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Exploring the Future: is HTML5 the solution for GIS Applications on the World Wide Web?

Trondheim, December 18th 2011

Project Assignment

NTNU
Norwegian University of Science and Technology
Faculty of Engineering Science and Technology
Department of Civil and Transport Engineering
Division of Geomatics

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Innovation and Creativity

NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF CIVIL AND TRANSPORT ENGINEERING

Report Title:

Exploring the Future: is HTML5 the solution for GIS Applications on the World Wide Web?

Date: December 18th 2011

Number of pages (incl. appendices): 86

Master Thesis Project Work X

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Abstract:

The unfortunate need to develop multiple native applications has emerged with the recent explosion in mobile device usage, and HTML5 promises to be a common platform for application development towards multiple different devices with different operative systems. Applications in the GIS domain is exposed to this in particular, because location-based applications are especially useful in mobile devices, and by developing the GIS application with HTML5, it can be used on any device that supports the parts of HTML5 that are used.

It is important to understand that HTML5 is a standard that consists of several, individual pieces -- some are well supported across browsers, and some are not. This paper explores elements of HTML5 (and specifications related to HTML5), and their use in web application development the GIS domain, and especially technology with essential features for GIS applications that has not previously been part of the open web. There are lots of existing, open GIS standards and GIS libraries already available, that decreases development time for GIS applications on the web, and promote cooperation and compatibility between GIS applications.

There is an overview and an in-depth analysis of interesting possibilities available with the new technology, and accompanies most elements with examples to preview the elements in a GIS application environment. Some elements that influence performance in particular, is tested in-depth to examine the benefits and improvements possible with the new technology.

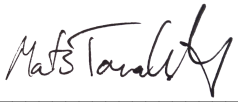
Visualisation with the canvas element or inline svg is especially interesting for mapping applications, and provides developers with tools to work with raster and vector data. The geolocation specification is a standard way to retreive the users' location. HTML5 enhances performance by decreasing latency and bandwith with the Web Sockets API and Server-Sent Events, and by launching non-blocking processes with the Web Workers API. HTML5 finally introduces native support for media with the video and audio elements; storing application data is easier and more secure with the Local Storage API and creating offline applications -- especially for mobile devices that often are without internet access -- is possible with Application Cache.

Although HTML5 is a young standard, some GIS applications have already been developed using the new technologies, and the paper provides an overview of how these applications utilize HTML5.

In conclusion, with the new HTML5 standard, the open web has taken a major step forward for providing developers and companies with the means necesseary to create GIS applications that may compete with their desktop-bound counterparts. While third-party plugins like Adobe Flash and Microsoft Silverlight are years ahead in terms of maturity, HTML5 lays a solid foundation for the future open web, and existing GIS applications that use HTML5 technologies are impressive both with regards to their performance, and their user interfaces.

Keywords:

1. HTML5, GIS, platform independence, mobile devices
2. canvas, inline svg, web sockets, web workers, geolocation
3. WHATWG, WC3



(signature)

Abstract

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Project assignment

Exploring the Future: is HTML5 the solution for GIS Applications on the World Wide Web?

Discipline: GISc, Cartography

Background: HTML5 and related technologies open for more functionality within a Web-browser environment. In this context it is interesting to study how this technology can be employed for GIS applications.

Task: Discuss the motivation for making GIS applications available on Web and explore how the HTML5 technology that can be utilized for this purpose. It is expected that simple prototype applications are developed to illustrate how HTML5 related technology can be used in connection with geographical information.

Terje Midtbø
September 2011

Preface

This paper, *Exploring the Future: is HTML5 the solution for GIS Applications on the World Wide Web?*, is the result of the in-depth project assignment in the course TBA4560 at the division of Geomatics at the Norwegian University of Science and Technology (NTNU), with a timespan constrained to five months in the autumn of 2011.

My primary advisers during the project, which I would like to thank especially for their valuable contributions and assistance, were Terje Midtbø and Alexander Nossum at the division of Geomatics.

I would also like to thank Sverre Wisløff at Norkart Geoservice AS for contributions and comments on the paper and HTML5 applications, and Atle Frenvik Sveen at Geomatikk IKT AS for sharing knowledge of existing HTML5 implementations.

December 19, 2011
Mats Taraldsvik

License

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1. Introduction

The past has given us desktop applications for GIS operations, requiring powerful computers for every user. Today, it's all about putting applications on the web, and an emerging technology, to free us from proprietary, third-party plugins, is HTML5.

The goal in this paper is to examine the new technologies that the HTML5 specification makes available, look at possible uses in GIS, and investigate current GIS applications that have been implemented with HTML5. The definition of HTML5 in this paper does not strictly adhere to the specification, but also includes important parts or modules that are important for web applications, although they were not standardized by the the Web Hypertext Application Technology Working Group (WHATWG)[2].

1.1. Source code for the examples

The examples that were developed by the author for this paper – either to illustrate the functionality of HTML5 modules, or for performance testing – is publicly available on the collaboration site github[3]. The url to the source code repository, is http://www.github.com/meastp/html5andgis/

2. What is HTML5?

2.1. History

HTML was created by Tim Berners-Lee – widely acknowledged as the "father of the web" – in 1989. It was created to ease collaboration between researchers at geographically distant locations, by enabling sharing of large amounts of data electronically. The methods for marking up content into structural units (paragraphs, headings, list items etc.) was inherited from an older markup language, while the genius idea of hypertext links was purely Tim's invention[4].

In the following years, a number of competing web browsers were developed. Most of them supported the HTML standard correctly, but some also added various extensions to the capabilities of HTML. This led to major problems where a page designed for one browser wouldn't display correctly – or indeed work at all – in other browsers. Thus, the World Wide Web Consortium (W3C)[5] was formed "to lead the World Wide Web to its full potential by developing protocols and guidelines that ensure the long-term growth of the Web"[6].

Even though there were several widely adopted versions of HTML in the wild by 1998 (HTML, HTML 2.0, HTML+, HTML 3.0), none of them were officially codified as standards. The first true standard for HTML – HTML 4 – was published by the W3C in 1998. HTML 4 added a lot of new features (style sheets, frames, embedded objects, complex forms etc.) and made the HTML standard more complex. Later, in 2000 and until today, newer standards based on Extensible Markup Language (XML) were developed (XHTML 1.0, 1.1, Basic and 2.0).

The demands for what the web should provide has changed dramatically in the short time that there have been standards for HTML. It was created merely as a tool for researchers to communicate across geographical boundaries, but has evolved to something no-one can live without. What users want nowadays is a web that behaves more like applications than documents, which is a tremendous effort with the existing standard, forcing web developers to implement the features through third-party (often proprietary) plugins, requiring installation of software and compatibility issues for the user.

As early as 2004, when the W3C was focusing future developments on XHTML 2.0, the Web Hypertext Application Technology Working Group was formed to update the HTML 4 standard, which had not been updated since 2000. The W3C abandoned the XHTML 2.0 work, and instead joined WHATWG in their work to update the HTML standard, named HTML5.

3. The motivation of HTML5

With the increasing sale of mobile devices, alongside steady growth in "traditional" desktop and laptop computers, companies providing GIS services and software are getting interested

in moving software to the web platform, targeting more users and several devices at once, with a single, common codebase. With proprietary extensions and third-party plugins, one is at the mercy of the providers with regards to device support.

Since the adoption of mobile devices has exploded[7], there is major advantage in having an application available to the mobile device market. This market is split between several platforms, however, and it is costly to develop native applications for several operative systems. HTML5 solves this by being a common platform that is accessible for every mobile device with a modern web browser and an internet connection.

When moving an application to the web, there is also a possibility of using it to collect contributions from users[8]. Using lots of users to collect or process data – also known as "crowdsourcing" is a good way to distribute the work load, and GIS/map based applications are already popular for crowdsourcing[9][10]. Using HTML5 means that a lot of devices can access the application, and thus a lot of users are able to contribute[11][12].

HTML5 is based on open standards, and introduces impressive technologies that ease implementation of GIS applications and services on the web. There are existing open formats for exchanging geographic data, which reduces the need for proprietary formats, and makes it trivial to exchange data between (competing) companies' GIS applications.

3.1. Replacing proprietary standards

Browser plugins and extensions emerged when the browsers were not as capable as they have become today and made it possible to create richer web sites than were possible with existing standards, in plain html, as well as games and applications. These plugins were either developed independently by browser vendors, who wanted to attract users and developers to their browser, or they were developed by a third-party company, who wanted to extend web functionality with their own product. Microsoft's ActiveX[13], which only worked with the Internet Explorer browser[14], is an example of the former, and Adobe Flash[15], which is a proprietary animation framework with no way to make an independent implementation, is an example of the latter.

With an open standard, one is free to implement support on even the least popular systems. On the other hand, since the technical specification is not available – at least for free – to anyone, one can not implement support on a specific system for a closed standard. Since it does not make sense for a company to support other systems than the most popular, that is exactly what will happen. A great example is standards for e-mail. If these were not open, one wouldn't be able to send e-mail between different providers (which actually was the case in e-mail's infancy, where several incompatible implementations were in use[16]).

One of the most fundamental ideas behind the web is to be accessible. With open standards, everyone is able to use and implement these standards and also compete on equal terms. Another important issue is accessibility, which often suffer in non-open standards[17]. The open standards that the W3C develop, however, are required to go through a process to verify

that they are sufficiently accessible. Trying to create accessible content in e.g. Adobe Flash is difficult compared to HTML[18][19].

3.2. Moving desktop applications to the web

For several years, there has been several incentives to move desktop applications to the web, where the largest might be by Google and their Chrome OS (a linux based operative system with a minimal native environment, focused on delivering applications and content through Google's own browser, Chrome[20])[21]. Most of the successful attempts have been made by Google (Maps[22], Docs[23], Reader[24], Plus[25]) or startup companies (Evernote[26], Remember the Milk[27], Sketchpad[28], Facebook[29]), and today these applications are used just like the "normal" desktop applications we use daily.

Web based applications can access data stored on the server directly, and there is no need for the client to download a complete copy of the data. By keeping a single, central copy on a server, the cpu and memory requirements are loosened, and devices such as smartphones and tablets – which are not very powerful – become appropriate as clients[30].

There has always been demand for platform independent applications that work on all the most popular operative systems (Windows, OS X, Linux), but since Microsoft Windows is dominating the market, this demand hasn't been critical for companies. However, the last few years has seen an explosive growth in powerful and capable mobile devices (smartphones, tablets) which is gaining quite a bit of market share very fast[7]. This, and especially the need to develop (native applications) for at least two platforms (Android OS, iOS), has led to companies looking for other solutions to reduce development cost. Development cost is reduced when one can make a single app based on standards that are supported across all target platforms, which is the case with HTML5.

This is why HTML5 is so promising and unifying for everyone. Open standards that work on all (or most) platforms desired, all with no extra or duplicated code required, since there is only a single platform. Unfortunately, all of HTML5's elements isn't supported by all major browsers yet (see Section 4.1), but it is a very young standard, and have gained *a lot* of momentum from major players (e.g. Google[31], Apple[32][33]).

There hasn't been a place for heavy GIS applications as pure web applications in the past (as opposed to simple map viewers, in which there are plenty of on the web), mostly for technical reasons which are now nearly overcome. GIS applications deal with mapping data, which often are tied to various licensing restrictions – therefore a hassle to get hold of – and often consume a non-trivial amount of space. There is also a lot of complex interaction involved in GIS applications while manipulating objects, and before HTML5 there was no standard way of providing this as vector graphics to the user.

3.3. Providing a service with open standards

With one of the primary motivations behind HTML5 being portability and independence (from a single company) by using open standards and open source languages (JavaScript), it would only be natural to encourage this at the application layer level as well. In addition to applications targeted for the end-user, there are also other possibilities, like creating services and libraries, while taking advantage of the new technology that the HTML5 standard provides.

For maximum exposure and reach, it is crucial for these services – and applications that use them – to communicate through open standards. The amount of users on mobile devices such as tablets, are increasing at a rapid phase. Since these devices use different operating systems, the easiest way to reach them is through the web browser, in an application written once, with HTML5.

Developing proprietary formats for every GIS system from scratch would mean that they were incompatible with each other and no geometric data could be exchanged (i.e. prone to data lock-in), and it would be *a lot of unnecessary work*. Even proprietary vendors support open standards already for precisely this reason (and anti-monopoly laws).

3.3.1. Open Web Standards for use in GIS

There are two groups of open standards, each with it's own definition of the term "open". For standards used in GIS, the Open Geospatial Consortium (OGC)[34], and the International Organization for Standardization (ISO)[35] are the most relevant, and represent both definitions. Standards developed by the International Organization for Standardization cost money[36].

For developers working on open source applications, collecting or donating the money required to buy the standards, is a hindrance – and essentially affects the standards themselves. Fortunately, the Open Geospatial Consortium develops standards[37] that are free for everyone to access and use[38]. Only standards developed or provided by the Open Geospatial Consortium – as well as other (truly) open and free standards to acquire and implement – will be examined in this paper.

Geography Markup Language Geography Markup Language (GML) is an XML grammar for expressing geographical features[39]. It is made as an interchangeable format for transferring geographic elements over the web, but is also intended as a base for specialized derivations, that define less generic objects. An example of the latter is CityGML, a derivation that defines roads, highways and bridges, instead of the generic points, lines and polygons[40].

Code Example 1: GML

```
// A snippet of GML embeded in a custom name space (cns)
```

```
<cns:Building gml:id="EiffelTower">
    <gml:name>Eiffel Tower</gml:name>
    <cns:height>50</cns:height>
    <cns:position>
        <gml:Point>
            <gml:pos>63.414751 10.406435</gml:pos>
        </gml:Point>
    </cns:position>
</cns:Building>
```

GeoJSON GeoJSON is based on – and even "backwards compatible" (i.e. parsers for JSON work equally well with GeoJSON) with – the widely known JavaScript Object Notation (JSON) open format[41], and extends it with geographic elements.

Code Example 2: GeoJSON

```
{
    "type":"Feature",
    "id":"Sears Tower",
    "properties":{},
    "geometry":{
        "type":"Point",
        "coordinates":[63.414751, 10.406435]
    },
}
```

It aims to be more compact and less verbose than XML (and thus also GML3.3.1), although it does not support the application schemas that derivatives of GML do.

Web Map Service Web Map Service is a simple HTTP interface that delivers map images on request [42]. The map images boundaries are specified in the request, and (if the implementation supports it) whether the map image should be transparent, making it possible to combine multiple images as layers. One may retrieve information about particular features on a map, but this is optional to implement.

