfway towards the requirement that the orbital periods of the outer planets should be progressively longer than for the inner planets. Only halfway because the period (as Kepler revealed in 1618) is proportional to $r^{3/2}$, where r is the mean radius of the orbit, whereas even had the present orrery been made to scale, the periods with a standard driving wheel would be proportional to r. The adjustment to the required periods is achieved by having different-sized driving wheels. Those for Mercury, Venus, Earth and Mars are on a common arbor and those for Jupiter and Saturn are on a sleeve that rotates around the arbor that, with the aid of 8:32::10:30 motion work, goes 12 times slower, exactly as in a normal clock. The tooth-counts and the periods they produce are given in columns 2 to 4 of **Table 1**. The periods, with one year corresponding to seven turns of the arbor, are obtained by dividing the torus tooth-count by seven times the driving wheel tooth count. For Jupiter and Saturn, this is then multiplied by 12 to take account of the motion-work. For example, the orrery period of Mars is 237/(7x18) and that of Jupiter is 12x332/(7x48). The toothed tracks are all in the same plane, whereas the tops of the driving wheels are at different distances below that plane, so idler wheels are required to connect the drivers to the tracks. The arrangement of these is shown in **Figure 1** together with tooth-counts. The actual wheel train is shown in **Figure 2**. Three equally-spaced arms extend from the centre and these support the nest of tori, one on the idler wheels and the other two on rollers. Only one of the roller arms is shown in **Figure 1**; the other is seen in **Figure 3**. The mechanism is driven by a removable crank-handle with seven turns corresponding to one year.

So much for the deliberate part of the design. Much of the

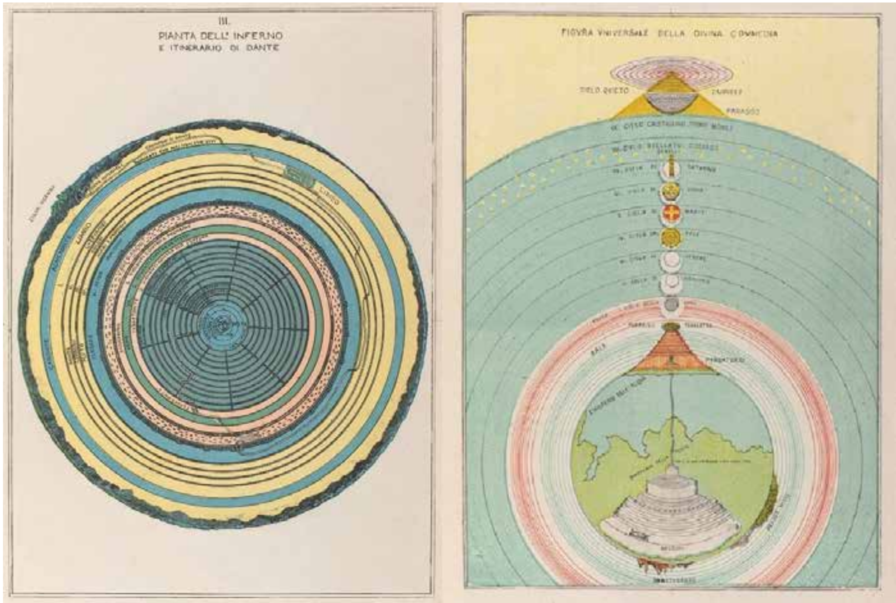


Figure 4. Caetani's illustrations for Dante's Inferno (left) and Paradiso (right).

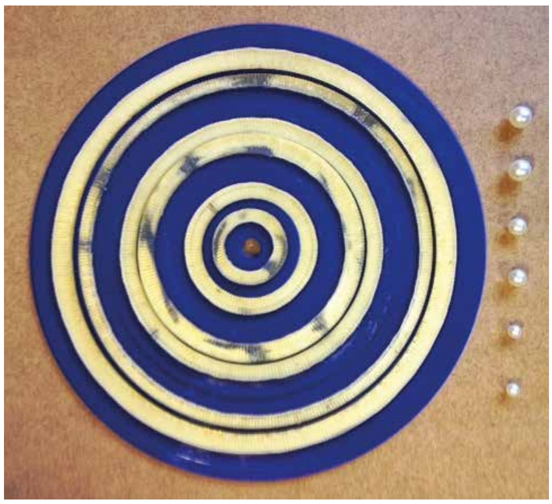


Figure 5. Nest of tori from below, showing the tracks. Also 'planets' to the right.

