Interactive Solar System Exploration for High School Education

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Abstract. The presented paper investigates the capabilities of 2-dimensional vector graphics for the visualization of physical and orbital characteristics of the planets in our solar system. The final aim is the development of an appropriate illustrative model for the Swiss World Atlas Interactive, the web version of the Swiss World School Atlas. Today we have already very detailed data about the planets, dwarfplanets, moons and asteroids. Various techniques exist for the generation of realistic and sustainable images of our solar system: Virtual 3-dimensional and interactive applications, planet trails[1], or 2-dimensional depictions in printed atlases. All techniques have specific benefits, but also drawbacks. However, a main principle is always the reduction of the presented data down to the essential information, like it is also done in the process of map editing. With the capabilities of the markup language Scalable Vector Graphics (SVG) for instance we can enhance 2d vector graphics by animations. Almost every motion in 2-dimensional space can be visualized in an easily observable way. Physical and orbital planet characteristics like equatorial and polar radius, axial tilt, or rotational and orbital speed can be shown in one composite animation. Beside the generalized planet depictions, relations between each planet and the solar system become visible. We see for instance the distance each planet covers in space during one revolution around its axis. The relation of that distance to its size gives us a realistic impression of its movement in space. After such direct comparisons, it is also important to get an idea of the extent of the solar system. Therefore we have to scale down the solar system to the size of our computer screen. For detailed views of the planets and moons in such a mini model, the user needs predefined levels and positions for zooming and panning straight to the object of interest. An animation generates the impression of a virtual flight. But, even the model

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[1] True 3D Models in the real world

of the Neptune system with its currently 13 moons fits on a computer screen only with adjusted values for orbital distances, object sizes and orbital periods. We cannot see all moons with the same scale and correct orbital distances. We need a few variations of the same model generated by altering the mentioned adjustable parameters. Hence the realistic impression evolves due to a combination of different views in our mind.

1. Introduction

The number of objects and the distances in our solar system are huge. Today eight planets are known, furthermore 50 dwarf planets and 172 moons. The number of asteroids in the 'main asteroid belt', between Mars and Jupiter, is estimated between 1.1 and 1.9 million space rocks larger than 1 kilometer in diameter. Almost 40 000 are catalogued so far. Beyond Neptune there is the 'Kuiper belt', with an unknown number of asteroids and comets. And beyond the Kuiper belt there are regions called 'Scattered Disk' and 'Oort Cloud'. As for scale, if the sun were the size of a peppercorn, the Earth would be 10 centimeters away, and Eris, the biggest Kuiper Belt object, 10 meters away. The Oort Cloud, however, extending halfway to the next star, would be 10 kilometers in radius (Chown 2011). This marks the extent of the sun's gravitational influence and the edge of the solar system. By comparison, Voyager 1, the furthest away man-made object from earth, had a distance of 123.5 astronomical units from Earth in March 2013, which is equal to 12.35 meters in the described model. That distance now increases 3.6 AU (= 36 centimeter) each year. The more we go into details, the more complex are the facts we get about the solar system and each object in it. Thus, for an introduction for students, we have to generate a simplified model, which shows the basic knowledge about our solar system in a sufficiently precise manner. What are our means for an accurate visualization of such a huge system for educational purposes? A computer screen with for instance 1024x968 pixels, or a page of a printed atlas with a size of 24x36 centimeters are given constraints which force us to focus on generalized depictions of the most important topics. The presented work compares various 2D-approaches concerning the visualization of our solar system, as a proposal for an interactive webatlas application. For an introduction, the main characteristics of the planets and an overview of the solar system can be visualized only with 2D-techniques, with the intention for the generation of some sustainable impressions by the atlas user. With the reduction to essential informations and a first visualization with a static depiction the main planet characteristics can be shown in the easiest way.

2. Planet Characteristics and Adequate Cartographic Depictions

In general we can divide the planet data into physical and orbital characteristics.

2.1. Main Physical Characteristics
- Size (radius or diameter)
- Flattening (ratio between equatorial and polar radius)
- Mass
- Mean density
- Volume
- Surface gravity *(equatorial)*
- Surface temperature
- *Rotation velocity (equatorial)*
- Rotation period (sidereal)
- Escape velocity
- Albedo

2.2. Main Orbital Characteristics
- Orbital radius (average distance from the Sun)
- Orbital period
- Length of day
- Orbital speed
- Orbital eccentricity
- Orbital inclination
- Axial tilt
- Apsidal precession

2.3. Further important Characteristics
- Number of natural satellites (moons)
- Atmospheric (chemical) composition

2.4. Cartographic Visualization
The well known visual variables for cartographic visualizations in this context are
- Size
- Shape
- Orientation
- Color (Lightness, Saturation, Transparency)

2.5. Scalability and Animation

For the interactive exploration of our solar system model we use
• Continuous scalability and
• Animation (translation and rotation with predefined timestamps)

