JSXGraph – Dynamic Mathematics Running on (nearly) Every Device

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Abstract

JSXGraph is a library for displaying dynamic mathematics, e.g. dynamic geometry, function plotting, turtle graphics, in a web browser. It is written in JavaScript and runs on a broad variety of devices from desktop computers down to smart-phones and tablet computers. JSXGraph is able to import various file formats like GEONE$_X$T, GeoGebra, Intergeo, and—at least partially—Cinderella. At the moment, this seems to be the only possibility to display content from these sources on upcoming small computing devices, which makes them usable in class room.

Since Java applets seem to be on the retreat in web application, other approaches for displaying interactive mathematics in the web browser are needed. One such alternative could be our open-source project JSXGraph. It is a cross-browser library for displaying interactive geometry, function plotting, graphs, and data visualization in a web browser. It is implemented completely in JavaScript and uses the vector graphics formats SVG and VML. No further plug-ins are required.

1 Introduction

In the late 1990s the availability of graphical web browsers that enabled easy access to the World Web Web brought many fresh ideas to the class room and to mathematics education. The programming language Java became the dominant tool to raise interactivity in dynamic mathematics to a new level. Countless new Java-based *Mathlets* came to existence to visualize many aspects of mathematics with levels varying from Kindergarten to University. Also, powerful software systems were developed that combined geometry and calculus under one graphical user interface. The most prominent examples are Cinderella [6], GEONE$_X$T [2] and GeoGebra [4] to name a few of them.

But now a new hardware generation is on the horizon which appears to be better suited for the class room than the old clumsy Personal Computer. The revolution started with the success of small and cheap netbooks and the appearance of powerful smart-phones. Now, these two complementary worlds seem to melt together into tablet computers. The success of the iPad by Apple confirms this. Probably, very soon many other hardware manufacturer will follow and produce cheaper tablet computers having more features than the iPad.

Now, mathematics education faces the challenge that most of the existing web-based software for dynamic mathematics is implemented in Java and embedded in web pages as so called Java applets. But there will be no Java plug-in available on most of these new machines. Without good software the new hardware is useless for learning mathematics in the class room.

With the project JSXGraph[1] at the University of Bayreuth we tried to take up this challenge and offer first class dynamic mathematics software that runs on every device including smart-phones, netbooks, tablet computers and Desktop PCs. Moreover, the goal is to provide compatibility for existing resources for mathematics education.

JSXGraph is a free software library for mathematical visualizations in a web browser. Its feature set covers *dynamic Geometry*, plotting of *function graphs* and *curves* of various types, *charts*, and *turtle graphics*

Usually, JSXGraph is embedded in web pages, for on- or offline viewing. The download size is a mere 80 kByte, when embedded in web pages. JSXGraph enhanced web pages can be viewed with all major web browsers on nearly every hardware platform and operating system. The supported hardware ranges from smartphones and tablet computers running iOS or Android to Desktop PC running Windows, MacOS X or Linux.

At the time of writing, JSXGraph is the only dynamic geometry system that runs on such a broad range of devices and web browsers—without installation of any plug-in or wathsoever additional software. JSXGraph is usable even on devices with limited computing resources, like older Desktop PCs running Microsoft Internet Explorer 6.0.

Thus, this library may prove to be helpful for the introduction of technology in mathematical education in developing countries.

JSXGraph is released under the Lesser GNU General Public License (LGPL), the source code is available at Sourceforge[2]

2 Computers in the math class room

As of today three types of computers are used by students in class room:

- Desktop PC: high computing power, runs desktop programs and web based software, the web browser contains Java plug-in and Flash plug-in, robust hardware, requires computer lab, need power plug, expensive.
- Programmable Desktop Calculator: low computing power, low graphical resolution, runs only special purpose software, no web access, no computer lab necessary, long battery life, very robust hardware, cheap.
- Laptop, netbook: medium to high computing power, no computer lab necessary, medium to long battery life, software like Desktop PC, but Java plug-in may not be available, or maybe slow, medium priced to expensive, fragile hardware.