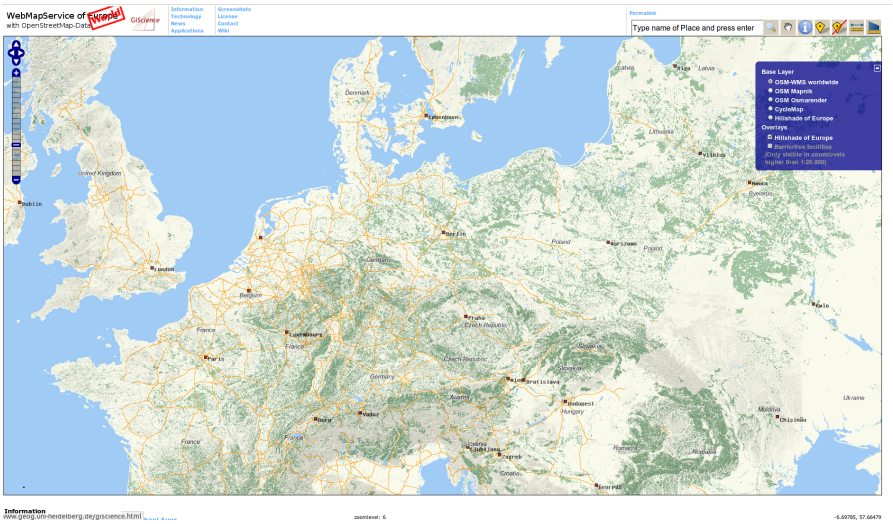


Figure 1: An example Web Map Service frontend by http://osm-wms.de/

Web Feature Service Web Feature Service delivers, and optionally works with, data in vector format – Geography Markup Language by default, although this is not a required format[43]. The interface is similar to what Web Map Service offers, i.e. HTTP-based with a specific set of commands, and optional interfaces for manipulating (create, update, delete) data.

Code Example 3: WFS GetFeature Request

```
<wfs:GetFeature service="WFSV" version="1.0.0"
  xmlns:topp="http://www.openplans.org/topp"
  xmlns:wfs="http://www.opengis.net/wfs"
  xmlns:ogc="http://www.opengis.net/ogc"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://www.opengis.net/wfs
      http://schemas.opengis.net/wfs/1.0.0/WFS-basic.xsd">

  <wfs:Query typeName="building:features">
    <ogc:Filter>
      <ogc:FeatureId fid="Feature1"/>
    </ogc:Filter>
  </wfs:Query>

</wfs:GetFeature>
```

Code Example 4: WFS GetFeature Response)

```
<?xml version="1.0" encoding="UTF-8"?>
```

```
<wfs:FeatureCollection (...) >

(...)

<gml:featureMember>
<building:features fid="Feature1">
  <building:name>Sample Building</building:name>
  <building:geometry>
    <gml:Point srsName="http://www.opengis.net/gml/srs/epsg.xml#900913">
      <gml:coordinates
            xmlns:gml="http://www.opengis.net/gml"
            decimal="." cs="," ts=" ">
        63.414876,10.406321
      </gml:coordinates>
    </gml:Point>
  </building:geometry>
</building:features>
</gml:featureMember>

</wfs:FeatureCollection>
```

The difference from Web Map Service is that the data results (see Code Example 3 and 4) (this example was shortened, see Appendix B for complete text) are not visual, but in vector format, and therefore more suitable for further processing in e.g. custom GIS applications, or for sending through to a Web Processing Service.

WPS The Web Processing Service standard defines a way to implement geospatial data processing as a web service, often used by client GIS applications, and not directly by users[44]. Like Web Map Service and Web Feature Service, the interface is exposed through HTTP (or SOAP). The data can be sent as input, or exist on the server, and – after processing – is either received, or changed on the server.

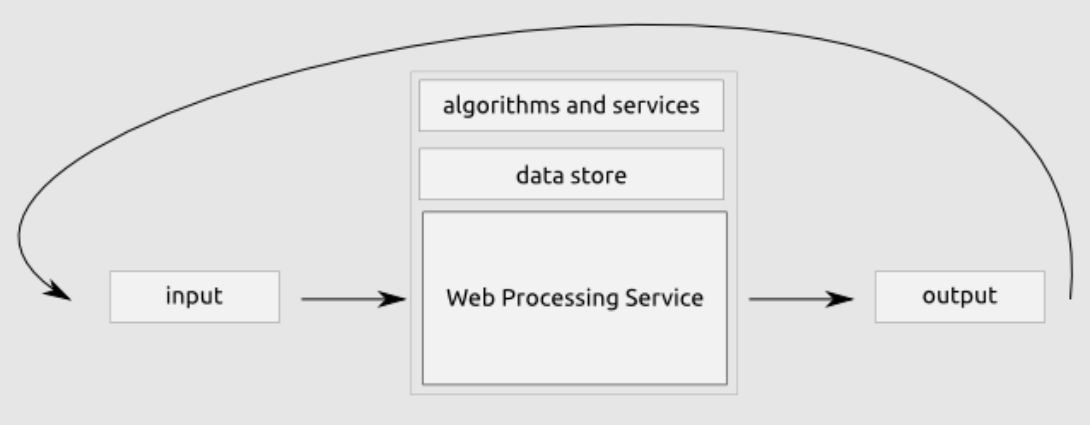


Figure 2: Simple illustration of a Web Processing Service

The processes are mostly used for spatial operations, although there is no limitation in the standard that enforces the Web Processing Service only working on spatial data. Examples of processes (working on geospatial data) are raster to vector (or vector to raster) conversion, transformation between coordinate systems, Delaunay triangulation and finding shortest paths.

Simple Features Access for SQL Simple Feature Access specifies a common storage model and naming scheme for geometry objects (e.g. point, polygon, multi-point)[45], and also specific implementation details for different formats (e.g. SQL[46]). They specify the well-known text5 and binary6 formats as the internal, as well as common serialization formats for input and output.

The coordinate reference system part of the object. Since most GIS systems – both on the web and desktop – need to store geographical data in SQL databases, the Simple Feature Access specification plays a very important role, since most of the value is in the data.

Code Example 5: Well-known text format (WKT)

```
POINT(1.2345 2.3456)
```

Code Example 6: Well-known binary format (WKB)

```
0001FFFFFFFF8D976E1283C0F33F16FBCBEEC9C302408D976E1283C0F33F16FB
CBEEC9C302407C010000008D976E1283C0F33F16FBCBEEC9C30240FE
```

However, there are a lot of geometry objects the Simple Feature Access standard does not cover. It only specifies objects in two dimensions, and does not have support for any non-linear curves, circles or arcs. Most of these are necessary in a modern GIS system, which regrettably results in vendor-specific implementations.

3.4. JavaScript – the language of the web

Hand in hand with the HTML5 standard, enjoying wide support and enabling developers to program the web, is JavaScript (other "web languages" (such as PHP, Ruby and Python) are used *server-side*, or have special requirements to function properly) – in fact, HTML5 relies on JavaScript for interaction and animation. JavaScript got ahead of other programming languages of the web by being invented as early as 1995 by Netscape, and quickly became widespread as a client-side programming language for web sites.

Some vendors were hesitant to use JavaScript, as it was not standardised, because they feared trademark issues (for example, Microsoft created their own implementation of JavaScript, called JScript, prior to the standardization process.[47]). Fortunately, JavaScript quickly became popular, and it was handed over to ECMA International in 1996 for standardization. ECMA International accepted it as a standard under the name ECMAScript, after which browser vendors could implement support without risking legal trouble[48].

Although JavaScript is primarily a client-side scripting language, recent years has seen it evolve, and it is now used server-side (e.g. node.js[49]), as well as for writing desktop applications (GObject introspection[50], GNOME (Shell)[51]).

Despite the name, JavaScript has nothing to do with the well-known, object oriented programming language Java. JavaScript does not have *classes* – with which you can instantiate a handful of objects with the same behaviour – but instead uses objects and prototypes[52]. Unfortunately, JavaScript is one of *very* few prototype-based languages with wide adoption[53], and most other widespread programming languages use classes.

Class-based languages are what developers are taught in universities and schools, what they know. Since this knowledge can not be used directly in JavaScript, this makes JavaScript hard (and sometimes frustrating) to work with. Efforts like CoffeScript – a language that compiles to JavaScript – has been created to make JavaScript easier to work with, but the fundamental issues still remain[54]. The lack of a module system makes it hard to create large applications in JavaScript.

There has been *a lot* of work put into performance and speed optimization of JavaScript, but the design of JavaScript makes this particularly challenging. While the execution speed of JavaScript has improved twentyfold in the last three years, traditional compiled languages like C and C++, are still acknowledged as (slightly) faster in benchmarks[55]. This will probably change as JIT compiler optimizations improve, which will probably happen sooner rather than later, as most interpreted languages (C#, Java), including JavaScript, use JIT as one of the primary ways of improving efficiency. (A Just-In-Time (JIT) compiler is an optimization that compiles and optimizes small portions of the program to machine code while the program is running.)

"First and foremost, we believe that speed is more than a feature. Speed is the most important feature. If your application is slow, people won't use it. I see this more with mainstream users than I do with power users. I think that power users sometimes have a bit of sympathetic eye

to the challenges of building really fast web apps, and maybe they're willing to live with it, but when I look at my wife and kids, they're my mainstream view of the world. If something is slow, they're just gone."[56]

For enhancing performance, the Google v8 JavaScript engine[57] supports a native API for calling C/C++ code, that developers could use to improve execution speed[58]. However, since one of the major motivations of HTML5 is platform independence, and using the v8 engine's native API would break this platform independence and introduce incompability with other JavaScript engines, it is a feature that should be used with caution.

JavaScript is still the only language that is *out there* and widely supported. JavaScript is here to stay, and an existing language, or new languages, for that matter, will struggle an extremely steep uphill battle to replace JavaScript, even though that language is "better". (Google is, at the time of writing, trying to push it's own web language, *Dart*[59], to the public, and is facing all of these issues.)

3.5. Thinking GIS in JavaScript

Since JavaScript has had such a long time to mature, and is the only widely supported programming language across all browsers, quite a substantial amount of useful libraries has emerged, making development with JavaScript easier. In GIS, there are a lot of open standards and libraries developed for use in geographic applications.

The open standards in a previous section, and the Open Geospatial Consortium, are obviously important as well, because they enable standard implementations to be shared between developers. The Open Source Geospatial Foundation (OSGeo) promotes and supports the development of open source geospatial software[60]. Some of the supported projects are implemented in JavaScript, or for consumption on the web.

Even though there is a lot of media attention on the HTML5 specification, the functionality of the specification itself is not enough – nor intended to – cover domains like GIS applications completely (there is no library for coordinate systems in HTML5, for example). What HTML5 does, is to expose and make accessible a lot of the native elements' functionality in JavaScript, precisely to ease integration with external tools and libraries written in JavaScript. In this way, existing JavaScript libraries and tools are even more useful with HTML5 technology.

4. HTML5 components suitable for GIS

4.1. Overview

Before discussing HTML5, it is important to emphasize that the HTML5 standard is composed of a number of *independent* modules, that are implemented more or less individually and can be used independently from each other. This means that while every part of HTML5 is not

fully supported across all browsers yet, some modules already have wide support, and can be used successfully today.

In the wake of lacking support and implementation across browsers, a handful of tools have appeared to check if specific features are supported in the browser – the most popular is probably Modernizr[61]. Libraries that backport several features for use in ageing browsers are also available, a great win for companies on the fence because of lacking support. Since the support status change rapidly, use of online sources to examine current browser support is encouraged (html5test.com[62], html5readiness.com[63] and caniuse.com[64]).

This part of the paper examines modules that are considered (by the author) as particularly interesting for use in a HTML5 GIS application, modules that solve major issues with web applications, and provide the developer with tools that previously have required third-party plugins or platform/browser specific code.

There were not room for every relevant bit from HTML5, because there are a lot of useful technology for GIS developers. *Forms*[65] are widely used, e.g. when the user needs to submit information, or query for information. HTML5 provide validation and widgets for forms, such as a date input field with a calendar pop-up to choose the date, without any additional code required.

There are a lot of extra text *attributes*[66] that could be useful for an application, like accesskey for keyboard shortcuts, tabindex for input field focus order (when continuously pressing the tab key), and even menu and command for defining toolbars and context menus (although not well supported yet). HTML5 *drag and drop API*[67] was not included because it is not considered mature yet, and not recommended for use. When it matures, however, creating interactive interfaces can be done natively with html elements.

The Messaging API[68] is not examined in detail, but used as part of Web Workers and Server-Sent Events. It also provides methods for passing text strings between domains (which has traditionally not been allowed, to prevent Cross Site Scripting[69] attacks).

4.2. Canvas

4.2.1. History

It was Apple who invented the concept of the *canvas* for use in the Mac OS X Dashboard and their web browser, Safari[70]. Before canvas was invented, one needed third-party plugins (Flash, Scalable Vector Graphics, Vector Markup Language) to be able to use a drawing API. Apple intended to keep it as a proprietary extension, but changed their mind, and handed the patents and standard over to the World Wide Web Consortium (W3C), and it became a part of the official HTML5 specification[71].

4.2.2. Basics

The canvas element has become the most celebrated module that the HTML5 standard provides, because it provides the developer with incredibly powerful tools, while still being relatively simple. Perhaps the best statement of its capabilities is the WebGL (see Section 4.2.5), which is an OpenGL-like implementation done in *the canvas element itself*.

What separates canvas from being – frankly – a very boring and inflexible element, is that the actual drawing and manipulation of this simple API, is done through JavaScript. This makes it possible to do a lot beyond simple drawings, albeit not as effortlessly as with the svg standard, since everything has to be done manually, where the svg element has a tree structure and native support for interaction and animation.

Canvas is often confused with the *svg* element (examined in Section 4.3), where graphics becomes part of the DOM, and have a defined relationship, and interfaces for animation and interaction[72]. The canvas element is a *bitmap* canvas, and no structure or relationship between the elements is maintained by the canvas element – when something is drawn on the canvas, it is simply part of a bitmap image. However, the API is vector based, which makes it possible to transfer "drawing instructions" from the server to the client, to save bandwidth. The perception of animation in the canvas element, is created by repeatedly drawing objects, and clearing the canvas, illustrated in Figure 3.

Figure 3: Animating in canvas (from left to right): (1) drawing a circle, (2) clearing the canvas and (3) drawing a (new) circle left of the circle in (1), creating a perception of movement

With the canvas API being such a simple one, developing complex animations and interactions from scratch require a lot of boilerplate code (i.e. code that is common to most implementations, and needs to be written over and over). Following the release, quite a number of frameworks emerged to simplify development with the canvas (HTML Canvas Library[73], EaselJS[74], gury[75], jCanvaScript[76], ocanvas[] ...), often by introducing an object-like development model with events. The libraries can be seen as analogous to their offline siblings, that were developed for exactly the same reason(s).

At the time of writing, there are a vast number of libraries in development, but none of them can be considered complete, stable and mature at present. Like is common with projects in their infancy, the documentation is also lacking, which makes the gain in using these debatable. However, as time progresses and the libraries mature, they will be very valuable tools for development with the canvas element.

4.2.3. Usage

There are multiple ways to use the canvas element in a GIS application, because the canvas element can be used at widely different levels in the application stack (see Figure 4). One way of using the canvas is to render tiles in multiple canvas elements, or implement the whole map in a single canvas element. An advantage with limiting canvas usage to static tiles or images, is that the functionality (i.e. drawing objects or rendering images) is supported natively through the canvas API.