3. Existing Illustrations in Current School Atlases

3.1. Examples

Solar system and planets are still a side issue in recent school atlases and usually covered on only one or two atlas pages. In most cases we see photographic depictions of the sun and planets in combination with a size comparison. Other commonly known illustrations show the Earth-Sun system, with explanation of day length and season, or the Earth-Moon system, with explanation of moon phases or eclipse of the moon or the sun. In the latest edition of the Swiss World Atlas the information about the solar system and the planets are illustrated with four graphical drawings: *Figure 1* shows a solar system overview with the inclination of the orbits in relation to the earth orbit.
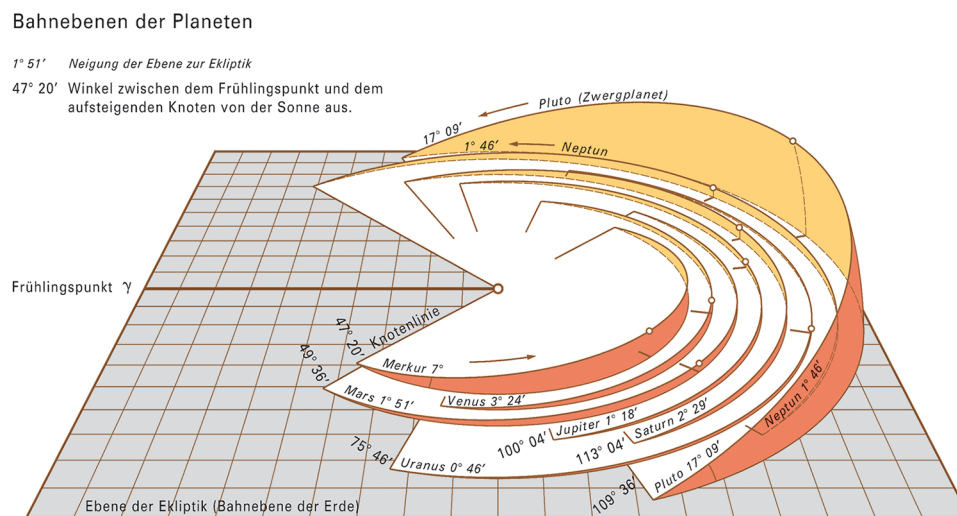

Figure 1. Solar System overview with orbit inclinations (Swiss World Atlas 2010).

Figure 2 shows the minimum and maximum of the visible planet sizes for a sky watcher on earth, and *Figure 3* a direct size comparison of the planets (scale 1:10 billion) in combination with a depiction of the orbital radius (scale 1:20 000 billion) and the numerical data of orbital periods.
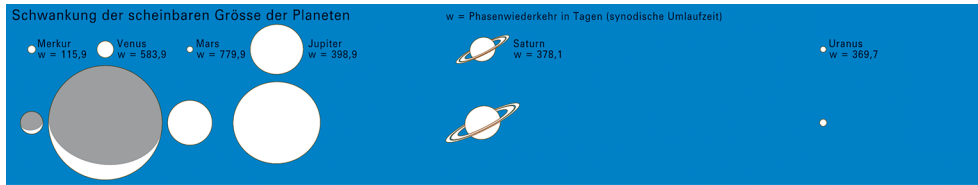
Figure 2. Minimum and maximum of visible planet sizes (cutout) (Swiss World Atlas 2010).
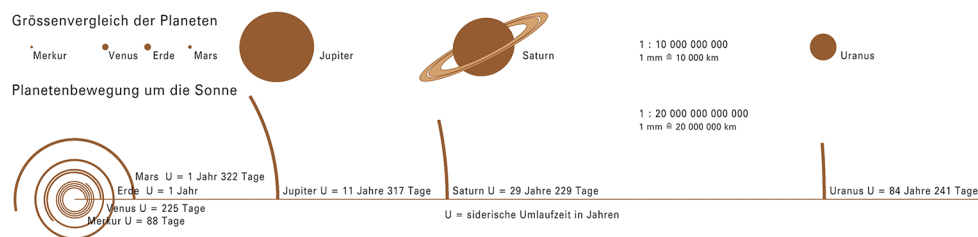
Figure 3. Direct size comparison (top), orbital radius and orbital period (cutout) (Swiss World Atlas 2010).

Another atlas page comprises five illustrations about the Earth-Sun-system, with focus on day length, seasons, apparent sun's orbit, and structure of the earth's interior. And a further page presents photographic depictions of all planets, in combination with data about the main physical and orbital characteristics. The current interactive edition of the Swiss World Atlas presents an illustrative dynamic 3D model of the earth's revolution around the sun. It shows the interrelation between axial tilt, season and day length, depending on the geographical latitude (*Figure 4*).
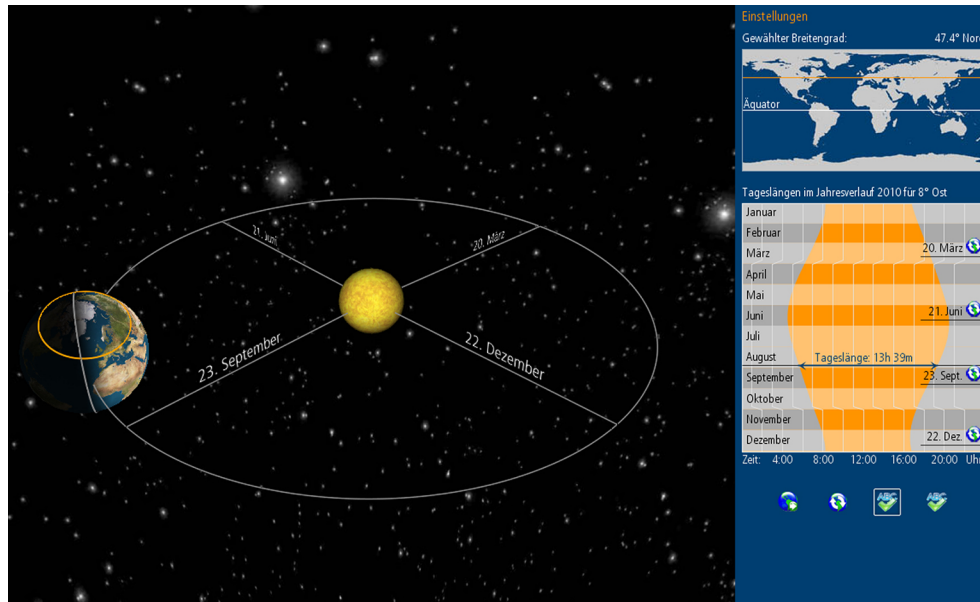
Figure 4. Earth's revolution around the Sun, illustrative dynamic 3D model (Swiss World Atlas Interactive 2011).