Soon, the new generation of tablet computers will be available and these devices will be well suited for the classs room: cheap to medium priced, robust hardware, medium computing power, long battery

[1] http://jsxgraph.org

[2] http://sourceforge.net/projects/jsxgraph/

	Firefox 3+	Internet Explorer		Opera	Safari	Chrome	
		4-8	9		incl. iPad	Desktop	Android ≤ 2.2
SVG	✓	–	✓	✓	✓	✓	–
VML	–	✓	–	–	–	–	–
Canvas	✓	–	✓	✓	✓	✓	✓
market share	22.93%	60.4%	–	2.37%	5.16%	7.52%	

Table 1: Supported graphics formats of the most popular web browsers. The market share data is from August 2010 by *Net Applications* [15].

life, running desktop special purpose programs and web based software, Java plug-in is not available, Flash plug-in may be available.

The tablet computers seem to combine the advantages of the Programmable Desktop Calculator and the laptop.

The most notable disadvantages of these devices are that typing is still not as easy as with a physical keyboard and that none of the available software for dynamic mathematics is available for these platforms. The situation for software developers is difficult because there exists a variety of different hardware and software platforms used by these devices. Thus, web-based software seems to be the only managable solution to provide dynamic mathematics software for all platforms simultaneously.

3 Background on web based visualization

For implementing dynamic mathematics software for the web browser for all platforms the only remaining prgramming language is JavaScript. In the first years of its availability JavaScript was running very slow, but recently the browsers come with very advanced Just-in-Time compilers for JavaScript. Moreover, the initalisation time of a JavaScript program is close to zero in contrast to some Java plug-ins.

For realizing graphical output in the web browser that can be manipulated by JavaScript there are several possibilities, depending on the browser:

- SVG:[3] Scalable Vector Graphics, vector graphics format.
- VML:[4] Vector Markup Language, vector graphics format.
- Canvas:[5] bitmap graphics.

Table 1 shows that if a software wants to support graphical output on all major web browsers then it has to support at least the canvas element and VML. In the context of dynamic geometry, the SVG format – if available – seems to be slightly better suited than the canvas element, see [16].

[3] http://www.w3.org/TR/SVG/

[4] http://www.w3.org/TR/NOTE-VML

[5] https://developer.mozilla.org/en/Canvas_tutorial

For tablet computers the Android version of Chrome and Safari seem to become the predominant browsers, since many of these devices are announced to be based on Android. For a future release of Android, SVG support of Chrome has been announced.

Even with the availability of the Internet Explorer 9 the need for support of VML will remain for some years, because Internet Explorer 9 will not be available on older machines running Windows XP. This seems to be especially the case for schools and public institutions which are typically slow on updating their computing infrastructure. The slow adaption rate is also underpinned by the survey [15] which shows that in August 2010 the Internet Explorer 6 still had a market share of 16.18% despite the availability of versions 7 and 8 since some years.

4 The library JSXGraph for dynamic mathematics

Geometry elements: point, glider, intersection, parallel, perpendicular, line, segment, axis, tangent, normal, vector, circle, circumcircle, ellipse, hyperbola, parabola, conic defined by five points, polygon, regular polygon, midpoint, mirror point, reflection point, semicircle, circumcircle arc, circumcircle sector, angle, bisector, bisector lines, exact loci computation

Calculus: function graph, parametric curve, polar plot, Lagrange interpolation, cubic spline, B-spline, Bezier curve, regression polynomials of arbitrary degree, Riemann sums, numerical differentiation, numerical integrations, numerical solution of systems of ordinary differential equations, matrix computions, Eigenvalue, -vectors

Chart types: bar chart, line chart, point chart, radar chart, cartogram

Other: slider, images, projective transformation, turtle graphics, various types of animation, various R-like statistical functions, Lindenmayer systems, shadows, HSV color palette, dynamic texts with LaTeX-support via MathJax[6]

The size of the JSXGraph code is about 380 kByte. If the web server delivering the content has data compression enabled (which should be the default anyhow) the size of the transmitted code is about 80 kByte. To compare it with Java software, for example the size of the GEONE$_X$T archive is about 1 Mbyte. JSXGraph does not rely on any other JavaScript library.