The other way is to create the entire application – or a major part of its functionality – in a single canvas element, and even though this approach is more complex, since the developer will at least need to extend the canvas API with support for interaction, the canvas element's simple API is implemented in most browsers, and the resulting application will therefore work consistently across more platforms than more complex technologies (such as svg).

Figure 4: Canvas can either be a part of the application, or the application itself can be implemented completely in canvas

Some implementations of the canvas element are hardware accelerated[77] – i.e. the rendering is done on the GPU – and this can be used to load and manipulate images – e.g. load, and run image algorithms on bitmap tiles – with less of a performance impact than the traditional *img-element*.

Since the canvas element has had a lot of exposure in the media as one of the most interesting and visual parts of HTML5, it has gotten a lot of uptake among "ordinary" developers. The

flexibility of the element has lead to multiple games and all kinds of software projects, which have been developed almost entirely within one or several canvas elements. There are even multiple sites dedicated to showcasing web applications made with canvas.

4.2.4. Encoding binary data

Central to the web domain is the efforts to transfer of data between client and server faster. The most obvious way to make a transfer faster, is to *transfer less data*, i.e. decrease the size of the data. The two most popular formats for sending and receiving data are XML[78] (or GML[79], which extends XML with geographical definitions) and JSON[41], and they are both text-based, human-readable and easy to parse. Note that pure XML and JSON are used in this example instead of GML and GeoJSON to reduce the size of the examples and (structural, redundant) data.

Code Example 7: XML

```
<geometry>
  <point>
    <type>car</type>
    <lat>63.414751</lat>
    <lon>10.406435</lon>
  </point>
  <point>
    <type>bus</type>
    <lat>63.414914</lat>
    <lon>10.406263</lon>
  </point>
</geometry>
```

Code Example 8: JSON

```
{
  "geometry" :
  [
    "point" : { "type" : "car",
                "lat" : 63.414751,
                "lon" : 10.406435
              },
    "point" : { "type" : "bus",
                "lat" : 63.414914,
                "lon" : 10.406263
              }
  ]
}
```

With the UTF-8 encoding, where each character is a single byte, the XML example's size is 163 bytes, and the JSON example's size is 121 bytes, and a single point, respectively, 70 and 50 bytes. These numbers does not look very high, but one rarely needs only a handful of points. If one want to transfer a 1024x1024 map, where one point is a single pixel, one would need 1 048 576 points, which is (when using JSON) $1048576 \cdot 50 = 52428800$bytes, and $\frac{52428800}{1024} = 51200$kB, which is quite a lot.

The most obvious way to decrease their size is to compress the data or represent the data in binary format. Unfortunately, neither XML nor JSON can handle binary data, and compression and decompression algorithms that work with them e.g. *base64* adds a noticeable performance overhead, and makes the achieved faster data transfer rates unnecessary as the end result (i.e. the perceived performance of our application) remains more or less the same.

A way to work around these limits is to transfer binary data in raster format, and processing them through the canvas element, although this remains a proprietary approach, as an open standard is currently lacking. With a 1024x1024 raster image, we can choose between greyscale, colours and colours+transparency, respectively 1x255, 3x255 and 4x255 values to store data in.

In the example, our points only have a single variable (type), so greyscale is the least demanding option (wrt. data size). Each pixel in greyscale only consume a single byte, so with this approach, the data's size is $1024^2 = 1048576$ bytes, or $\frac{1048576}{1024} = 1024$kB. Quite an improvement when comparing to JSON's 51MB, and a way to utilize the canvas element for decreasing data size.

4.2.5. WebGL

For GIS applications requiring 3D visualization, the canvas element itself is not sufficient, as it only provides 2D functionality. One needs 3D for virtual reality scenarios, e.g. a map street view where the user can move around and se the environment in 3D, and for any 3D environment (see Figure 5 for an example of the WebGL Globe[80]). WebGL (Web-based Graphics Library) is an extension to the canvas element[81], and provides a "low-level 3D graphics API based on OpenGL ES 2.0"[82].

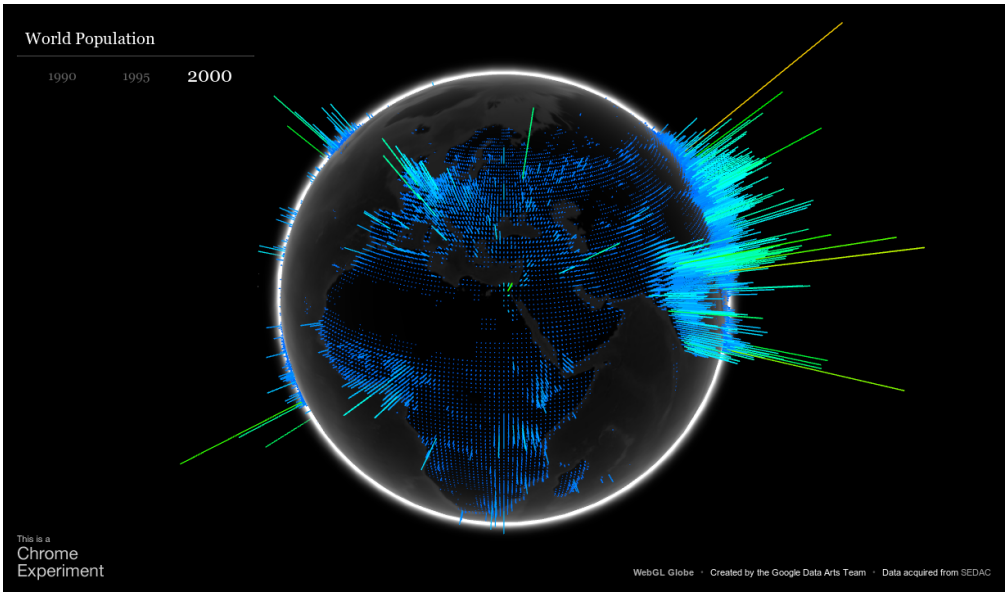


Figure 5: Example showing the world population in 1990, 1995 and 2000 using WebGL

WebGL is managed by the non-profit Khronos Group, which also hosts the rest of the OpenGL specifications, and was not developed by the WHATWG, but it is still considered a HTML5 technology. Since the OpenGL ES 2.0 is supported by hardware in both mobile devices as well as desktops, this not only gives the developers access to 3D functionality in the browser, but *hardware accelerated* 3D functionality on the web, with wide support on a lot of devices. This aids the primary goal of moving applications from the desktop to the web.

Care has been made to develop the API for JavaScript programmers that are not experienced with languages where one has to manually manage memory (such as C and C++). A lot of third party libraries (such as three.js[83]) have emerged to further close the gap between (traditional) JavaScript code and WebGL code, to make development easier and faster.

Security One major browser that has yet to implement support for WebGL (at the time of writing), is Microsoft Internet Explorer. The main reason given for not implementing WebGL is "lack of security", as this low level component may introduce ways to compromise the browser or computer it is running on[84].

The concerns are certainly valid, but not really more so than any other young technology that enters the web. Other major browser vendors have implemented support (Mozilla Firefox, Google Chrome, Opera, Safari), and continue to discover and improve issues and concerns, as well as performance.

4.3. Scalable Vector Graphics (SVG)

4.3.1. History

The Scalable Vector Graphics (SVG) specification has been in development since 1999, after Precision Graphics Markup Language (Adobe, IBM, Netscape and Sun), and Vector Markup Language (Microsoft, HP, Macromedia and Visio) were submitted as proposals for open standardization to the W3C[85]. SVG reached "recommended" status in 2001[86].

Unfortunately, native support for SVG across all of the most popular browsers were not achieved until Microsoft implemented support for SVG in version 9 of Internet Explorer (older browsers only had support for Microsoft's VML). Limited support in browsers (especially the mobile browser segment, which is becoming very relevant) might be the primary reason why adoption of the SVG format has been moving at a slow pace.

The HTML5 specification introduced inline SVG[87], which meant that authors did not have to include their (external) SVG files with the *object*-element, but instead keep the SVG code directly in their HTML document.

4.3.2. Basics

SVG is a language where two-dimensional graphics is described in XML[86]. Each graphics object, which may be either a vector shape, raster image or text, are all valid graphic objects, is retained in a hierarchy and thus easy to reference. All elements support attributes (location, size, colour), transformations and styling (e.g. with CSS). SVG also support collecting elements into groups, where e.g. transformation can be applied to the group as a whole.

Because the standard has been in use for years (on the desktop), there are several mature vector graphics applications suitable for producing SVG files, like Inkscape[88] and Adobe Illustrator[89]. There is therefore no need to learn or develop new software for creating SVG graphics.

An SVG document is not static, but interactive and dynamic, and animations are defined (and triggered) ether as SVG animation elements[90][91], or with scripting languages such as JavaScript. The retained document object model makes SVG very appropriate for dynamic content where elements should interact with the user.

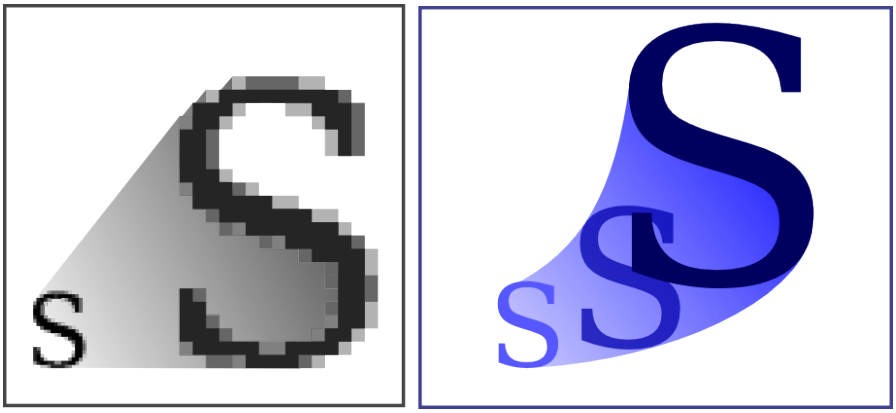


Figure 6: Example of pixel-based and vector-based scaling: raster graphics (left) and vector graphics (right)[92]

Vector graphics are defined by mathematical formulas, shapes and paths, instead of pixel values, and support indefinite scaling (see Figure 6). For applications that require the ability to view the graphics in different sizes while retaining quality, vector graphics is the best fit.

An SVG file is smaller than the corresponding bitmap image, on average[93]. Many web browsers support delivering web pages as compressed files, and since SVG is (text based) XML with repetitive patterns, it is a key candidate for compression. An SVG tree that is compressed with gzip[94] consumes only 20%-50% of the uncompressed file[95].

SVG is very capable by itself, and it does not need support from a library for most uses, since the standard already support dynamic and interactive graphics. When developing rich user interfaces with canvas (Section 4.2), one need to develop (or find a library that supports) an object model to reference the interface objects, and events on these objects, before even starting to develop the actual application.

The largest drawback with SVG is its complexity. An XML-like document which is a part of the DOM itself, makes SVG much harder to implement correctly than the (simpler) canvas, and the performance suffers from this complexity as well[96]. If a vendor can not deliver a consistent experience across all target platforms, or the technology is too resource hungry, that vendor will look for a different solution.

The complexity of SVG currently limit the amount of objects and complexity that can be used without noticeable delay. Therefore, there is an ongoing effort to hardware-accelerate the drawing, and offload the CPU, to get better performance. Especially manufacturers of low-powered devices such as mobile phones and tablets want this to save power. Microsoft has implemented hardware accelerated vector graphics in their Internet Explorer 9[97], and the rest of the browser vendors are expected to implement similar functionality, e.g. with OpenVG[98], which is a standard for acceleration of 2D vector graphics

4.3.3. Usage

The support for inline SVG makes a great difference from including external SVG files. Inline SVG elements easily integrate into the existing application, instead of having to keep the whole – or a distinct subset of – the application in the contained svg element (like canvas, Section 4.2, does). For example, interactive list elements and forms can trigger events on a selection of the svg paths, or touch events on svg objects can trigger events on the html elements (see Figure 8).

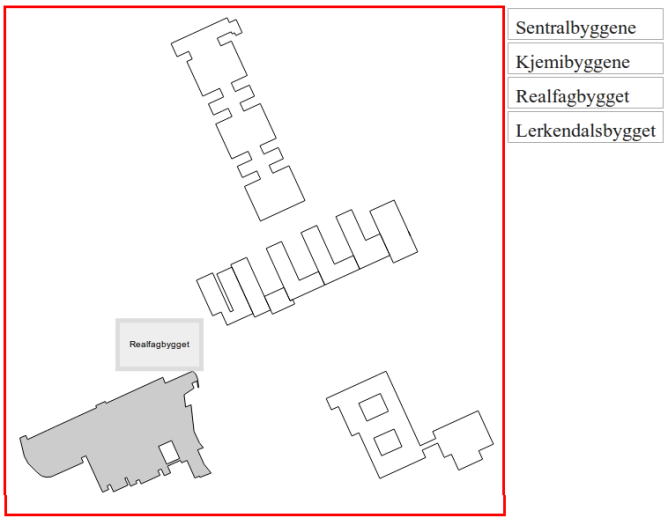
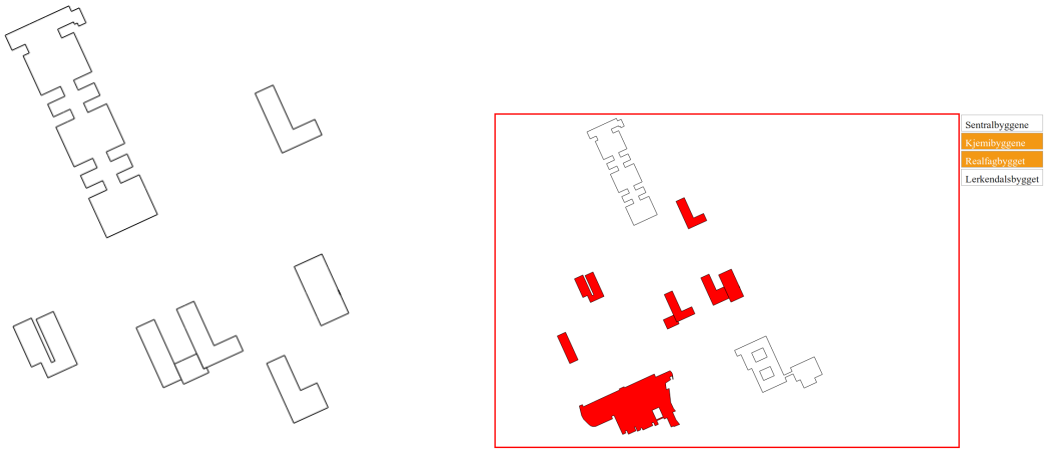


Figure 7: Overview of the example SVG application

An example application was developed (see Section 1.1 for source code), that show various ways to provide interaction with SVG. Through the element itself, all the buildings can be moved with the mouse pointer, and will show the building name on hover (see Figure 7). The inline SVG was developed with the library Raphaël[99], the buildings were taken directly from a raw SVG file imported from OpenStreetMap[100] and jQuery UI[101] was used to implement support for events and styling the list of buildings.