An obvious disadvantage of the upper illustration is that the user gets no information about the real proportions and the distance between the sun and the earth. A second 3D visualization shows a virtual globe of the moon, with optional additional information about the landing places of all manned missions since 1969.
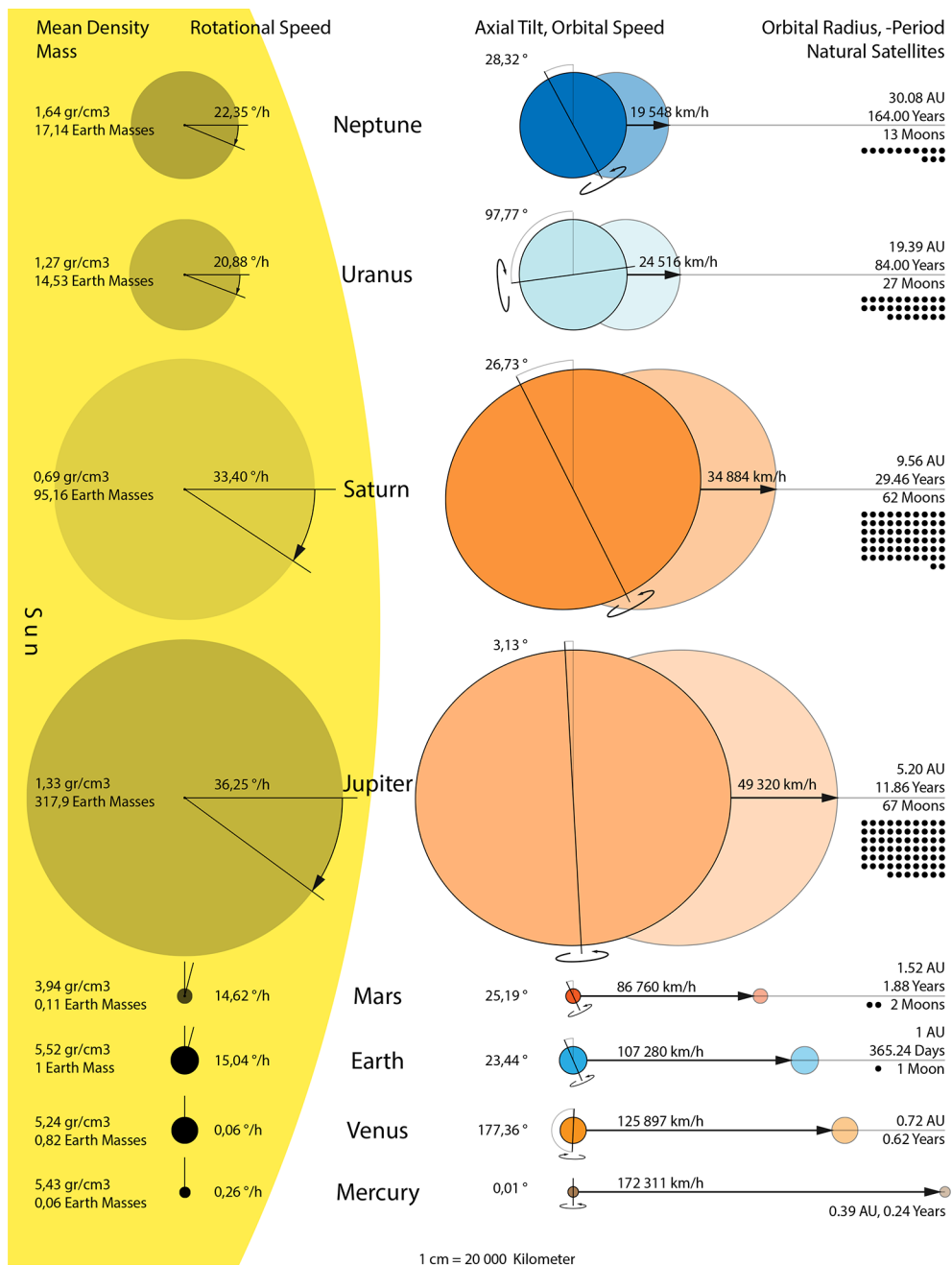
4. Examples of Illustrations in an Interactive Web Application