JSXGraph runs on every hardware and operating system which has a graphical web browser. The range of supported hardware thus reaches from Desktop PCs down to tablet computers and smartphones.

In order to use JSXGraph the developer has to include only two files in the HTML file: the JSXGraph code and a CSS file.

JSXGraph is a pure JavaScript implementation, it does not rely on other libraries. JSXGraph uses the vector graphic format SVG[7] for graphical output in a web browser. If SVG is not available, JSXGRaph falls either back to the alternative vector graphic format VML[8] or to the new HTML 5 element canvas[9].

[6] http://mathjax.org

[7] http://www.w3.org/TR/SVG/

[8] http://www.w3.org/TR/NOTE-VML

[9] https://developer.mozilla.org/en/Canvas_tutorial

All the mainstream web browser are supported, Firefox 3+, Internet Explorer 6+ (including the upcoming version 9), Google Chrome (all versions). Also, the browsers Safari, Opera are supported since at least 2008.

For smartphones the Opera mini is supported but without interactivity. Also Android based devices are supported since the release of the JSXGraph v0.82. The default browser on these devices (at least up to Android 2.2) does not provide SVG or VML graphics. But in the latest version of JSXGraph the use of the HTML canvas element is enabled. Thus, a new range of devices is able to run JSXGraph.

With JSXGraph it is possible to access modern mathematical content even with these old machines. Many smart-phones come with the operating system Android2, also many already announced tablet PCs are suspected to be Android based. The default web browser on Android does support neither SVG nor VML, but it allows to draw bitmap graphics with the new HTML element canvas. Starting with release 0.82, JSXGraph supports the canvas element, too. Even on more powerful computers JSXGraph has the advantage over Java based software that the downloading time and the initialization time is much shorter than for comparable Java-applets. In summary, JSXGraph is usable on a huge amount of devices and should be able to take up the challenge and support dynamic mathematics on the upcoming hardware generation. At the time of writing, there is no other software for dynamic mathematics that can be used on such a wide range of devices.

5 JSXGraph as DGS viewer

JSXGraph is able to read and display the following file formats:

- GEONE$_X$T[10] [2, 3]
- Intergeo[11] [5]
- GeoGebra[12] [4]
- Cinderella[13] [6]

The support of the GEONE$_X$T file format by JSXGraph is close to 100%. Only very few GEONE$_X$T resources are misinterpreted by JSXGraph. In Figure 1 the construction to the right is the GEONE$_X$T Java-applet, to the left is the same file displayed by JSXGraph.

The Intergeo [5] format is an upcoming common file format supported by the most European implementors of dynamic geometry systems. JSXGraph possesses one of the most complete implementations of the file formats. At the time of writing, the file format just starts to gain popularity.

The support for GeoGebra is not complete, but covers the most common features of GeoGebra. In Figure 2 the construction to the right is the GeoGebra Java-applet, to the left is the same file displayed by JSXGraph.

[10] http://geonext.org
[11] http://i2geo.eu
[12] http://geogebra.org
[13] http://cinderella.de