The example contains a selection of buildings (from campus Gløshaugen, NTNU, Norway) that are interactive – they will show a pop-up window with the building's name when hovering the mouse pointer over the building, the buildings can be moved (see Figure 8a) by dragging (click and hold the mouse pointer, then move the pointer), and double clicking a building will remove it from view. This is "self-contained" functionality – all done in the inline SVG element itself.



(a) Moving buildings

(b) Select (group of) buildings from the list

Figure 8: Interacting with the example through both SVG and HTML elements

There is also a list of building groups (although some groups only consist of a single building) in a separate, standard HTML, unordered list element, and the elements are selectable by clicking and clicking while holding the ctrl-key or drawing a rectangle with the mouse to select multiple list elements at once. Selected groups are coloured red (see Figure 8b). This is an example of how to integrate functionality with inline SVG into existing html web elements, and using existing html elements as part of an application, thus utilizing the many improvements that the html5 specification has in other areas. It saves work for the developer, and makes better use of the standards (opposed to inventing the elements anew inside the SVG element).

4.4. Geolocation

The geolocation API of HTML5 lets you share your location (as latitude, longitude) with web applications[102]. The standard requires the geolocating function to be implemented as opt-in, i.e. the user must explicitly give his or her permission before use. This is important, as privacy is a major concern when using such a feature. Although geolocation is not strictly part of the HTML5 standard – it was developed as a separate W3C specification[103], and not by the WHATWG – it is commonly referenced as a HTML5 feature.

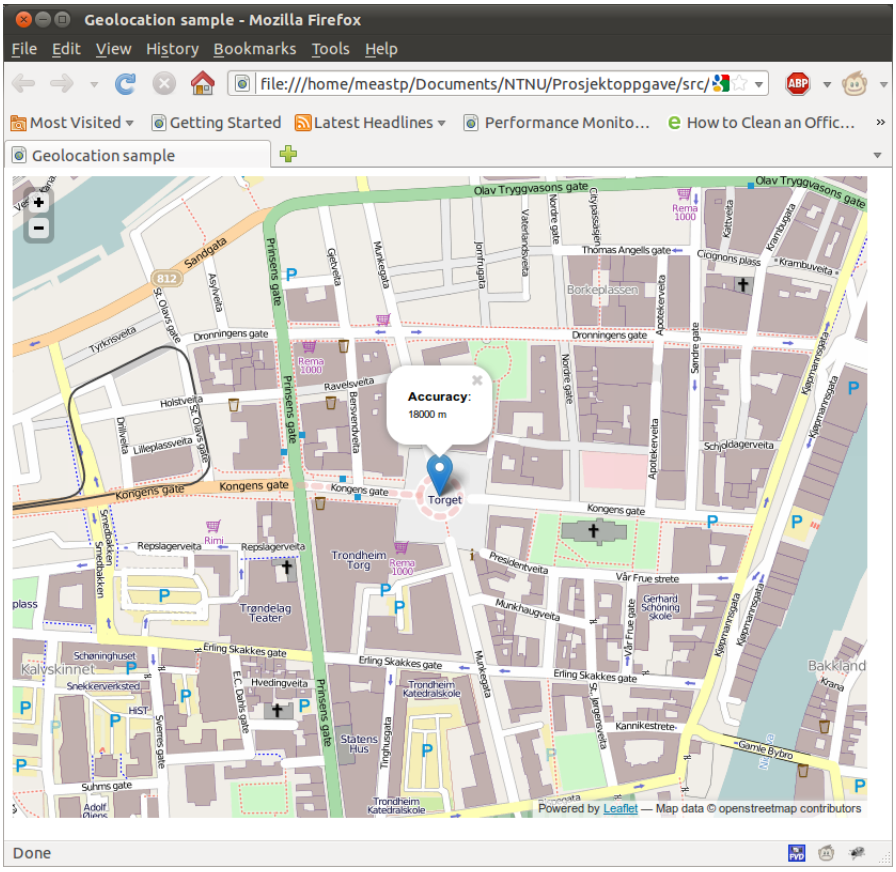


Figure 9: Example showing geolocation used to (somewhat accurately) pinpoint a visitor's position on a map

Locating the computer is done with the best means available. Mobile devices often have more options, but also the most important to position accurately means geolocation by lookup (IP address or WiFi access point database) or a *triangulation technique* such as GPS or cell phone towers. Application developers also need to keep in mind that most desktop computers/laptops does not have a GPS, unless the application is targeting a very specific group of users.

Code Example 9: Sample geolcation API use

```
navigator.geolocation.getCurrentPosition(
  function(position) {
      current_position = position;
      marker_location = new L.LatLng(
                          current_position.coords.latitude,
                          current_position.coords.longitude
                          );
```

```
        position = new L.Marker(marker_location);

        map.setView(marker_location, 16).addLayer(position);

        position.bindPopup("<b>Accuracy</b>:<br/><small>" +
                           current_position.coords.accuracy +
                           " m")
                           .openPopup();
    },
    function(error) {
        alert('Error occurred. Error code: ' + error.code);
        // error.code can be:
        //   0: unknown error
        //   1: permission denied
        //   2: position unavailable
        //      (error response from locaton provider)
        //   3: timed out
    }
);
```

In the example implementation (Figure 9) (see Section 1.1 for source code), the method used was probably IP address-based, because of the low accuracy (done at the University campus through a wired network connection). A snippet of the example source code (see Code Example 9), show that the geolocation API is not terribly difficult to use, mostly because the methods and properties available are not extensive.

The API supports separate querying with *getCurrentPosition*, and continuous tracking with *watchPosition* and *clearWatch*. Using the *Position* object(s) that is aquired, one may query the altitude (height above the reference ellipsoid), accuracy (in metres, one for coordinates and one for accuracy), travel direction, speed and the timestamp (when the position was captured)[104].

Despite the simplicity of the geolocation API, it provides the developer with an incredibly important piece of information – *the location of the user*. Knowing where the user is can be used in a number of ways e.g as a hint for default language, currency and other regional settings. A solution for desktop computers could be providing GIS tools with an approximate area that would (statistically) be most useful to cache, based on the user's location. Locations are perhaps even more popular and appropriate in mobile applications, as people tend to move around a lot with mobile devices – with the opportunity for more active use of the location – and be more stationary in front of a desktop computer.

4.5. Web Sockets and Server-Sent Events

While the canvas element (and SVG) solves a lot of the limits of creating rich interfaces, a huge problem when dealing with web applications and the server-client architecture, is latency and bandwidth. When a browser visits a web page, an HTTP request is sent to the web server which hosts that page, and the server sends back the response (known as *polling*). When dealing with web *pages*, this is normal behaviour, and is how the web has operated for years[105].

However, in applications where information is continuously updated – such as a GIS tool showing real-time air traffic on a map for use by air traffic control – the delay that occurs between the browser's request and the server's response, could lead to outdated information on the map (which, in the case of air traffic control, could be outright dangerous)[106].

There are two current available strategies to create real-time web applications, known as server-side push, where Comet is the most widespread. Server-side push uses either long-polling or streaming as it's strategy to avoid the problems discussed[107].

Long-polling is like a normal poll, except the connection between the client and server is kept open for a set amount of time before it is closed, and the server sends all the data responses that occur in this timespan. This eliminates the need to send requests for each response, and the inevitable time delay this causes.

The second technique is called *streaming*, and the difference from long-polling is not that great. The connection is kept open like with long-polling, upon a request, but the responses that are sent is never completed (i.e. the server never sends an "end of response"). The problem with streaming is that a proxy server or firewall may buffer the response, increasing the latency.

There is a *lot* of unnecessary overhead with the HTTP header information for each request and response, since an application that updates continuously generates a lot of headers, and thus a lot of data and bandwidth wasted. This applies to all of the techniques mentioned, since all of them go through HTTP requests and responses.

The request/response behaviour is half-duplex, meaning one can send or receive data, but not both at once. Keeping two open connections to simulate this, is expensive and will not scale. One can conclude that HTTP is not suitable for real-time applications, which isn't that surprising – after all, there were no demand for this when HTTP was designed.

The lack of an API (Application Programmer's Interface) for high-performing communication between client and server in web applications is the reason that WebSockets is part of HTML5. WebSocket provides native full-duplex communication through a single socket over the Web, eliminating the latency and overhead with prior solutions[108].

After an initial handshake (see Code Example 15), the upgrade from the HTTP protocol to the WebSocket protocol is done, and WebSocket data frames can be sent back and forth between the client and the server through the defined interface. The connection is open until

explicitly closed by the client, saving even more unnecessary overhead of opening and closing connections.

Currently, there is no supported way of sending binary data to JavaScript through Web Sockets (Web Sockets support binary, but JavaScript has no byte type, and therefore can not handle data in binary format), so text based JSON strings is the best option (for more on binary data, see 4.2.4). When the socket is closed by the client, there is no way to reopen that socket – a new socket connection needs to be created.

The importance of HTML5 Web Sockets for the establishment of software on the web, especially real-time applications, should not be taken lightly.

"HTML5 Web Sockets provides such a dramatic improvement from the old, convoluted "hacks" that are used to simulate a full-duplex connection in a browser that it prompted Google's Ian Hickson—the HTML5 specification lead—to say: "Reducing kilobytes of data to 2 bytes... and reducing latency from 150ms to 50ms is far more than marginal. In fact, these two factors alone are enough to make Web Sockets seriously interesting to Google.""[107]

4.5.1. Example of usage

A map application was developed (see Section 1.1 for source code) that uses, and tests the latency of, HTML5 Web Sockets. When the user clicks on the map, the coordinates are sent with Web Sockets through to the server[109]. The server sends the data back, and the time used from sending the data packet, to receiving it, is measured. The marker is placed on the map only after it has been received from the Web Socket server.

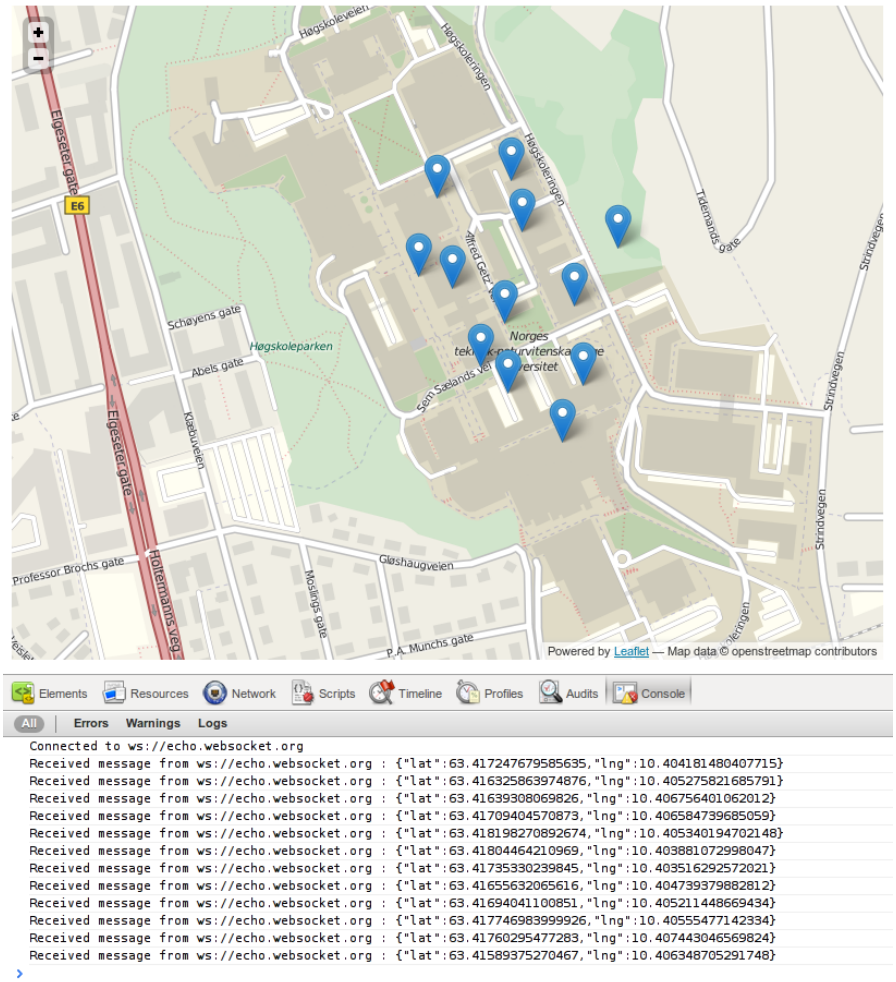


Figure 10

Even though the markers are placed on the map *after* the data has been sent between the client and server twice (first to the server, then back), the application does not feel unresponsive. The latency between sending and receiving data is sufficiently low in this example for a server to process data and send the data back (e.g. find nearest bus stop in the server spatial database, and send it back quickly enough that the user perceives it as near "real-time"). Further testing with this example is found in Section 6.3.1. Similar results have been found by others as well[110].

4.5.2. Server-Sent Events

Server-Sent Events fits usage where one only needs one-way communication[111]. The API is similar to Web Sockets, but only able to deliver data from the server, to the client. A

difference from Web Sockets is that a Server-Sent Event connection conveniently reconnects if the connection is interrupted, and resends any updates that were interrupted or not sent during the disconnect [112].

Server-Sent Events have not received as much exposure as Web Sockets, but using it does not require more than traditional HTTP and thus does not require special implementations to work. Although it uses HTTP, the implementation is as efficient as Web Sockets, and does not require polling and request/response patterns. If it is only listening that is required, consider using of Server-Sent Events instead of Web Sockets.

4.6. Offline Storage

Storage in web applications has traditionally been solved using *cookies*, a tiny dictionary of data values that are stored in the browser and sent with every http request (to the web server) and response (see Section4.5 for more on HTTP request/response)[113]. This is clearly not an optimal model, which is why the amount of data in cookies are restricted in size (to reduce the overhead upon request/response). This limit is about 4kB in practice – too small for documents or larger data structures. By exposing the network to the stored information on every request/response, the security is also decreased if the cookies are not properly decrypted[114].

There have been attempts to solve these problems by third-party plugins, however, to be compatible across browsers is very important for these technologies, so developers may rely on them, and use them at the very core of their application(s). So, instead of cookies, the storage solution needs to be able to handle more data and the data must not use bandwidth when not needed. Which is what the HTML5 Local Storage[115] solves, technically. There is also HTML5 Application Cache[116], which allows an application to be developed for offline use. Since they complement each other nicely, the umbrella term *offline storage* is used for both of them.

Obviously, this gives us storage we can rely and save bandwidth on, and save data during or across sessions. However, perhaps even more important – especially since the mobile device market is increasing at such a rapid pace – is the possibility to develop reliable GIS applications and services that work without an internet connection, either short-term (unreliable wifi, driving through a tunnel) or more long-term (working a whole day in the field without a connection, uploading results/data when necessary).

Some privacy concerns have been raised regarding the storage API[117]. The HTML5 storage API *specification* increases security compared to cookies – increased security was a primary concern when the storage API was made – primarily by not sending data back and forth like cookies do, but also preventing domains from accessing data from other domains than their own. However, it is unclear how well this is implemented by the browser vendors, and this should be investigated before storing sensitive data.