4.1. Direct comparison of planet characteristics

Various new depictions were composed as proposals for the second version of the Swiss World Atlas interactive. The main intention hereby was to create impressions about the real proportions and distances in our solar system. A first model shows a direct comparison of all planets with their main characteristics. All planets are put in a row, with a pole view and a side view (both orthographic projections). The main orbital and physical characteristics of a planet, as listed in chapter 2, are probably the first data an illustrative cartographic model should depict. In general we should consider that many of these precise numbers, which today are provided by numerous websites, are approximated or average values. The characteristics

of the planets in reality are such different in some cases that, at a first look, it seams to be disputable to show them merged on one atlas page, depicted with simple shapes and colors. Jupiter is a good example to explain these thoughts more precisely: Its rotational speed differs from equator to pole, and there is no surface like on earth. Its density also alters remarkably between outer mantle and core. Therefore, how can we define an accurate and also easily understandable depiction which includes a combination of these special properties? We need simplified and clear depictions for an introduction of a student into a scientific domain like astronomy. For a better comprehension of all these large numbers, we also need at least direct comparisons. This principle was yet followed in the current and the former editions of the printed Swiss World Atlas. But these illustrations are placed on the bottom of the pages, mostly too small, and therefore rarely noticed. Beyond an enlargement of the above-mentioned depictions also the arrangement of the graphics could be improved. Therefore one aim could be the visualization of all planet data on one atlas page. Moreover, alternative depictions could be elaborated for a better or more adequate representation of the existing data. Following these considerations, a draft was generated that shows all planets in a direct size comparison, and with two different perspectives (*Figure 5*).

Physical characteristics like mass, mean density and rotational speed (left) are shown together with orbital characteristics like orbital speed, -radius and -period (right). Two different views or perspectives of each planet are necessary: A pole view that shows the equator outline, to visualize equatorial diameter and angular speed, and a side view to show axial tilt, profile (flattening) and the orbital speed of each planet. The time slot for the visualization of the movements is set to one hour. With the distance that Mercury (planet with highest orbital speed) covers within one hour it is still possible to fit the whole model into the predefined format of an atlas page. And the values for the angular speed of most planets are also well presentable within the chosen scale: Jupiter (highest angular speed) rotates around 36.25 degrees during one hour. Venus, with the slowest rotation, advances only with 0.06 degrees within the same time frame. The rings of Saturn and Uranus were omitted for a clearer depiction of size and shape. With the presented combination of size and shape comparison on one hand and the orbital movements on the other hand, every planet can be characterized in an easily comprehensible way. The interrelations between some physical and orbital parameters are described by a single illustration. This draft was the basis for further developments for the interactive atlas edition.

Mean Density Mass

Rotational Speed

Axial Tilt, Orbital Speed

Orbital Radius, -Period Natural Satellites

Neptune
28,32 °
1,64 gr/cm3
17,14 Earth Masses
22,35 °/h
19 548 km/h
30.08 AU
164.00 Years
13 Moons

Uranus
97,77 °
1,27 gr/cm3
14,53 Earth Masses
20,88 °/h
24 516 km/h
19.39 AU
84.00 Years
27 Moons

Saturn
26,73 °
0,69 gr/cm3
95,16 Earth Masses
33,40 °/h
34 884 km/h
9.56 AU
29.46 Years
62 Moons

Jupiter
3,13 °
1,33 gr/cm3
317,9 Earth Masses
36,25 °/h
49 320 km/h
5.20 AU
11.86 Years
67 Moons

Mars
25,19 °
3,94 gr/cm3
0,11 Earth Masses
14,62 °/h
86 760 km/h
1.52 AU
1.88 Years
2 Moons

Earth
23,44 °
5,52 gr/cm3
1 Earth Mass
15,04 °/h
107 280 km/h
1 AU
365.24 Days
1 Moon

Venus
177,36 °
5,24 gr/cm3
0,82 Earth Masses
0,06 °/h
125 897 km/h
0.72 AU
0.62 Years

Mercury
0,01 °
5,43 gr/cm3
0,06 Earth Masses
0,26 °/h
172 311 km/h
0.39 AU, 0.24 Years

Sun

1 cm = 20 000 Kilometer

Figure 5. Planets, physical and orbital parameters (draft for a printed atlas page).

Time is the new dimension in the use of animated graphics, especially the continuous change of an illustration during a defined time span. The predefined time span, which was used so far for the compilation of the static depiction (*Figure 5*), can be adopted for the first implementation of a dynamic depiction. Angular speed and orbital speed, in direct comparison, within the same scale, become now visible in a new way. The basic model remains the same but is now augmented by the power of motion (*Figure 6*).