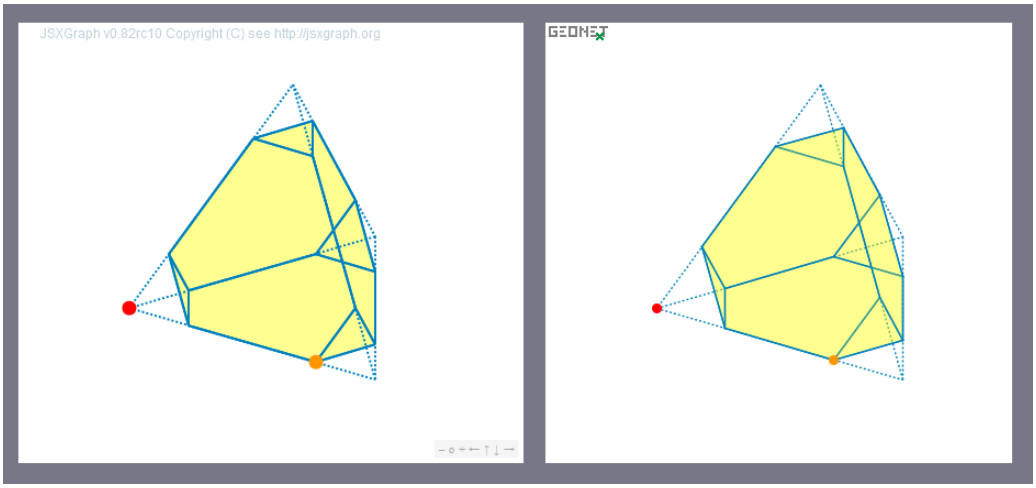

Figure 1: The right image shows a GEONE$_X$T java applet, the left image contains the same construction displayed by JSXGraph.

The support of the Cinderella file format [6] by JSXGraph is in a very early development stage. At the moment it comprises most of the Euclidean Geometry part of Cinderella. In Figure 3 the construction to the right is the Cinderella Java-applet, to the left is the same file displayed by JSXGraph.

6 Constructing with JessieScript

JSXGraph comes with a simple geometric construction language called JessieScript, which is closely related to the syntax students use in school to describe their construction by compass and ruler. An example is shown in Figure 4, the online version is available at http://jsxgraph.uni-bayreuth.de/jessie. The whole web page consists of three elements: the form for the text input of the construction, the display of the construction and a log window.

The most important commands are:

– `A(1,1)`: Point with name '`A`' at position $(1, 1)$

– `ZY(0.5|1)`: Point with name '`ZY`' at position $(0.5, 1)$

– `]AB[`: straight line through points A and B

– `[AB[`: ray through points A and B, stopping at A

– `]AB]`: ray through points A and B, stopping at B

– `[AB]`: segment through points A and B

– `g=[AB]`: segment through points A and B, named by '`g`'

– `k(A,1)`: circle with center A and radius 1

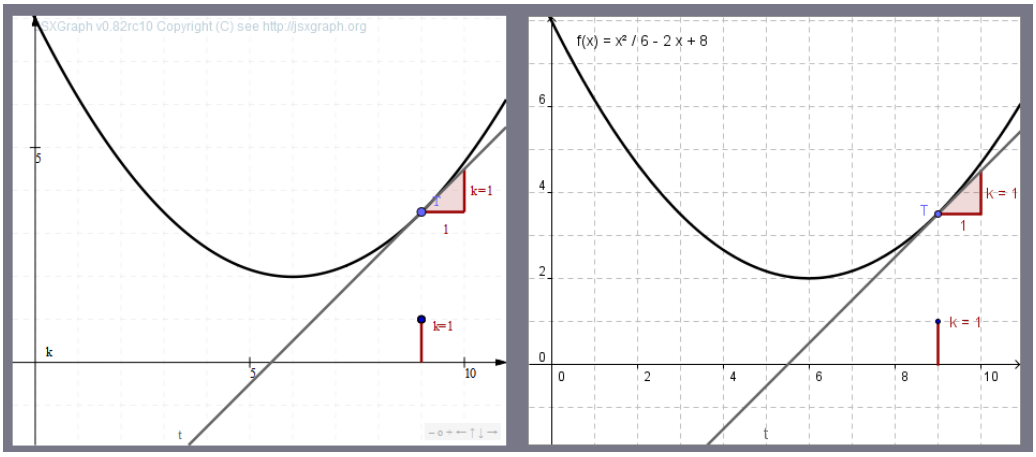

Figure 2: The right image shows a GeoGebra java applet, the left image contains the same construction displayed by JSXGraph.