Data not being stored on the server, means that user data will not be compromised, even if

the web server has a security breach. The storage API is vulnerable to the following types of attack:

DNS Spoofing Compromise DNS server(s) and make domains point to different servers. This would give the attacker access to other domains local data.

Multi-user environments If a browser is shared by multiple users, the local data can be accessed by every user, since the browser only differentiates on domain, not per user.

There are other concerns, such as the fact that sensitive data should be stored encrypted, which is always valid, although it is more of a general security issue, which is not influenced particularly by the storage API.

4.6.1. Local Storage

The Storage interface of HTML5 Local Storage has a *sessionStorage* attribute, and a *localStorage* attribute. The former stores data while a window or tab is open, and deletes the data as soon as it is closed; while the second is useful for indefinite data storage, or data shared between more than a single window or tab. The API (for both storage types) is simply a (key,value) dictionary-like data structure which you can write items to and read or delete items from.

There is also a method for clearing the database, since there is no way to loop through the data structure. Unfortunately, the specification recommends a minimum amount of only 5MB storage space (per origin), optionally prompting the user to grant more space. This means that while the amount of data one is allowed to store is increased manifold compared to cookies, it is still far from unlimited, and something the developer must be aware of – data loss during offline use *must be avoided*.

4.6.2. Application Cache

Although the Application Cache also provides an API, the functionality is primarily accessed through a configuration file (see Code Example 10, and Figure 11) – for example *manifest.appcache* (the official recommended extension for manifest files is .appcache) – that is linked to from the *html tag*. The file begins with CACHE MANIFEST, and after is divided into the three sections: *explicit* (the CACHE header), *fallback* (the FALLBACK header) and *online whitelist* (the NETWORK header)[118]. If there are no sections defined, the explicit section is used for all content – it defines files to be cached explicitly.

Code Example 10: manifest file

```
CACHE MANIFEST

# Versions are kept in the comment
# to trigger a cache update when
```

```
# the verion number is increased
#
# ver 1

CACHE:
# the 'index' page is cached implicitly
jquery.min.js
leaflet/leaflet.css
leaflet/leaflet.ie.css
leaflet/leaflet.js
leaflet/images/marker.png
leaflet/images/marker-shadow.png
leaflet/images/popup-close.png
leaflet/images/zoom-in.png
leaflet/images/zoom-out.png
glosh_wgs84.json
glosh_build_wgs84.json

NETWORK:
*

FALLBACK:
storage.js storage_offline.js
online.jpg offline.jpg
```

Some scripts will not work when not connected to the internet, and needs alternate implementations when the user goes offline. This is what the fallback section is for; to specify fallback files or modules. The last section, online whitelist, specifies resources that must never be cached, and only available when the user is online.

The Application Cache's API provides events for the different caching states one can hook into through JavaScript, for example forcing a page refresh when the cache is updated, because the page content is not automatically replaced when the cache is updated – it is only done on the next page refresh. An example of hooking into the cache JavaScript events is in Code Example 11

Code Example 11: event hook

```
// An event that fires if (from the specification):
// "The manifest was a 404 or 410 page, so the attempt to
//    cache the application has been aborted."
// "The manifest hadn't changed, but the page referencing
//    the manifest failed to download properly."
// "A fatal error occurred while fetching the resources
//    listed in the manifest."
```

```
// "The manifest changed while the update was being run."
//
appCache.addEventListener('error',
  function(e)
    {
      alert("Error: Could not update the cache");
    }
  , false);
```

4.6.3. Offline Storage Example

An example application developed for this paper, illustrate some techniques and possibilities with both Local Storage and Application Cache in a GIS setting. While the Local Storage API behaved mostly as expected, the Application Cache standard did not behave consistently or as expected across browsers. One example is the *window.navigator.onLine* property, which is supposed to return a boolean that indicate whether the client is connected to the internet or not.

In some browsers (Mozilla Firefox), the property only returns *false* when the user manually sets the browser to work in "offline mode", and other browsers (Google Chrome, Safari) just ignore the property – i.e. it always return *true*. The fact that it is a caching standard makes debugging worse, so one should be careful when developing advanced applications with Application Cache, at least at the time being, or only use the manifest file (see Code Example 10), which seem to work reliably.

The example (see Section 1.1 for source code) is a simple mapping application that creates markers on a map, and stores the last created marker in localStorage. It works equally well even if the user is not connected to the internet (obviously though, the application need to be cached before going offline), using a simple local vector layer map, instead of the updated OpenStreetMap[119] tiles from a MapQuest[120] server. Figure 11 gives an overview of how the Application Cache features work, what is kept locally, and what will not load without an internet connection (some files excluded for clarity, see Code Example 10 for a complete list).

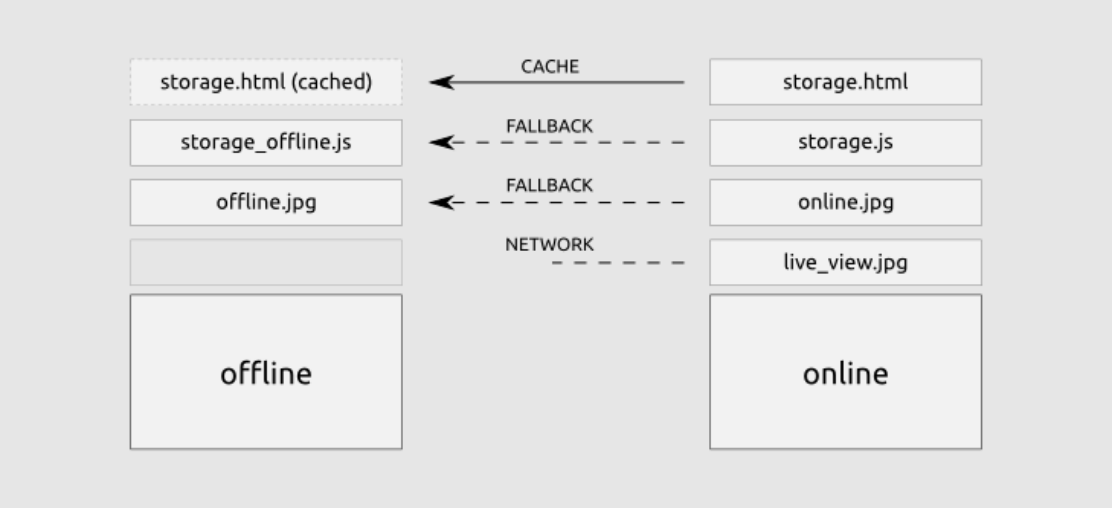


Figure 11: An illustration of the manifest file in Code Example 10

The local vector layer was downloaded from OpenStreetMap as an ESRI shape file, and converted to GeoJSON and WGS84 with the very useful MyGeodata Converter online application[121]. It is very simple, and shows how an offline solution could store and load a simple map with a low footprint (see Figure 12 and Figure 13).

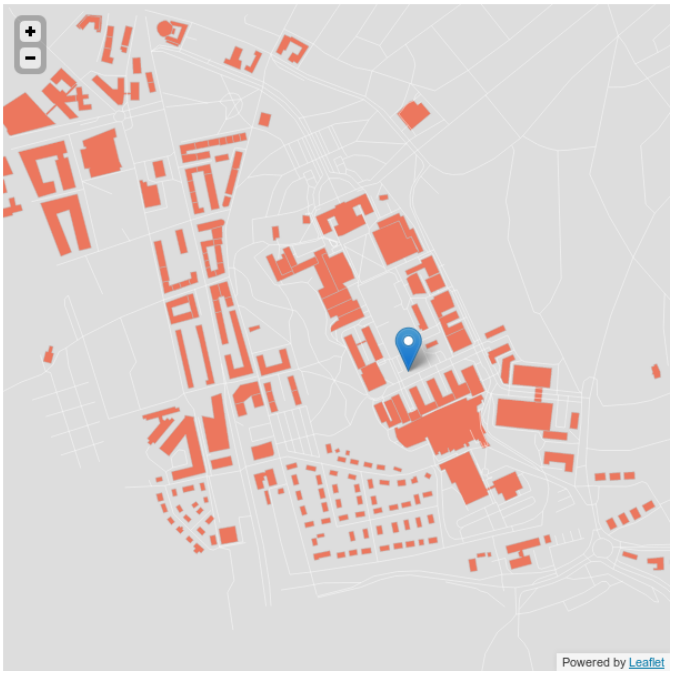


Figure 12: If the user disconnects from the internet, the tiles are no longer available, and a locally cached vector layer is used instead

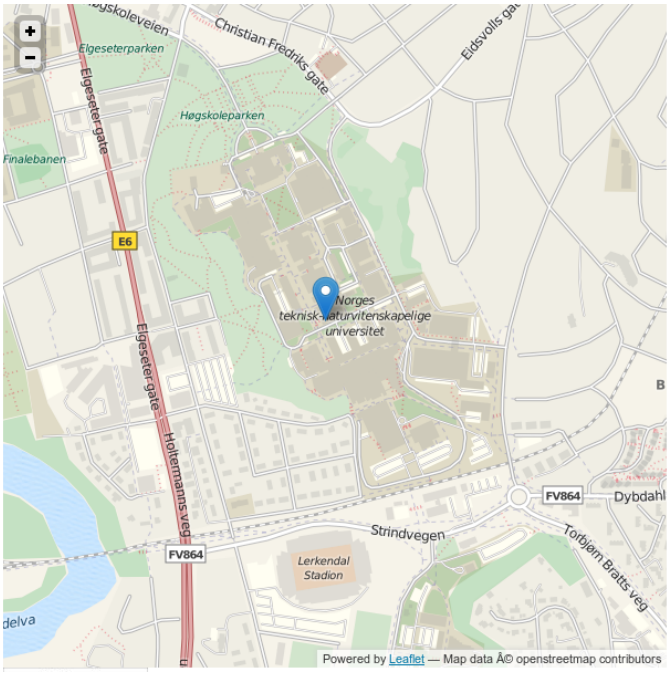


Figure 13: When the user is connected to the internet, the tiles from MapQuest are used as the background map

Since the last marker is saved to offline storage immediately, and is not dependent on an internet connection in any way, the user can retrieve and replace the marker in local storage during both online and offline use (see Figure 14). In a larger GIS application, the marker data could be saved to local storage if the application is used without an internet connection, and uploaded to a server when the user gets back online.

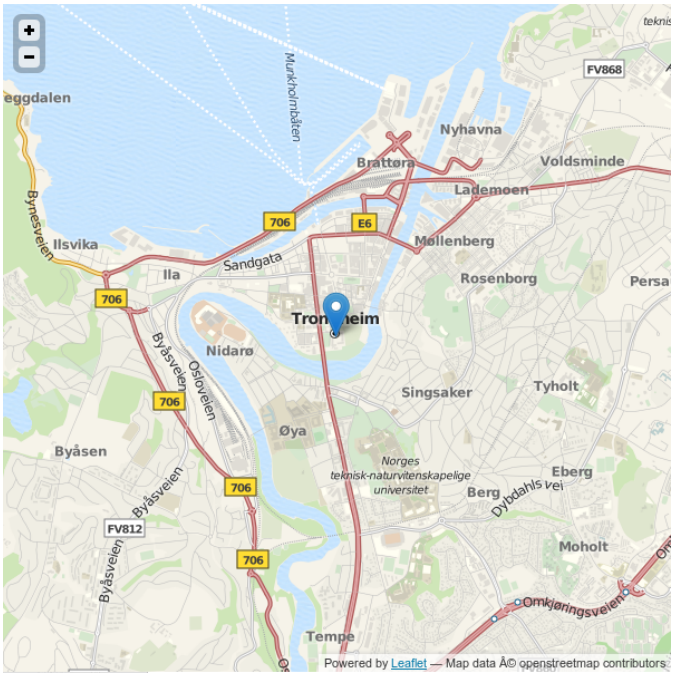


Figure 14: When the marker is moved, it replaces the current marker in localStorage, and is loaded into the map on page refresh

4.6.4. Future

Although the local storage tools are a great boost compared to previous solutions, the traditional way for storing data on the web is in a SQL database. Adapting this to a simple dictionary-like API isn't always sufficient. This is why there are plans for an SQL local storage solution, with familiar SQL queries and possibility for more complex data storage[122]. However, this isn't really part of the HTML5 specification, since it still isn't properly standardized yet – on the contrary neither supported nor alive as a standard[123]. However, there are efforts to create an SQL like storage solution.

4.7. Web Workers

Most computers these days are multicore (i.e. they manage do to several things at once), and more performance is often achieved by introducing more cores, instead of making each core of the CPU faster. Desktop applications are written to spawn several processes instead of one to take advantage of processors with more than one core, and GUI (Graphical User Interface) applications have the user interface in its own thread, so it does not freeze when computationally intensive tasks are run in the background.

HTML5 introduces Web Workers to solve this for web applications as well, and provides

developers with a tool for working in a multicore/multithreaded environment with tasks that should be executed independently of e.g. the main user interface[124]. From a user's perspective, this means that the web application is responsive, instead of hanging on page refresh (while the task is executed), and warnings of an unresponsive page popping up (see Figure 15). In GIS applications, which may use time and resource consuming algorithms for certain tasks, being able to run these without freezing the CPU is very important, if not a requirement.

With Web Workers, developers no longer need to mimic this behaviour themselves. Current efforts that do not utilize Web Workers, mimic concurrency in JavaScript by using setTimeout(), setInterval() and XMLHttpRequest, but it comes with a whole lot of problems, mostly since JavaScript was not designed with multi-threaded environments in mind.

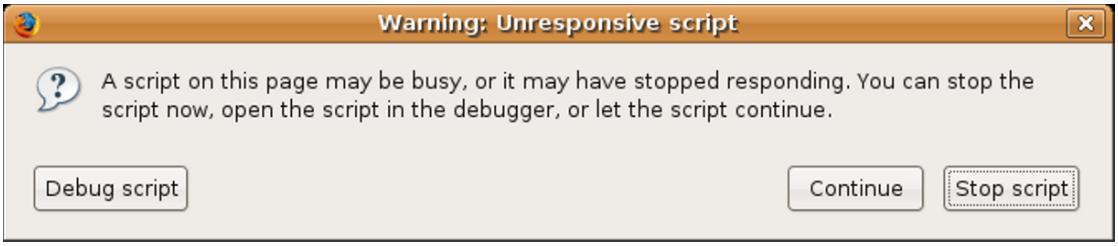


Figure 15: Firefox warning when a script is slow (or unresponsive)

It is important to keep in mind that the Web Workers – running in separate threads – does not have access to the DOM (Document Object Model – the node tree on the web page) or other UI objects, and therefore can not directly manipulate any of them. However, one is able to set up a callback function that listens for messages from the worker, which the main thread may respond to by updating the UI appropriately. Note that there is a high start-up performance and memory cost[124] for Web Workers, and they are expected to be long-lived and few (at the same time).