In an interactive atlas application, the user probably wants to select the numerical informations about physical and orbital characteristics of a planet only after a first moment of contemplation. Hence those data can be presented with an optionally visible layer (or additional layer). As first examples, layers were implemented which show the numerical data and the sunlight intensity on each planet. The latter is interesting especially in combination with the albedo and apparent size of a planet. More detailed information is provided by links to local HTML-files and subject-specific websites. The provided links in our model become visible with a mouseover event, through enlargement and color change of planet names.
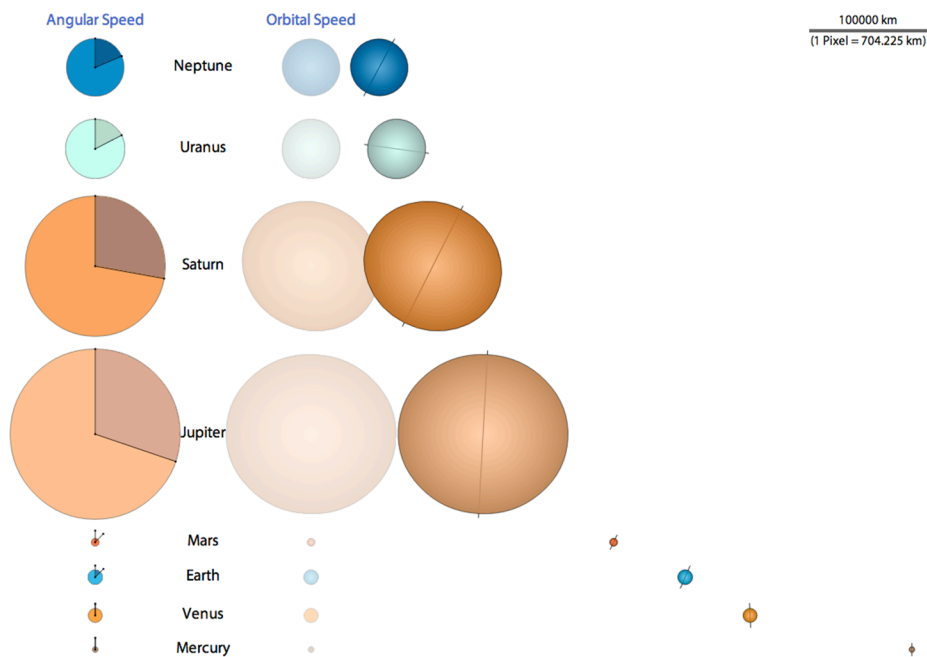
Figure 6. Planet positions after 3 hours (animated with 10 seconds).

4.2. Solar system overview

It's actually not possible to present an accurate overview of the solar system on a computer screen or a double page of a printed atlas. The planets and moons are too small to be visible in relation to the extents of their orbits. With the possibilities of dynamic and interactive web technics we can resolve or mitigate the problem. By means of animated graphics completely new impressions and interrelations affecting the presented subject can be communicated. The atlas user can interactively modify the appearance of the presented model by defining specific scale parameters for each object class. By applying the potentials of interactive scalability, the user can 'switch' between different 'selfmade' variations of the same model. Therefore he or she gets lasting impressions which, in conjunction, create an imagination about the real extents of the solar system. In a first overview we only see the planet orbits, depicted as generalized circles with a minimal stroke width. The planets and even the sun in the center are still not visible due to small scale (*Figure 7*).
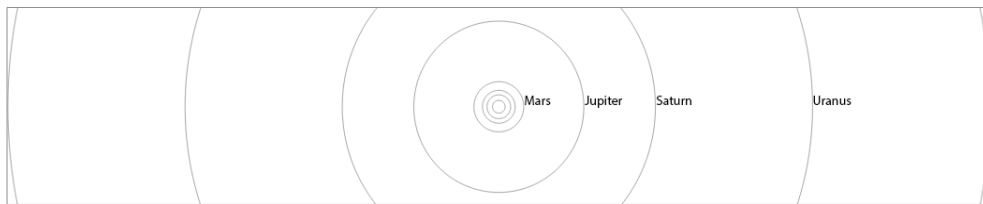

Figure 7. Solar system overview with true-to-scale depiction of orbital distances.

The Orbit lines have a stroke-width of two Sun diameters. This unusual representation of the solar system was yet partially given with the depiction of *Figure 3* ("Planetenbewegung um die Sonne"). In this graphic we also see only the planet orbits, and due to the omission of all planets in the same graphic a better impression of the large distances between the orbits is given. With a first animation triggered by the 'Sun button' we enlarge the whole graphic continuously, whereby an impression of a flight towards the center of the solar system is provided. During this virtual flight the sun appears slowly, first as a very small dot. The proportions between the sun and the orbits of the inner planets become clear now. At least we see only the Sun and the orbit of Mercury, due to the limited screen size. Mercury is still too small for being visible at this scale (*Figure 8*).
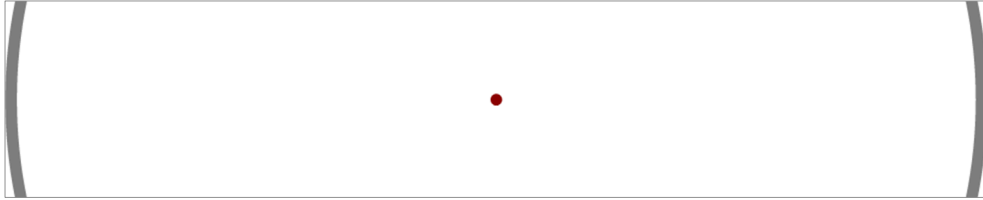
Figure 8. Sun and Mercury orbit at the same scale.