Figure 6. The completed orrery. The crank handle is inserted, so the Sun is switched on.

rest results from chance. The dimensions of the orrery were determined by those of a convenient round wooden salad bowl. The original idea was to have the top plate made of 1.5 mm brass, but the prospect of accurately cutting a sliding set of six tori from it with a piercing saw was too daunting. Laser cutting would be the solution, but I was unable to find any firm that would tackle it, so instead of brass I opted for 3 mm acrylic, as offered by a model shop. Most of the still-modest cost was for laser time rather than acrylic, so I had several nests cut in various colours, all done within my allotted half-hour. The blue one was pleasingly reminiscent of Michelangelo Caetani's illustrations for Dante's *Divine Comedy*, **Figures 4,** cf. **Figure 5**, so that was what I chose. Dante's universe was geocentric, but no matter. Whether I ended up with his Inferno or Paradiso is as yet undecided – the illustrations are confusingly similar.

Having accepted a plastic top-plate, it was not unreasonable to use plastic wheels, packets of which can be obtained very cheaply from China via the internet. They are primarily aimed at robot-makers and are all cut to module 0.5, so that decided the module. All of the wheels had even numbers of teeth, so that was a further constraint. This could be accommodated without loss of precision by adjusting the tooth-counts on the tracks, since the tori are wide enough to allow for a few teeth either way by changing the track radii. The single nine-leaf pinion that came in the package was used as the Jupiter idler wheel, but the Earth had to make do with a slightly displaced 20-tooth idler. Naturally, the luxury Mark 3 model – the Solar System on a Silver Salver – will be all-metal, with no compromises. What happened to Mark 2? This actually has a fighting chance of being realised, as will be explained later.

Seen from above, the dark blue top-plate is intended to suggest the night sky, **Figure 6**. The Sun is represented by a plastic bead containing a 3-volt LED bulb, which comes on when the crank handle is inserted. The light shines on the planets, represented by faux-pearl beads, illuminating only one side of each of them. In a darkened room, therefore, it shows the planets' phases, or day and night in the case of the Earth. A spike above the Earth casts a shadow on the inside of the bowl's rim, where it indicates the month and the zodiacal constellation through which the Sun is passing. Since the tori are held in place only by gravity, each one may be lifted clear of its idler wheel using the pearl as a handle, and rotated to set the initial direction from the Sun. These directions are given for any chosen date in an astronomical almanac, or on the internet, as heliocentric longitude, which is marked on the orrery between the zodiac and the date scale. While the orbital periods are very close to reality, the positions of the planets in their orbits can be set only to the nearest tooth on the track. This corresponds to a possible inaccuracy of up to about half a degree for the outer planets, rising to nearly three degrees for Mercury.

As a belated apology to an Argentinian colleague who took me to task in my youth for giving a lecture on tides in which I used a symbol for the New Moon with its horns pointing to the left, I here abandon the 'view from above the North Pole' convention in favour of the view from the southern hemisphere. After all, this is not intended to be a conventional orrery. This also avoids the risk of the winding-square coming unscrewed! To switch hemispheres, all that is required is a mirror-image date scale and anti-clockwise rotation of the handle, most readily done by turning the bowl around and then cranking with the left hand.

The main problem in making the orrery was the construction of the toothed tracks, which are certainly not 'off the shelf' and are too large to cut on a modest lathe. This was solved by Justin Koullapis, who generously provided both his expertise and the use of his large lathe. The radial teeth of the tracks were cut from one of the spare sets of tori. Since each track has to share the underside of its top-plate torus with the supporting rollers, the width of the track has been reduced with the aid of a piercing saw to allow space for this. With the minimum of smoothing and the application of a touch of Shin-Etsu silicone grease, the plastic tori slide very easily around each other.