4.7.1. Dedicated Workers

The type of Web Workers known as Dedicated Workers, run in an isolated thread, separate from the main program[125]. Because JavaScript was designed as a single-thread language (and to avoid user error), this means that the task that is to be executed separately from the main thread, needs to be contained in a separate file. The Worker object is constructed with the path to the JavaScript file that shall be executed in a separate thread, and the task execution can then be managed through the Worker object.

The ability to communicate with Dedicated Workers is realized through message passing. Messages are sent to the worker with *postMessage*, and received through a custom defined method in the *Worker.onmessage* event callback.

4.7.2. Shared Workers

Shared Workers are more complicated than Dedicated Workers, because any window on the same domain can share the use of a worker thread between them. This is an advantage for applications where it is common to use multiple windows, and for saving the memory and start-up performance cost that creating multiple Dedicated Workers would consume. However, one needs to consider if the saved memory and CPU is worth the added complexity of Shared Workers.

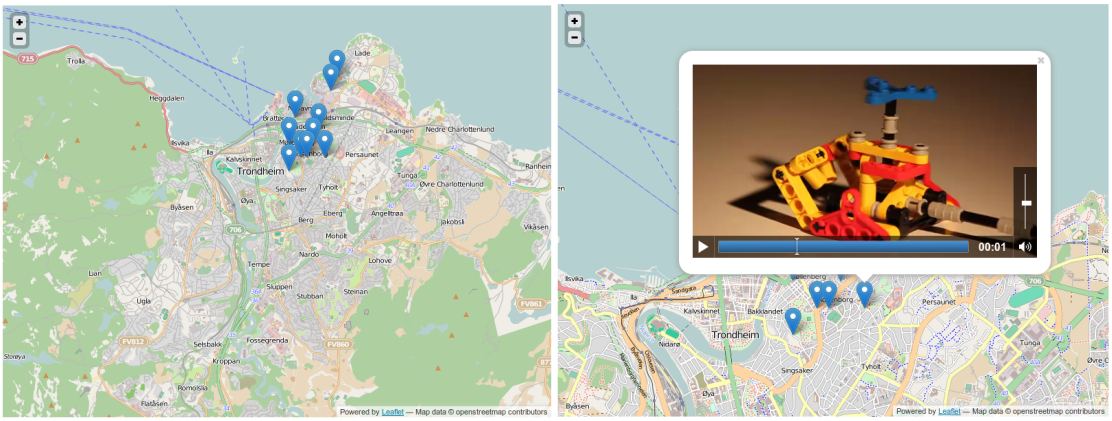
The main difference with Shared Workers is that each window needs a separate identification – a port – when communicating with the Worker, and if one wants multiple Shared Workers, they need to be constructed with a name[126]. The rest is almost identical to Dedicated Workers, and handled "behind the scenes". A Shared Worker is active as long as there is at least one open connection to it (e.g. when you close some of the windows attached to a shared worker).

4.8. Video and Audio

HTML5 introduces new elements for embedding video and audio without needing to use third-party software[127]. While the usefulness of these new elements for GIS applications may not be immediately apparent, they provide a very simple way to add media to applications. GIS developers might, for example, want to add interactive "get started"-tutorials and -walkthroughs for new users, and this is trivial with the new video and audio elements.

The elements also provide a set of controls, auto play etc., which are easily added with minimal amount of code[128]. For those wanting to add advanced controls, such as a timeline[129], both elements provide standardized APIs to enable custom behaviour.

However, despite the video and audio *elements* being standardized, which codecs to use on the web were never standardized. Therefore, different browsers/browser vendors support different sets of video and audio codecs, and, unfortunately, there are no codecs with ubiquitous support, and one need to provide media in more than one format (the creators were pragmatic enough to add support for multiple video files in a single video element).



(a) Video markers on a map (b) Clicking on a marker reveals the video and controls

Figure 16: Multiple markers on a map which contains video clips that can be controlled by the user

The video example (Figure 16) (see Section 1.1 for source code) shows a map with multiple markers. Clicking on a marker (Figure 16b) reveals a pop-up that contains a video. There is also an additional JavaScript function, hooking into the video API, to fix problems in early versions of Android OS[130] in the code. Users of Microsoft Internet Explorer prior to version 9, and other browsers without support for the video element, will be presented with the download link (support for Internet Explorer could be implemented with a custom ActiveX applet, and transcoding the video file to .wmv-format) instead.

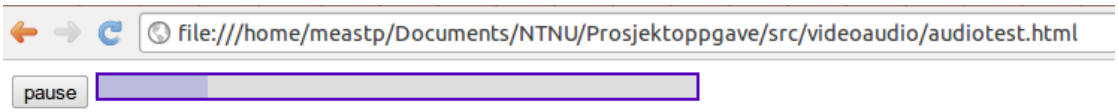


Figure 17: Example showing an audio element with styled html elements as controls

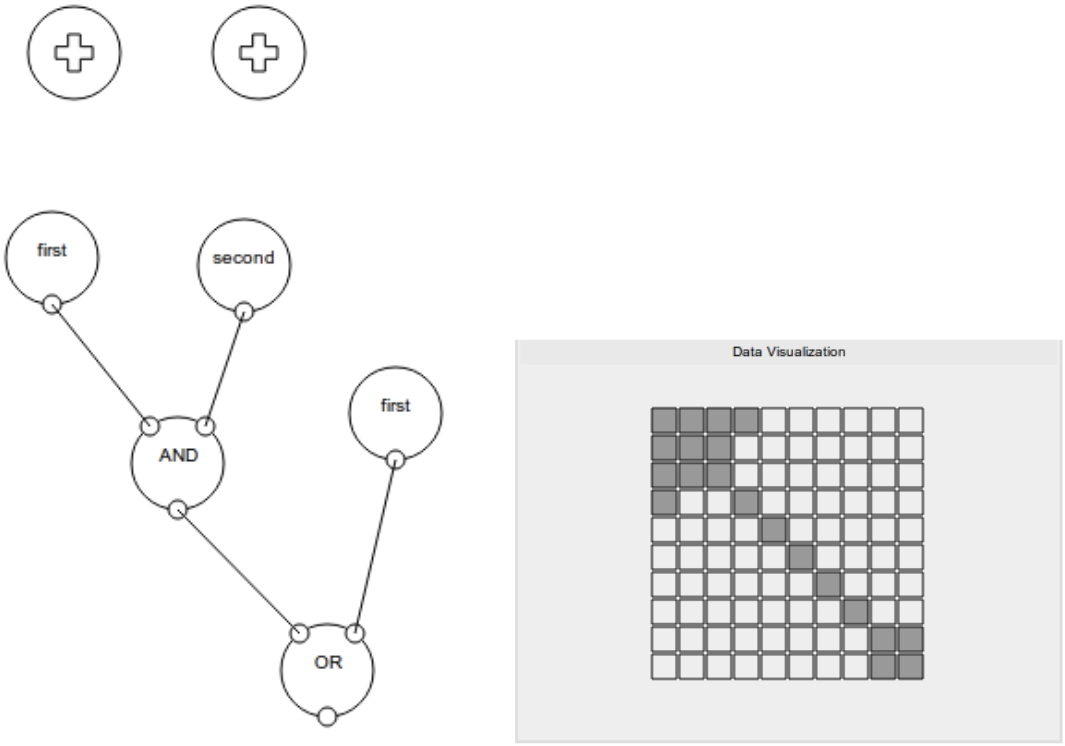
The audio example (Figure 17) (see Section 1.1 for source code) does not use the provided, default controls, but uses ordinary html elements styled with css as the interface, and interaction is defined in JavaScript via the audio API. This is obviously just a simple example, but shows the possibilities of customisation through the API. For more advanced examples of customizing the audio element, visit the PagePlayer[131].

5. Existing GIS tools built with HTML5

The last couple of months has seen some early adopters building new GIS tools built with HTML5 technology. Also, some existing libraries and applications have been (partly) rewritten to make use of HTML5 technology. With HTML5 being such a young standard, however, at the time of writing, the existing base of GIS applications and libraries using it, is rather sparse. This section contains a selection of GIS tools that are known to use parts of HTML5 with success.

5.1. Simple Educational GIS

The author is developing a simple GIS system for educational purposes[132] using HTML5 technology while this paper is being written. The system works with raster data, and the goal is to teach simple boolean data operations and other common concepts (reclassify etc.). The idea is burrowed from existing GIS systems, that use a binary tree to manipulate data (see Figure 18).



(a) The data tree

(b) Visualisation of a data layer

Figure 18: A simple, educational GIS system

The inline SVG JavaScript library Raphaël[99] is used for most of the program, and provides svg features for interaction in a way that is easy to work with through JavaScript.

Libraries using the canvas element was initially used for development, but after several bugs and a resulting slow interface, Raphaël and inline svg was chosen instead. Compared – and in contrast – to most (competing) libraries that rely on the canvas element, Raphaël is both easier to use, covers a lot of uses, and feels more mature and bug-free.

5.2. Cartagen

Cartagen[133] is a mapping framework, developed at the MIT Media Lab, that uses the canvas element for rendering maps from various sources, using JavaScript. Instead of using pre-rendered and cached tiles on a server, that are transferred to the client on demand, Cartagen downloads the raw vector data from the server, and uses the client to render and display the map.

Using the client for map rendering has a couple of key advantages. The data is downloaded once, instead of every time the user interacts with the map (zoom, pan), and rendering only consumes CPU processing power on the client, which means that the server can handle more clients simultaneously, or during a given period of time, because they avoid repeated requests for new data.

Figure 19: Example of a GSS style that retrieves localized building names

Cartagen further exploits the client rendering by using a custom styling format for maps – Geographic Style Sheets (GSS) . The GSS format is derived from Cascading Style Sheets (CSS), which are known to all modern web developers, and the goal is to make map styling more accessible. It also expands on CSS since it includes support for JavaScript callbacks and functions (see Code Example 12 from the cartagen web site). For developers, this means that a lot can be achieved just by creating a Geographic Style Sheet, e.g. localization (see Figure 19 from the cartagen web site).

Code Example 12: GSS file with JavaScript function

```
building: {
  opacity: 1,
  lineWidth: 0.001,
  fillStyle: "#444",
  text: function() {
    if (this.tags.get(
          'name:'+Config.get_url_params().language)
```

```
            )
        return this.tags.get(
                    'name:'+Config.get_url_params().language
                    )
      else
        return this.tags.get('name')
    },
    hover: {
      fillStyle: '#222',
      action: function() {
        console.log('hover')
      }
    },
    mouseDown: {
      lineWidth: 18,
      strokeStyle: "red",
      action: function() {
        console.log('mousedown')
      }
    }
  },
  landuse: {
    fillStyle: "#ddd"
  },
  rail: {
    lineWidth: 4,
    strokeStyle: "purple"
  }
```

For a client – browser – that is less powerful, handing raw data and expecting it to do all the work may result in a slow and choppy experience when interacting with the map. Browsers or computers that do not have or support hardware rendering on the graphics processor, will not have a pleasant experience (tested first-hand by the author, on a browser without hardware acceleration support).

5.3. Leaflet

Leaflet is a modern mapping library developed by Cloudmade[134]. It is a tile-based library, and supports both canvas and svg technologies for rendering raster and vector tiles, respectively (and also VML, for older versions of Internet Explorer). The different rendering backends are mainly supported for platform compatibility reasons, but may also be forced[135].

With the map library being tile-based, the actual map rendering and caching of the tiles is done on the server, and this is displayed in the client. There is support for vector objects that

are either individual or part of a vector layer – polygons, circles, markers, lines – and they are styled with CSS3. While the vector layers are static, the rendering of vector objects are done by the client, and also support custom behaviour on mouse, touch or keyboard events.

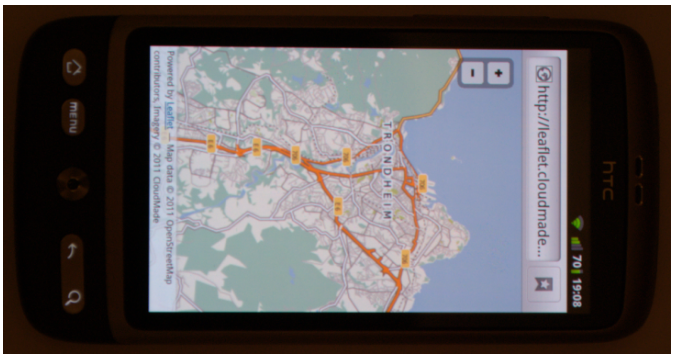


Figure 20: The official leaflet mobile example[136] on an Android mobile phone

One of the strengths of Leaflet, is that it is well supported across a lot of platforms, and that it supports mobile phones and tablets. Creating a fullscreen web application using Leaflet that correctly reacts to touch events is very straightforward (see Figure). Geolocation is also well supported through a custom function to zoom and center the detected location of the user.

Most of the examples in this article use Leaflet, because it makes it very straightforward to create examples that combine background tile maps with custom features and vector layers.

5.4. KothicJS

Kothic JS[137] is a map rendering engine for generating and presenting vector based tiles in HTML5 canvas elements, written in JavaScript. Leaflet5.3 supports using Kothic JS as a backend, for using true vector tiles rendered in canvas.