The stroke width of the orbit is equal to the sun diameter. Then, with a second animation, we further enlarge and translate our model to the position of Mercury. The smallest planet appears as a small red dot in the middle of its orbit line. Thus we have a very illustrative size comparison between Mercury and the Sun. During a second zoom phase the orbital speed of Mercury becomes visible true-to-scale. After for instance one minute we can see the difference between the current position (red point) and the position before the animation was triggered (faded-out silhouette). For size comparison we can show the earth's contour with a thin blue line (*Figure 9*).
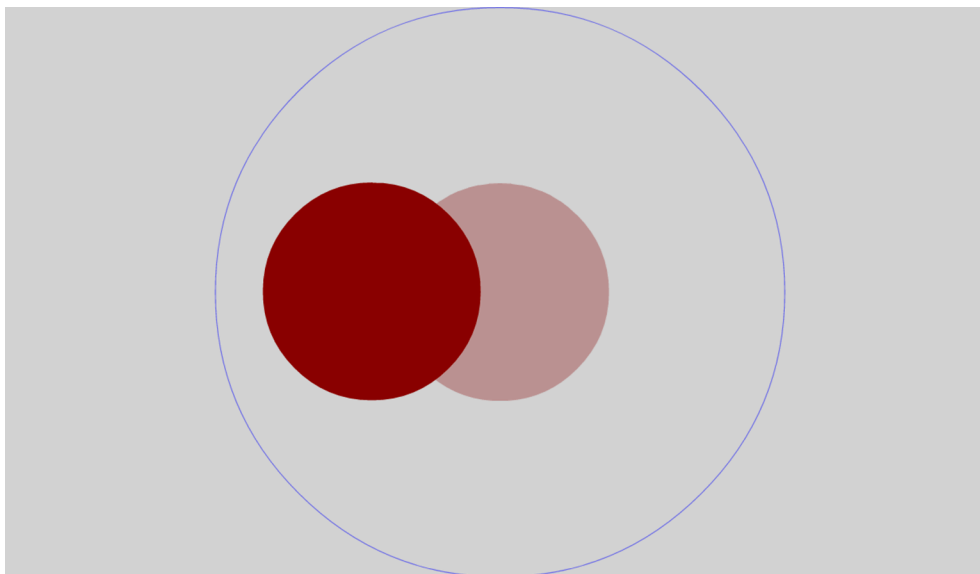
Figure 9. Mercury covers a distance of more than half of its diameter every minute. The blue circle shows the earth's size for comparison.

Another illustrative example is for instance a direct comparison between the Earth, the Moon with its orbit, and the Sun. And in the same manner every planet system can be observed and explored. Object sizes, orbital distances and orbital velocities are the main parameters in this model. As already mentioned they can be adapted interactively by the atlas user (with sliders, choice- and radio buttons) for the generation of the desired detailed view or overview. A permanent visible scale number and a scale bar are available to enable size comparisons between the different generated depictions. Objects can optionally be set to visible or hidden, the latter in case of unwanted overlying or exceeding density. The name and additional information of each object can be provided in a separate info window, either permanently, or temporally, made visible by a mouse event.

Modifications of the presented model can generate completely new depictions. With a focus on the orbital speeds or orbital periods a modified overview shows the solar system like in the depiction below (*Figure 10*). The screenshot was taken after one Earth revolution (1 year). Distances of the planets to the center of the model are equally spaced.
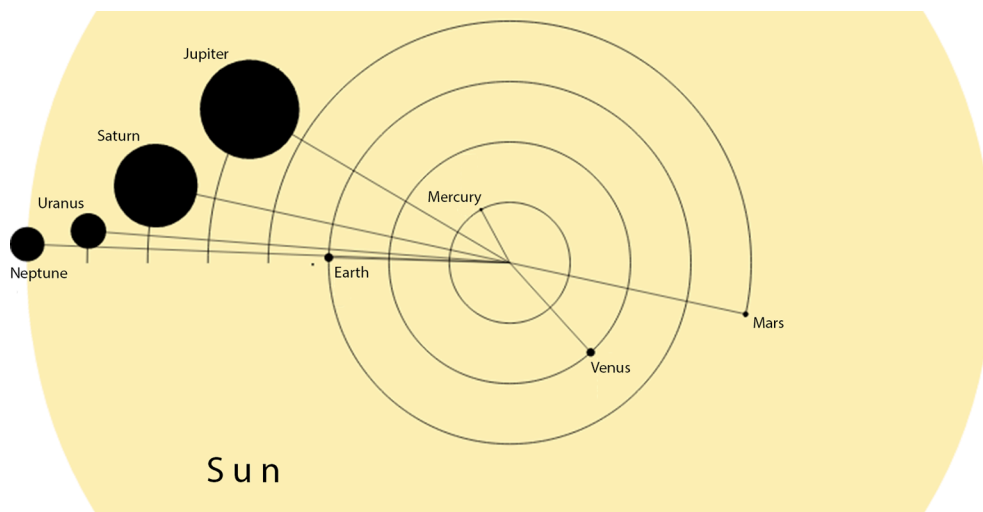

Figure 10. Solar system overview with depiction of Sun and planet sizes and orbital speed (animated).

