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 Wide 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 [7], GEONE$_x$T [2] and GeoGebra [4] to name a few of them. Also, desktop programs are of importance. Examples are *The Geometer's Sketchpad*[1] and *Cabri II plus*[2], both available for Windows and MacOS.

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

[1] http://www.dynamicgeometry.com
[2] http://cabri.com

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[3] 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.

2 Computers in mathematics education

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.

[3] http://jsxgraph.org

	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* [8].

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 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 implementors of dynamic mathematics software 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 possible programming language is JavaScript [1]. 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, see the online versions of Figures 1, 2, and 3.

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

- SVG:[4] Scalable Vector Graphics, vector graphics format.
- VML:[5] Vector Markup Language, vector graphics format.
- Canvas:[6] bitmap graphics.

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

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

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

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 [5].

For tablet computers Safari and the Android version of Chrome will most likely 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 [8] 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

The open-source library JSXGraph, developed at the University of Bayreuth, addresses the above problems. JSXGraph is a pure JavaScript implementation, it does not rely on any other library. By default, JSXGraph uses the vector graphic format SVG for graphical output in a web browser. If SVG is not available it falls back to either VML or canvas.

Another pure JavaScript implementation of a Dynamic Geometry system is GeometryEditor[7], formerly known as GeoSVG. But there, the graphical output is restricted to SVG.

First publicly presented in 2008 [3], JSXGraph offers all functionality of Dynamic Geometry System (DGS), including conic sections. Meanwhile, the features of JSXGraph go far beyond the possibilities of most DGS. The following list gives an overview of possibilities of JSXGraph.

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, homogeneous and affine coordinates

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 compution, root finding, Eigenvalues, -vectors

Charts: 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

Display options: HSV color palette, shadows, dynamic texts with LaTeX-support via MathJax[8], flexible layers

[7] http://wme.cs.kent.edu/geosvg/

[8] http://mathjax.org

The goal of JSXGraph is to be real dynamic. For example, the degree of a regression polynomial[9] or the fill color of certain elements[10] may depend on other elements.

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.

In order to use JSXGraph the web developer has to include only two files in the HTML file: the JSXGraph code and a CSS file. JSXGraph is released under the Lesser GNU General Public License (LGPL), the source code is available at Sourceforge[11].

As explained in Section 3, JSXGraph runs on every hardware and operating system which has a graphical web browser. All the mainstream web browser are supported, Firefox 3+, Internet Explorer 6+ (including the upcoming version 9), Google Chrome (all versions). The browsers Safari, Opera are supported since at least 2008. The range of supported hardware thus reaches from Desktop PCs down to tablet computers and smartphones.

With JSXGraph it is possible to access modern mathematical content even with old computers running Internet Explorer 6. But 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 platforms.

5 JSXGraph as DGS viewer

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

- GEONE$_X$T[12]
- Intergeo[13]
- GeoGebra[14]
- Cinderella[15]

The support of the GEONE$_X$T [2, 3] 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.

[9] http://jsxgraph.uni-bayreuth.de/wiki/index.php/Polynomial_regression_I
[10] http://jsxgraph.uni-bayreuth.de/wiki/index.php/Infinity
[11] http://sourceforge.net/projects/jsxgraph/
[12] http://geonext.org
[13] http://i2geo.eu
[14] http://geogebra.org
[15] http://cinderella.de

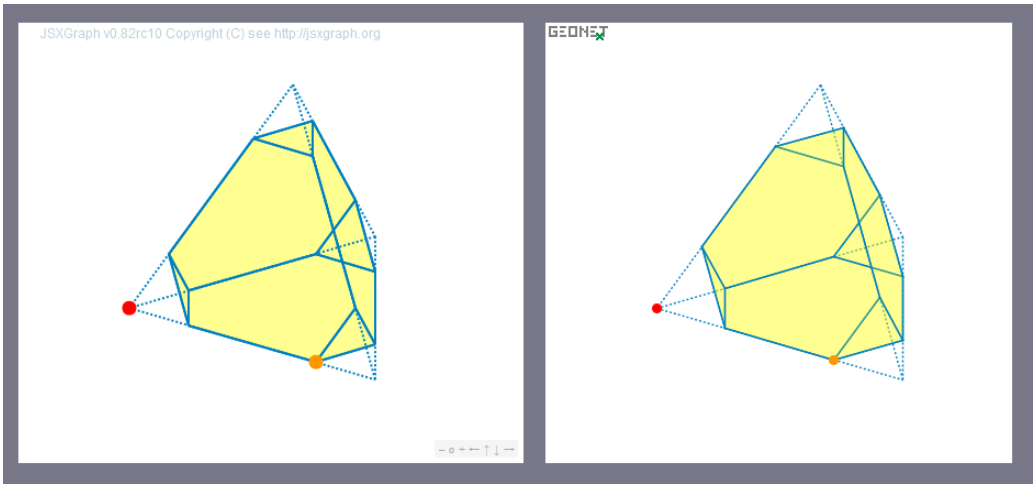

Figure 1: The right image shows a GEONE$_X$T Java applet, the left image contains the same construction displayed by JSXGraph (online version).