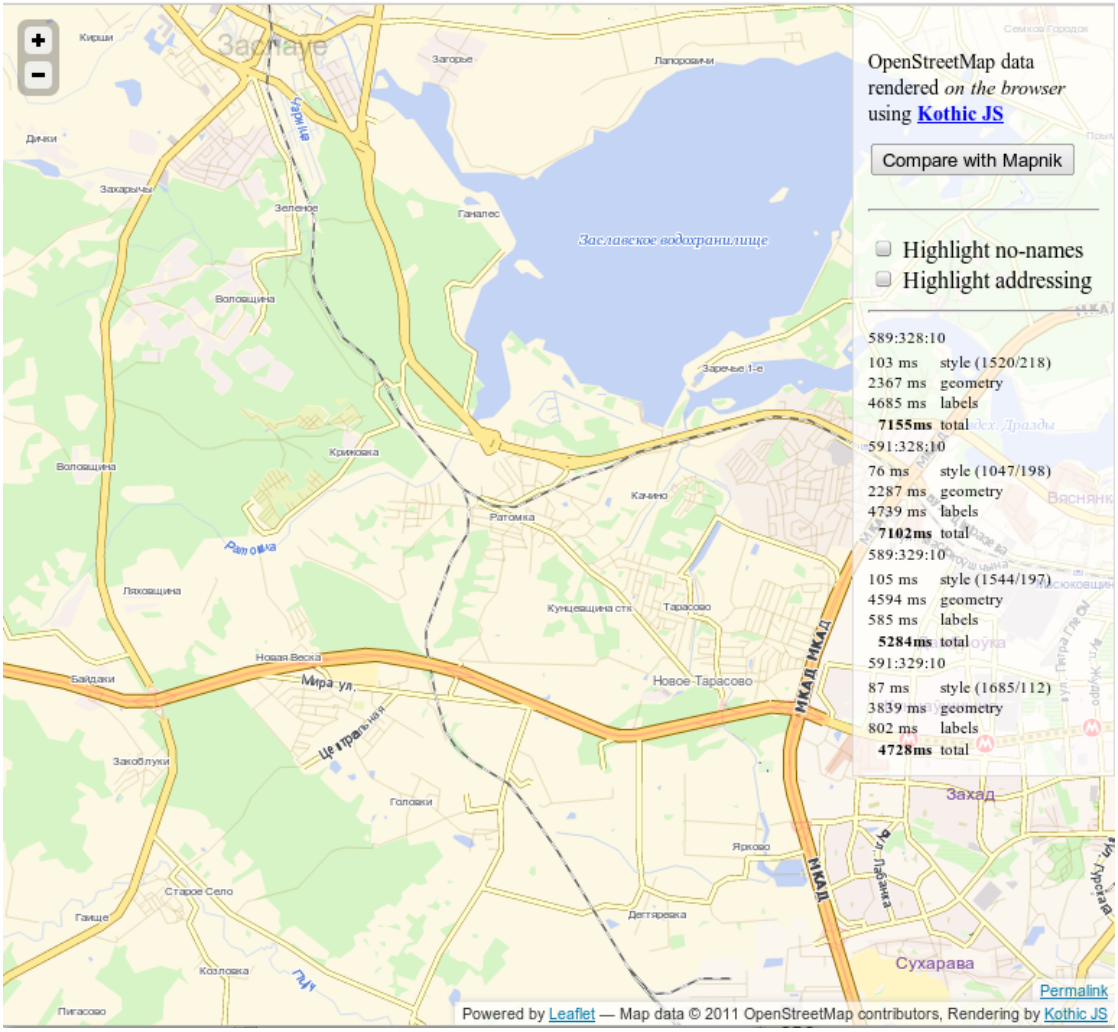


Figure 21: Example use of Kothic JS rendering vector tiles with Leaflet used as the map frontend

The tiles in Kothic JS have a similar naming scheme to traditional raster tile engines (i.e. grouped into /x/y/zoom tiles), and use vector data in GeoJSON format(see Section 3.3.1) for rendering the tiles. With Kothic JS being a javscript rendering engine, it can be used to render tiles on-the-fly from GeoJSON vector data, based on a user-supplied MapCSS file.

MapCSS[138] is a simple and declarative stylesheet language for maps (see Code Example 13), and is – like GSS (see Section 5.2) – derived from Cascading Style Sheets (CSS). The goal is to create an easier experience for amateurs and professionals that want to make customised maps without the barrier of e.g. creating a mapnik[139] style. The language only supports arithmetics through very simple JavaScript through the *eval*-function, and not variables, like GSS, and is therefore somewhat limited for projects that need complex features. It is also

very OpenStreetMap-centric, and may not support datasets where metadata is implemented differently.

Code Example 13: MapCSS example

```
line[highway=primary],
line[highway=secondary] {
    width: 5;
    color: #E77817;
    casing-width: 5;
    casing-color: #E77817;
    text: name;
    font-size: 12;
    text-position: line;
}

line[waterway] {
    width: 5;
    color: blue;
}

area[building] {
    fill-color: grey;
    text: addr:housenumber;
}
```

5.5. tile5

Tile5[140] is a mapping library with an emphasis on being well supported across multiple platforms through HTML5 technology. Tile5 is vendor neutral, and support several existing mapping engines that provide tiles through public APIs (such as Cloudmade[141], deCarta[142], OpenStreetMap[119]). The long term goal is to work equally well on most platforms, but currently, most effort has gone into the support for mobile devices.

Code Example 14: tile5 simple tile example

```
map = new T5.Map('mapContainer', {
        padding: 'auto'
});

map.layer('tiles', 'tile', {
        generator: 'osm.cloudmade',
    // demo api key, register for an API key at http://dev.cloudmade.com/
    apikey: '7960daaf55f84bfdb166014d0b9f8d41'
```

```
});

map.zoom(8).center('-27.4695 153.0201');
```

Figure 22: Simple example of tile5 rendering OpenStreetMap data from Cloudmade

Since there are a lot of mobile frameworks for providing user interfaces, tile5 tries to complement them, rather than compete with them. To ensure a smooth experience, integration testing is done with the most widespread and popular of them (jQTouch[143], jQuery Mobile[144], Sencha Touch[145]).

Tile5 supports several backends built on HTML5 technology. The most prominent – and most stable – is the backend using the canvas element, but rendering through svg is also available as a beta feature through Raphaël, which is a third party library to increase cross browser support for SVG.

5.6. giscloud

Giscloud[146] is a collection of tools for storing, accessing and manipulating spatial data on the web. The stack uses the HTML5 canvas element both on the server and in their client – apparently (since the source is not available for examination, this is based on examination of what's available from third parties, they (among other techniques) process binary data (see Section 4.2.4) through the canvas element to achieve an impressive performance boost[147].

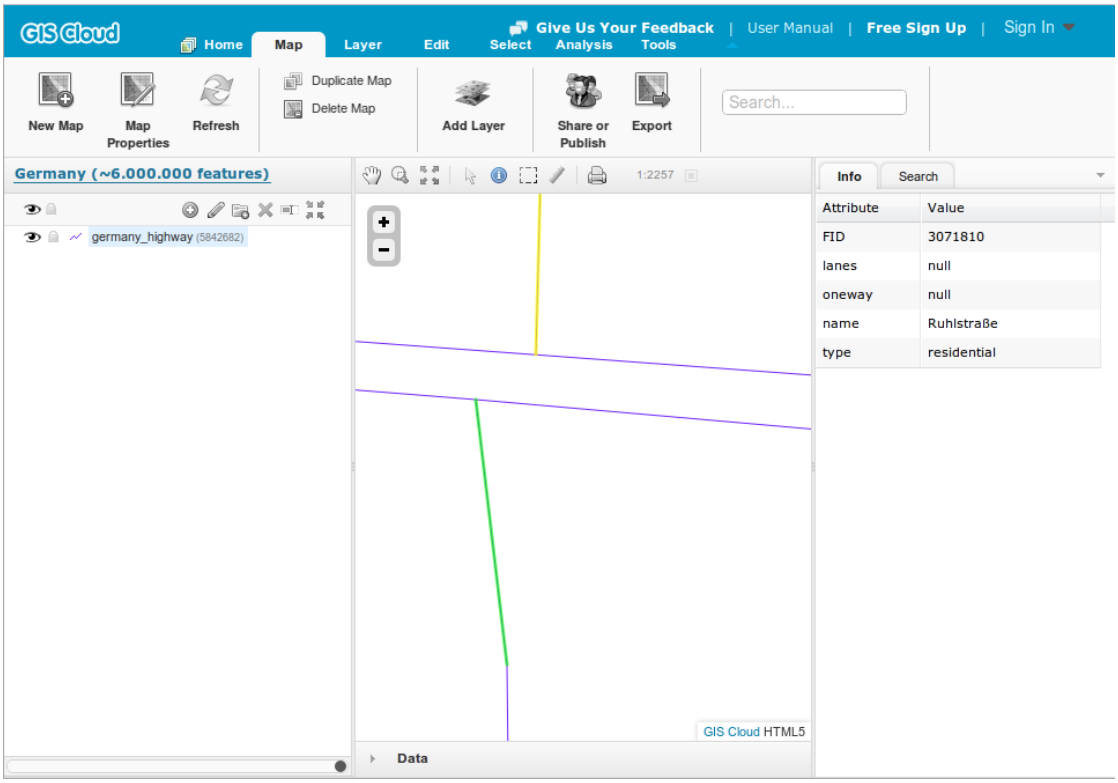


Figure 23: Example of giscloud client which uses html5 canvas for rendering elements that are individually selectable http://www.giscloud.com/map/16594/germany-6000000-features

Although giscloud is a collection of tools, the map engine – which is interesting for its use of canvas – is very similar to Kothic JS (see Section 5.4) because it uses vector data to render tiles in real-time instead of relying on cached raster tiles.

6. Performance of HTML5 GIS tools

6.1. Measuring performance

There are a lot of ways to measure performance, since it means different things depending on the software, the requirements of the software and those who are going to use it. While in a real-time application it is crucial that the delay from the GPS to the rest of the system is as short as possible, an offline GIS application might value the application's ability to handle large amounts of data higher (a responsive application with large amounts of data).

Requirements and importance of the different ways to measure performance will also be prioritised differently based on the actual subset of HTML5 technology the application is using. Knowing the performance "cost(s)" of a particular module during development will certainly be an advantage if the resulting application is required to satisfy a specific set of performance requirements.

6.2. Defining performance

Performance has been the driving factor for software engineering for years, which has compromised a lot of other important software qualities (such as security, modifiability, testability)[148]. This is fortunately changing along with the $\frac{price}{performance}$-ratio dropping, and the cost of developing software rising. Because JavaScript is a relatively young language 3.4, performance is still the major concern when moving GIS applications to the web. However, even though this section focuses on performance, it is important not to forget other quality attributes.

Performance is about managing resources, to receive and respond to events. The time it takes to respond after an event is received, is called latency, and *increasing performance* is defined as minimizing latency[149]. Previous literature divide performance issues into two categories, depending on the way they delay the response (and thus increase latency); the amount of resources the process consumes (where resources include network bandwidth, memory, CPU) is called *resource consumption*; the time a process needs to wait because it needs to use a resource that is unavailable, the time delay that is caused by sharing a resource with other processes, or the time a process needs to wait for a computation to finish (and the computation itself might need another computations result to initiate) is called *blocked time*.

To emphasise other important points when one considers moving from the desktop to the web, this definition is loosened a little, to include things that indirectly influences the performance – the performance as it is *percieved* by the user – where this makes sense.

6.3. Web Sockets

Web Sockets has a very simple API, that only supports opening and closing a connection, sending and receiving data, and retrieving the connection state and also an error handler. The only overhead is the handshake footprint, and the start and end bytes for each data transfer, which both consume only a single byte. This is significantly better than normal HTTP communication.

Code Example 15: WebSockets handshake (request and response)

```
GET /text HTTP/1.1
    Upgrade: WebSocket
    Connection: Upgrade
    Host: www.websocket.org
    (...)

HTTP/1.1 101 WebSocket Protocol Handshake
    Upgrade: WebSocket
    Connection: Upgrade
    (...)
```

To compare the older, HTTP-based approaches up against WebSockets, a traditional implementation was made[107] that continuously (once per second) polls real-time stock-data from a RabbitMQ message broker, and this application was also built with WebSockets for comparison.

Code Example 16: HTTP request header

```
GET /PollingStock//PollingStock HTTP/1.1
 Host: localhost:8080
 User-Agent: Mozilla/5.0 (Windows;
                          U;
                          Windows NT 5.1;
                          en-US;
                          rv:1.9.1.5)
Gecko/20091102 Firefox/3.5.5
 Accept: text/html,
         application/xhtml+xml,
         application/xml;q=0.9,*/*;q=0.8
 Accept-Language: en-us
 Accept-Encoding: gzip,deflate
 Accept-Charset: ISO-8859-1,utf-8;q=0.7,*;q=0.7
 Keep-Alive: 300
 Connection: keep-alive
 Referer: http://www.example.com/PollingStock/
```

```
Cookie: showInheritedConstant=false;
        showInheritedProtectedConstant=false;
        showInheritedProperty=false;
        showInheritedProtectedProperty=false;
        showInheritedMethod=false;
        showInheritedProtectedMethod=false;
        showInheritedEvent=false;
        showInheritedStyle=false;
        showInheritedEffect=false
```

Code Example 17: HTTP response header

```
HTTP/1.x 200 OK
 X-Powered-By: Servlet/2.5
 Server: Sun Java System Application Server 9.1_02
 Content-Type: text/html;charset=UTF-8
 Content-Length: 21
 Date: Sat, 07 Nov 2009 00:32:46 GMT
```

The overhead for a single set of HTTP request and response headers, is 871 bytes (see Code Examples 17 and 16). The overhead for the HTTP request and response headers with 100,000 clients polling every second is 871,000 bytes (or 6.6 Mbps), while the overhead for the WebSockets (start and end bytes) with 100,000 clients receiving 1 message every second is 200,000 bytes (or 1.6 Mbps). Figure 24 illustrates the difference in data size. For an average user with an average broadband bandwidth, the HTTP approach eats up a considerable percentage of the bandwidth – remember that this is *just the overhead data*(!).

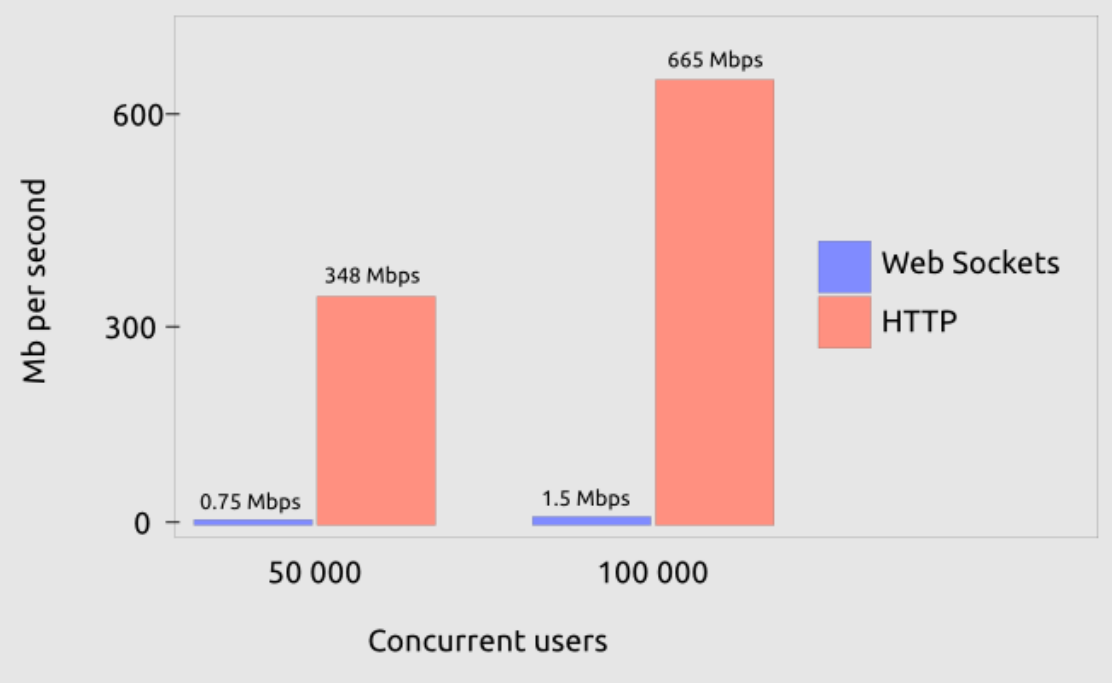


Figure 24: The difference in data transfer overhead and bandwidth requirements with HTTP and Web Sockets

The substantial savings in bandwidth is only one benefit of Web Sockets – there is also a reduction in latency because one does not have to poll for new data, and the server may send the data immediately (see Figure 25). To simplify the illustration, and make the point more clearly, the packets arrive immediately on the illustration, although there will be a 50ms delay in reality (in our case the latency is 50ms between client and server). With HTTP, one first sends a request, then receives the response. If the latency between client and server is 100ms, the time from the request is sent, until the response is received, is $2 \cdot 100ms = 200ms$.