4.3. Further Illustrations

Another variation for direct comparisons of planets and moons is an alignment of all objects along a regular grid, with equal distances between the nodes. The scale of all objects can be modified with a slider to make

small moons visible. Transparency allows overlay of enlarged objects, for a comparison of a moon with its planet. Characteristic data is presented in an info window, triggered by a mouse event. The distances between two objects (cell size of the grid) can also be adapted (*Figure 11*).
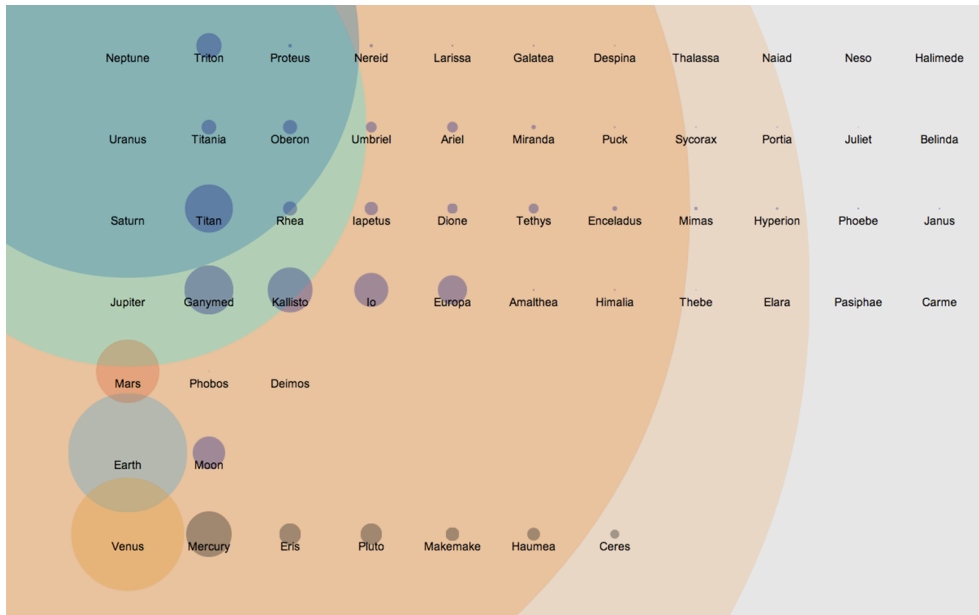

Figure 11. Regular alignment of the largest objects in the solar system.

Selected planet data can be shown with models different to the former compositions. For instance the apparent sun size on each planet in combination with an animation of the sun sets.
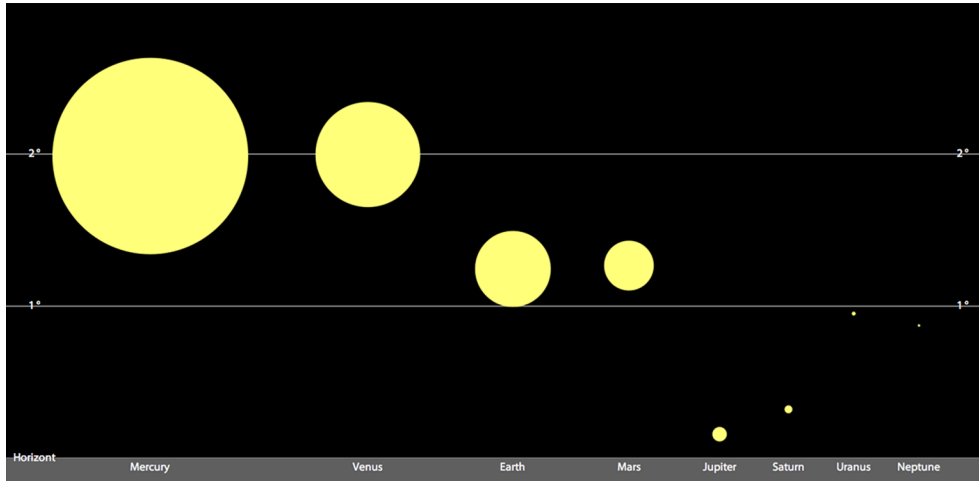
Figure 12. Apparent size and speed of the Sun on each planet. (Start position of all Suns is 2 degrees above horizont).

Figure 12 shows the distance from Sun and the rotational speed of each planet from a new perspective (viewed from each planet). Another possibility to show the spatial dimensions of the solar system is to simulate a camera flight in relation to the propagation of a light beam emitted by the Sun. On a virtual flight from the Sun to the edge of the solar system the camera passes the planet orbits after a time period proportional to its distance to the sun (= average orbital radius). As we know, light has the highest possible speed with about 300 000 kilometers per second, and it takes 8 minutes and 19 seconds for a light beam emitted by the sun to reach the earth (149.6 million kilometers = 1 astronomical unit).
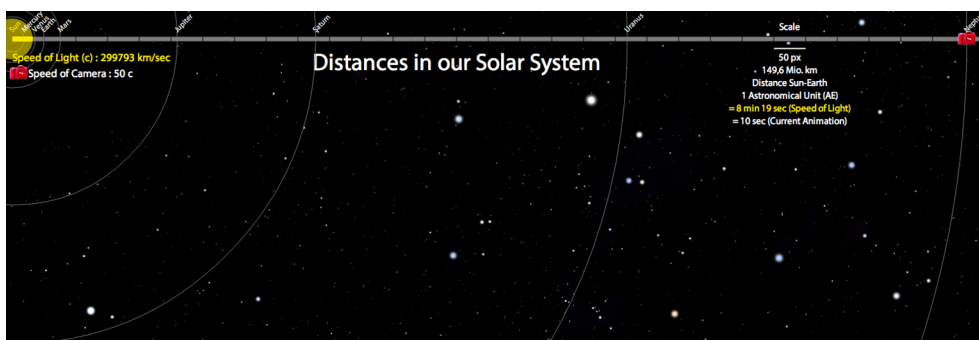
Figure 13. The Virtual Flight from Sun to Neptune with a speed 50 times faster than the speed of light still takes about 5 minutes.