– `k(A,B)`: circle with center A through point B on the circle line

– `k(A,[BC])`: circle with center A and radius defined by the length of the (not necessarily existing) segment `[BC]`

– `k_1=k(A,1)`: circle with center A and radius 1, named by '`k_1`'

The JSXGraph homepage contains the full description of the syntax.

7 JSXGraph for Mathlet programming

With JSXGraph it is possible to create special purpose mathematics visualizations. These are sometimes called *mathlets*, see for example [7].

JSXGraph provides an API (application programming interface) to build dynamic mathematics applications for the web browser. The differential equation plotter1 on the JSXGraph home page is one example for using JSXGraph in mathematics education on the university level. Other applications are function plotters, turtle graphics, and support for various possibilities to create charts. This is especially interesting for publisher of e-books or provider of e-learning content. In this way, JSXGraph meanwhile is used in situations that are different from mathematics education, like medical information systems2 or landslide prediction3.

The JSXGraph wiki4 contains more than 170 examples for dynamic mathematics, covering many areas like charts, function plotting, calculus, geometry, and turtle graphics, to name a few.

Flexible layer system.

Here is a quick overview on the available mathematical elements of JSXGraph.

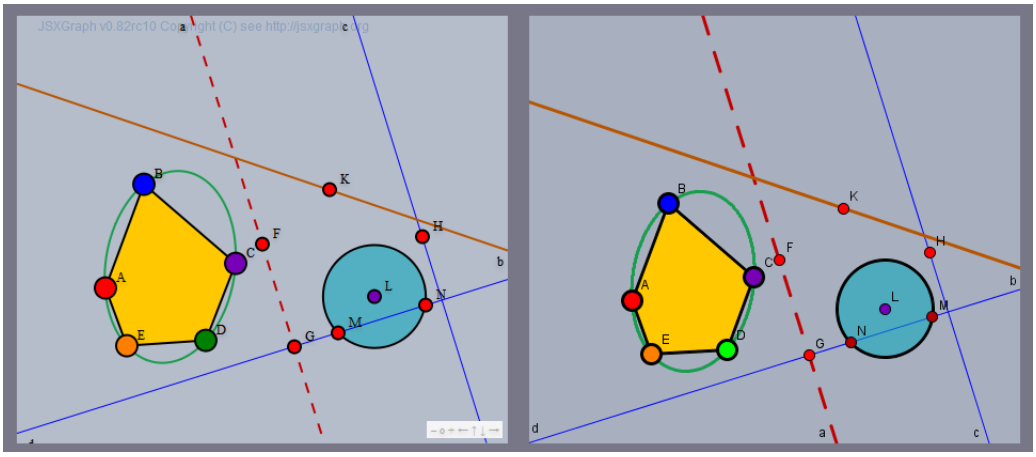

Figure 3: The right image shows a Cinderella java applet, the left image contains the same construction displayed by JSXGraph.

7.1 Geometry

JSXGraph is a complete DGS (dynamic geometry system) for plane Euclidean geometry. It contains support for homogeneous and affine coordinates. The following element types are available:

7.2 Calculus and function plotting

Function plotting, parametric curves, polar plots. Differential equation solver.
Interpolation: Lagrange interpolation, cubic splines, B-splines, Bezier curves.

7.3 Animations

7.4 Other topics

Projective transformations, Turtle graphics, charting. Initial attempts to display 3D points.