The Intergeo [6] 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.

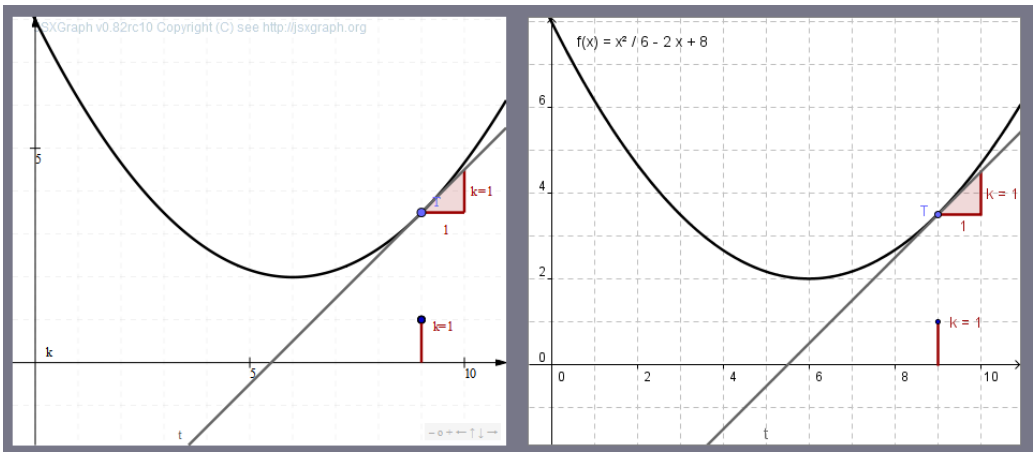

Figure 2: The right image shows a GeoGebra Java applet, the left image contains the same construction displayed by JSXGraph (online version).

The support of the GeoGebra [4] file format 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.

The support of the Cinderella [7] file format [7] 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.

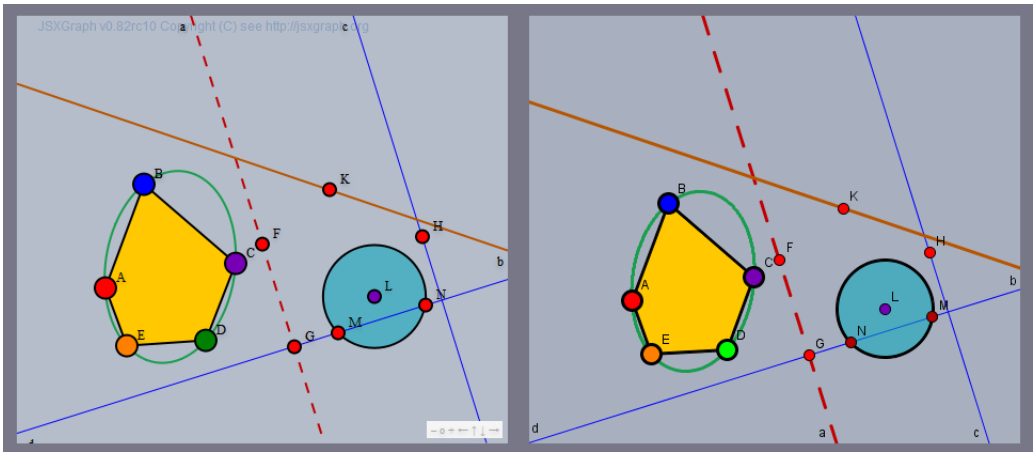

Figure 3: The right image shows a Cinderella Java applet, the left image contains the same construction displayed by JSXGraph (online version).

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. Another side effect of JessieScript is security. In the web application of Figure 4 input is restricted to JessieScript syntax, all other input is ignored. This makes it difficult to infiltrate malicious JavaScript code.