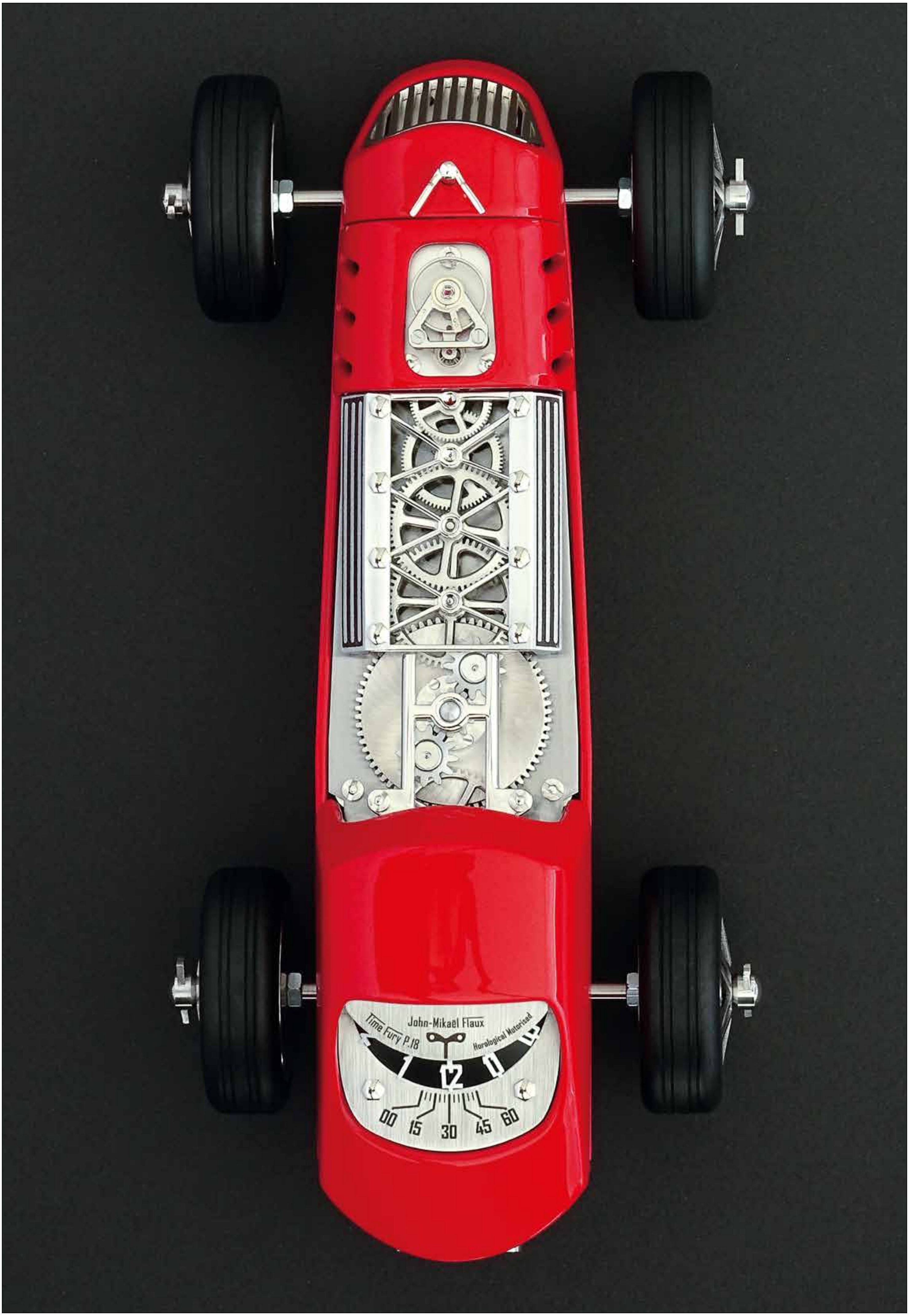
The advantages of the system used here are:

- Precision of orbital periods, as may be seen by comparing the first and last columns of **Table 1**
- Relatively simple gearing
- Very little depth, so it could be adapted to a clock or watch without impinging greatly on the space required for the going train.

This brings us to Mark 2. This is an even flatter version which retains similar gearing but has all the wheels with their faces horizontal. The teeth on the tracks below the tori are radial, instead of pointing downwards as at present. An additional advantage of this is that it reduces the tendency of a torus to jump a driving tooth if cranked too fast. So far, Mark 2 has yet to leave the drawing-board.

ENDNOTES

1. Stuart Malin, 'Towards a Ptolemaic Orrery', *Horological Journal*, vol.152 (June 2010), pp266–71.
2. Stuart Malin, 'Ptolemaic Orrery', *Horological Journal*, vol.158 (Dec 2016), pp548–53.
3. Stuart Malin, 'Constructing the First Ptolemaic Orrery', *Astronomy & Geophysics*, vol. 58 (Feb 2017), pp1.41–1.42.


John-Mikaël Flaux
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