8 Exact loci computations

9 Other Features

9.1 Plug-ins

* moodle * wordpress * mediawiki

```
<jsxgraph width="500" height="500">
  var brd = JXG.JSXGraph.initBoard('jxgbox',{boundingbox:[-2,2,2,-2]});
  var p = brd.create('point',[1.5,1.5],{face:'o', size:8});
```

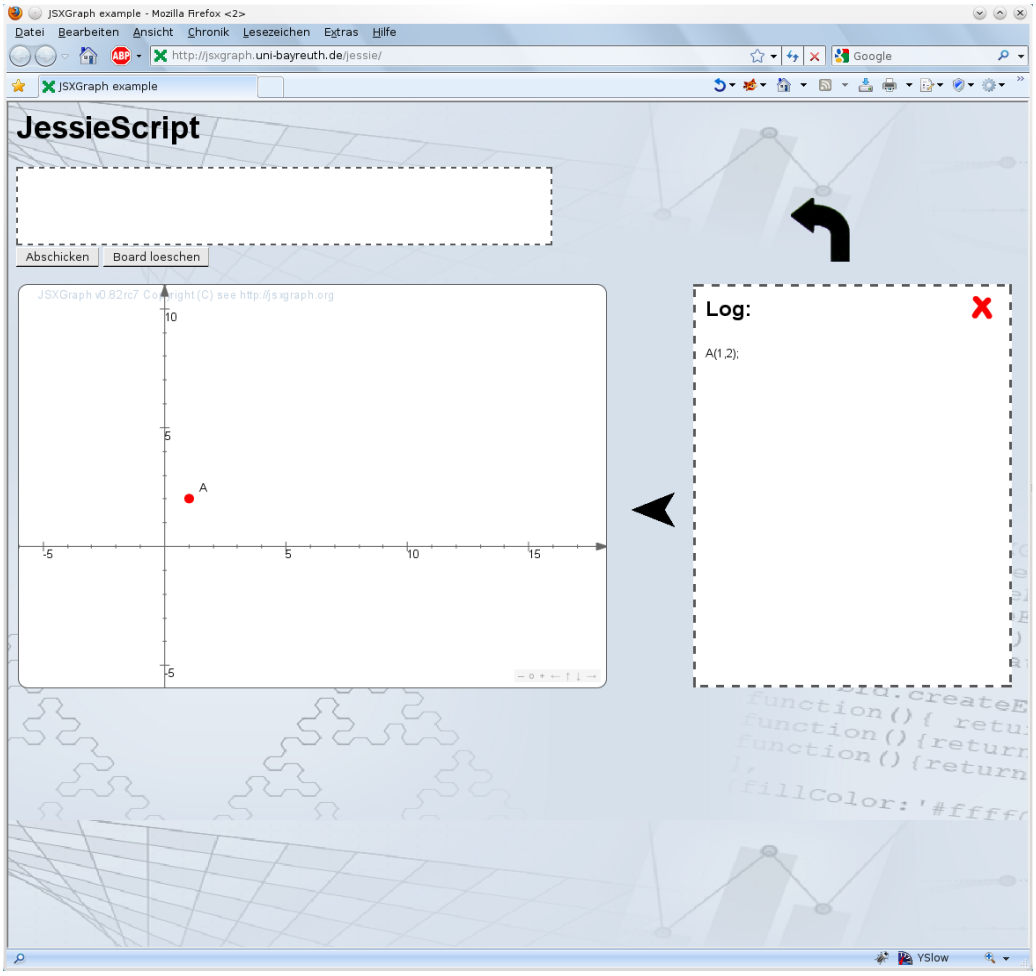

Figure 4: A simple web page for constructiong with JessieScript.

```
  brd.create('segment',[[0,0],p],{dash:3});
</jsxgraph>
```

* drupal

9.2 New features

* Bezier curves * Conic sections * LaTeX syntax for labels and texts o ASCIIMathML (falls back to Google chart API) o MathJax (http://www.mathjax.org) * Animations

9.3 Conclusion

JSXGraph enables the usability of existing mathematical resources on a broad variety of new, small computing devices. These devices seem to be very well suited for use in class room, but up to now

there is a lack of good mathematical software, since Java-applets are not longer supported. The goal of JSXGraph is to change this situation.

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[12] http://geonext.de

[13] http://geogebra.org

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