The most important JessieScript 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
- `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]`

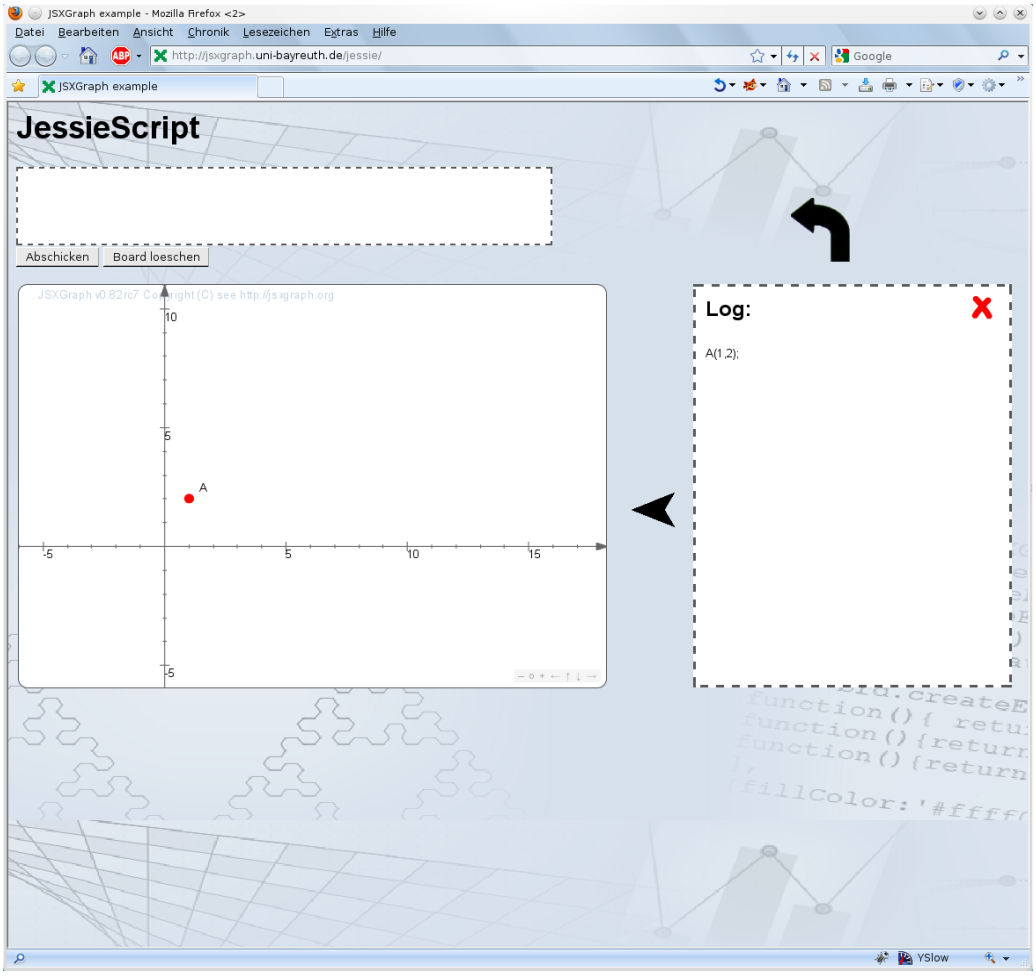

Figure 4: A simple web page for constructiong with JessieScript (online version).

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

The JessieScript wiki page contains the full description of the syntax.

7 Developing Mathlets with JSXGraph

With JSXGraph it is possible to create special purpose mathematics visualizations. These are sometimes called *mathlets*[16].

JSXGraph provides an API (application programming interface) to build JavaScript based dynamic mathematics applications for the web browser. The differential equation plotter in the JSXGraph wiki is one example for using JSXGraph in mathematics education on the university level. Other applications are function plotting, turtle graphics, and support for various possibilities to create

[16]See for example http://math.mit.edu/mathlets/

charts. This may be especially interesting for publisher of e-books or provider of e-learning content. Further, communication between JSXGraph and special purpose software on server side is very simple, see Section 8 for an advanced example.

JSXGraph meanwhile is used in situations that are different from mathematics education, like landslide prediction.

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

For some wide-spread content management systems there exist plug-ins to ease the integration of JSXGraph code. At the moment, plug-ins exist for drupal, mediawiki, moodle, and wordpress. For example, the code to include JSXGraph code into a wiki page powered by mediawiki with JSXGraph plug-in installed looks the following (online version):

```
<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});
  var q = brd.create('point',[-1,-0.5],{face:'x', size:5});
  brd.create('segment',[p,q],{dash:3});
</jsxgraph>
```

The plug-in introduces the new tag name `<jsxgraph>` which is an HTML `<div>` element containing the JSXGraph construction.

8 Exact loci computations

9 Conclusion

JSXGraph enables the usability of mathematical resources on a broad variety of platforms including new small tablet computers and old, outdated Desktop PCs. These tablet 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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