However, we need to set the speed of our virtual camera significantly higher than the light speed, for instance 50 times faster. Although this is not possible in 'real physics' it helps us to make the phenomenon perceivable (*Figure 13*). The earth for example now appears after nearly 10 seconds and the flight to Neptune still takes about 5 minutes. With such a speed, the planets normally would not be visible anymore. And due to performance constraints of our computer a graphical animation of such a high-speed flight is not possible. Thus a photograph of each planet appears at the moment when the camera passes the planet orbit. During such a photo stop the animation of the camera continues to move in the background, and the planet can be observed for a second. The shortest distance in that animation is between Venus and Earth (2.8 seconds). Its important not to degrade the impression of the extreme travel speed with a long-lasting observation of a photo. Above the animated flight visualization, a scale bar can be placed to show the distances between the Sun, the planets, and our current position. On that scale bar, we see a horizontally growing yellow line (extending from the left side) which shows the velocity of a light beam emitted by the sun. In case the first appearance of a planet in the animation (for 1 second) was to short, the atlas user can review each photo by using the related button in the control area. Furthermore, he or she gets some basic information about each planet, similar to the former illustrations. An additional system message informs about the potentially still running animation process (to avoid overlying photos). The parameters of this animation can also be modified partially by the atlas user (especially the velocity of the flying camera). It is important to show the distances without time distortions during an animation. Hence, a slider to accelerate the animation speed intuitively would probably be popular but perhaps not helpful to generate a sustainable impression of the orbital distances. At least the user needs some patience to get a real impression about the dimensions of our solar system. Further animated illustrations could show for instance the apparent sizes of all planets for a sky watcher on earth (minimum and maximum), or the animation of a solar eclipse.

5.   Technical Annotations

Web pages and all illustrations for the interactive web application are built with HTML, CSS (graphic styles), JavaScript (client side programming) and SVG (Scalable Vector Graphics). An alternative to JavaScript could also be PHP (server side programming). Adobe Illustrator was used to draw the basic model for the first illustration (*Figure 5*). SVG and JavaScript, in contrast to proprietary software like Adobe Edge for instance, have the enormous advantage of being open source. (Watt 2002). SVG supports media elements similar to the Synchronized Multimedia Integration

Language (SMIL) 3.0 (W3C 2008). SMIL 3.0, the current release of SMIL, "was developed to bring presentaton-level interactive multimedia to the Web and mobile devices, ..." (Bulterman & Rutledge, 2009). The (current) version 1 of the Swiss World Atlas interactive is based on Java technology. This stand-alone application can be run from the homepage of the Swiss World Atlas and starts from every browser. Java is an object-oriented programming language developed by Sun Microsystems, which since 2010 is part of the Oracle Corporation. Version 2 of the Swiss World Atlas interactive will be a Web application outside the current atlas environment, running in a browser window. Hence, the presented application can be used directly, without the need to install a Java runtime. SVG is now part of the HTML5 specification and works in almost every browser.

6.   Conclusion and Outlook

Beside the examination of the capabilities of 2-dimensional Web graphics in the visualization of commonly known planet data, the main goal of the presented work was the generation of a new illustrative model for the Swiss World Atlas interactive. Relations between some physical and orbital parameters of the planets, and also, in a wider view, correlations between the apparently separated planets in our solar system become visible with the new depictions. With the presented four models, relations to other school subjects (outside the classic geography) can be highlighted by the teacher (for instance in physics). The presented model first shows an alternative to the existing illustrations of the solar system in the current edition of the Swiss World Atlas (Printed Edition), and then a proposal for an additional module for the Swiss World Atlas interactive (Web edition). Hence, the 2D-model shown with *Figure 5* could finally be used for both atlas editions. The model shown in *Figures 7 to 10* is a schematic and simplified approach, and can still be improved in terms of realness and detail, to visualize for instance Kepler's laws of planetary motion. Nevertheless, the main information about the true distances and proportions of the Sun, planets and orbits in our solar system is already available. Obviously the potential of the visualization of astronomy data with animated Web graphics is much higher than with static depictions only. Some essential information can be presented also in a static illustration. And for an introduction of students into a new subject, the depictions should probably be static first. The longer a depiction is observed the stronger is the generated sustainable impression. Nevertheless, after a short phase of contemplation and explanations, the lesson should definitely be enriched by animated visualizations. Beside the animation of 2D graphics and photos, an augmentation with audio content is also possible. Oral explanations, well accentuated music or simple sound patterns can be

added to enforce learning effects. "The map reader recalls information better when it is presented in a graphically pleasing way and with the use of different media (e.g. images, sound, text, animation)." (Jenny et al. 2008). Furthermore, the third spatial dimension is needed for the generation of realistic visualizations. Today we already know sophisticated virtual 3D applications showing us the solar system and planets in a very natural way. Animated 3-dimensional Web graphics can be generated by using WebGL. And this will be the next main topic in the development of the introduced solar system web module.

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