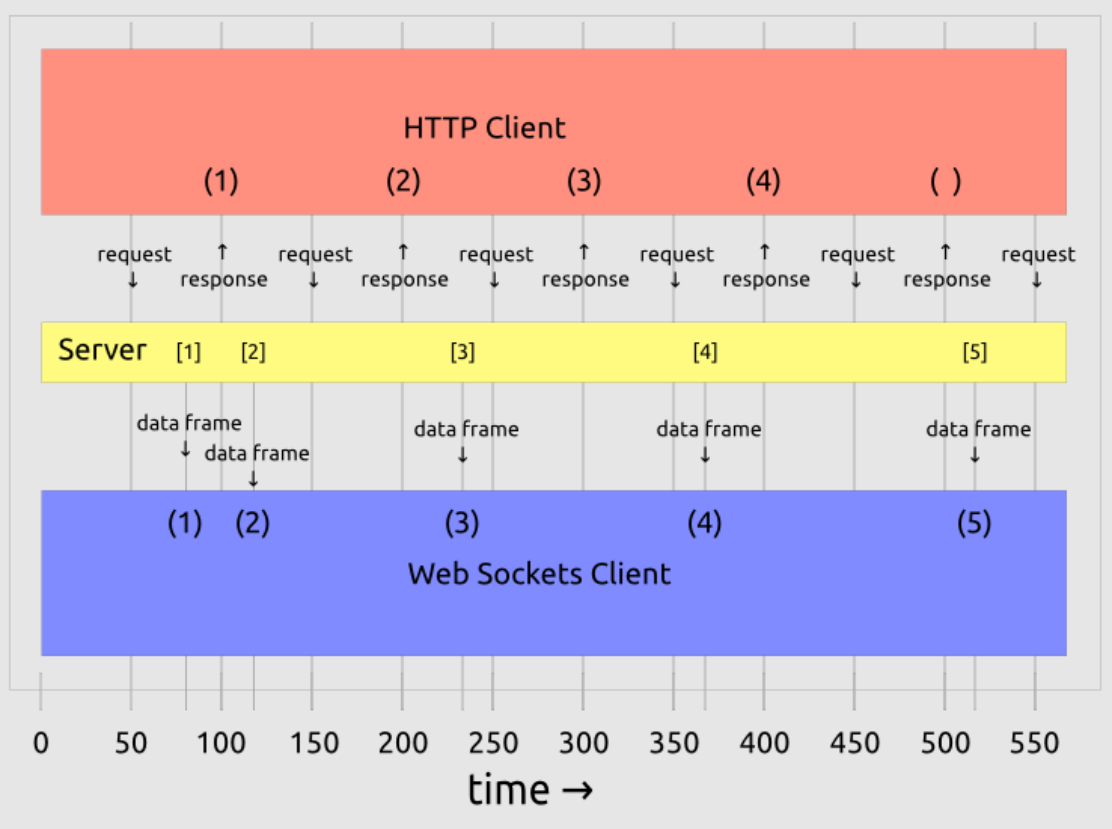


Figure 25: The difference in latency with HTTP and Web Sockets, where [1] is the first update on the server, (1) is the first update received by the client and ( ) is an empty (and redundant) packet

A Web Socket does not use this pattern – after the handshake is established, the server can send the data directly. It is important to note that while the client will always be busy sending requests and receiving responses, just to check if there is new data, the server only sends data through the established Web Socket when it has an update to send, and is free to do so immediately (i.e. not wait for the next HTTP request). The client using Web Sockets therefore has more resources to do other work, since it does not need to poll constantly.

6.3.1. Latency test

The Web Sockets example (see Section 4.5.1) was used as a starting point to develop a realistic test for examining the latency overhead in Web Sockets (see Section 1.1 for source code). The Web Sockets server used[109] just relays the data immediately, sending it back to the client. The latency results in the tests are therefore the time it takes from the client sends the data to the server until it receives the data back (from the server).

The tests are performed manually, to avoid erroneous results because of the client, and technical limitations. The actual interaction works exactly like the Web Sockets example (see Section 4.5.1, Figure 26), i.e. by clicking on the map and placing markers, and the results are stored for later analysis.

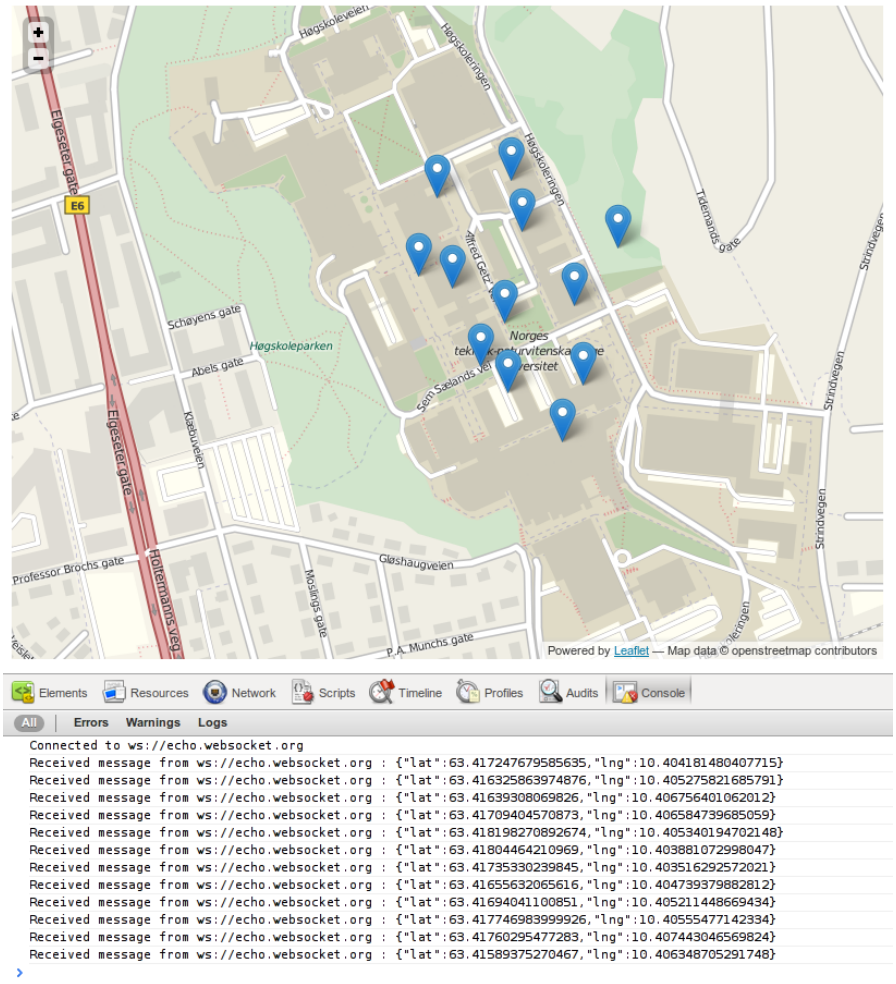
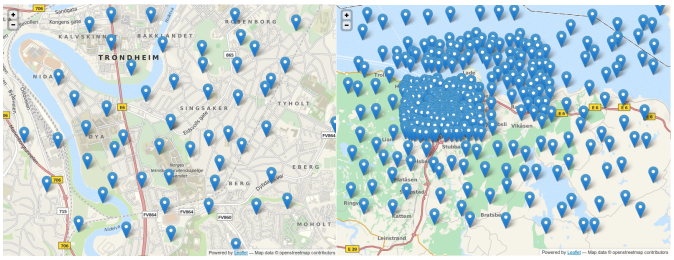


Figure 26: The user interacts with the map by placing markers, and the latency between client and server is measured and stored

A lot of markers were created (see Figure 27) to make sure that temporary speed increases and decreases did not influence the results. The tests were also done on different hardware, operative systems and browsers.



(a) (b)

Figure 27: Markers that were made in the web browsers during testing

Before analysing, abnormal latency due to hangs or freezes in the JavaScript engine on the client (here, after inspecting the results to determine the "normal" range, latency above 350ms) caused by either the client or server, were removed.

For each of the collected results, mean value (μ) and standard deviation[150] (σ) were estimated. Then the normal distribution was created with the probability density function (see Equation 1)[151]. (There were 586 observations for Chromium on Linux and 808 observations for Chrome on Windows, which means that n should be large enough to approximate normal distribution, in both cases[152].)

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{1}$$

A JavaScript plotting library, flot[153], was used to visualise the results. As we can see in the results (Figure 28 and 29), the standard deviation differences between the two collected results are marginal (linux: $\sigma \approx 16ms$, windows: $\sigma \approx 17ms$). The mean latency for Chromium on Linux and Chrome on Windows was 134ms and 136ms, respectively.

We observe that the latency results are fairly low. Generally, users are less tolerant of unresponsive desktop applications[154] compared to web pages[155] (i.e. information retrieval). Since our intention is to evaluate Web Sockets for use in web applications that replace desktop applications, the requirement for responsiveness should be as strict as the latter, for the former (Jakob Nielsen says[154] "These guidelines have been the same for 37 years now, so they are also not likely to change with whatever implementation technology comes next.").

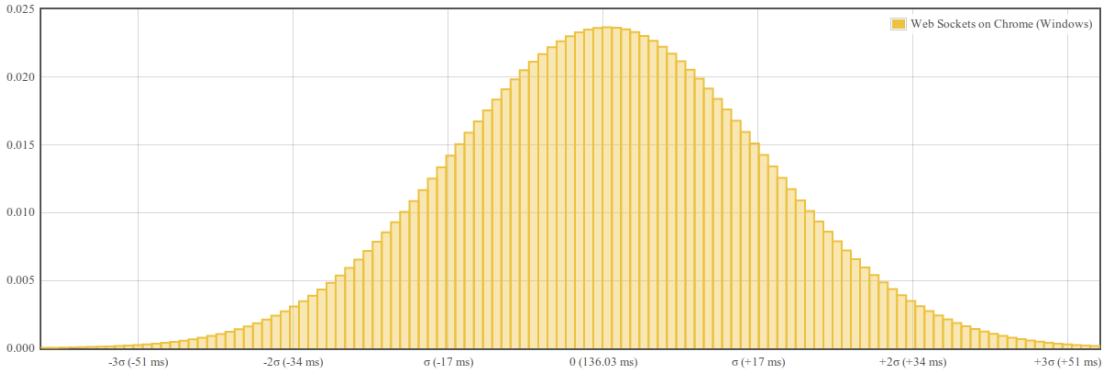


Figure 28

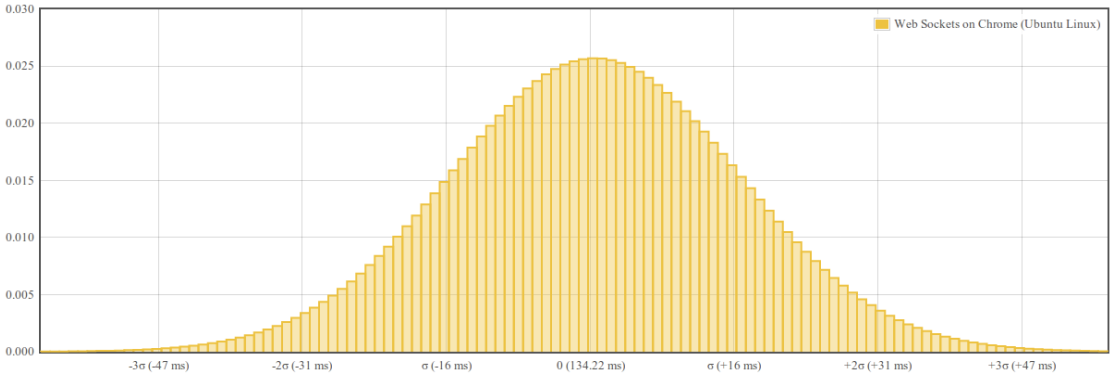


Figure 29

The responsiveness requirement for users to feel that they are manipulating directly in real-time (this is typical for GIS applications where spatial objects are edited and/or queried) is 0.1 second. Our results show that the mean values are sufficient to satisfy this requirement, and as long as we are below 150ms (with the precision chosen, all values below 150ms is within 0.1s).

A quick look at Figures 28 and 29 relieves that the limit is approximately a single standard deviation from the mean value.The probability that the request and response is below this (artificial) limit of 150 ms ($P(X \leq 150)$), is sensible to examine. To be able to use the values from the table[152], the data need to be converted to standard normal distribution (N(1,0)), with the function $Y = \frac{X-\mu}{\sigma}$, where X is our existing variable.

Calculating the probability that X is 150 ms or less using Chromium on Linux :

$$
\begin{aligned}
P(X \leq 150ms) &= P(\frac{X-\mu}{\sigma} \leq \frac{150-\mu}{\sigma}) \\
&= P(\frac{X-134}{16} \leq \frac{150-134}{16}) \\
&= P(Y \leq 1) \\
&= \phi(1) \\
&= 0.8413
\end{aligned}
$$

and with Chrome on Windows :

$$
\begin{aligned}
P(X \leq 150ms) &= P(\frac{X-\mu}{\sigma} \leq \frac{150-\mu}{\sigma}) \\
&= P(\frac{X-136}{17} \leq \frac{150-136}{17}) \\
&= P(Y \leq 0.82) \\
&= \phi(0.82) \\
&= 0.7939
\end{aligned}
$$

Most requests and responses will be perceived as "real-time" by the user in this application. The longest time spent between client and server in most cases, is found by constructing a confidence interval of 99% :

$$
\begin{aligned}
Z = \frac{\bar{X}-\mu}{\sigma} &\sim N(1,0) \\
P(Z < z_{\alpha/2}) &= 1-\alpha \\
\alpha &= 0.01 \\
z_\alpha &= 2.326
\end{aligned}
$$

By choosing an α of 0.01, we get $z_\alpha = 2.326$ from[152]. The results for Chromium on Linux :

$$
\begin{aligned}
P(\frac{\bar{X}-\mu}{\sigma} < 2.326) &= 1-0.01 \\
P(\mu < 134 + 2.326 \cdot 16) &= 0.99 \\
P(\mu < 134 + 37) &= 0.99 \\
P(\mu &< 171)
\end{aligned}
$$

and Chrome on Windows :

$$
\begin{aligned}
P(\frac{\bar{X} - \mu}{\sigma} < 2.326) &= 1 - 0.01 \\
P(\mu < 136 + 2.326 \cdot 17) &= 0.99 \\
P(\mu < 134 + 40) &= 0.99 \\
P(\mu &< 174)
\end{aligned}
$$

The results show that in most cases, the time from a request is sent from the client, until the response is received, is less than 171 ms and 174 ms. Even though some results will be above the 150 ms limit, most will be below (see above) 150 ms, and the user probably will not notice a substantial difference in the few cases where it is.

However, this is only a test of one server. While the results will vary depending on distance and bandwidth between client and server, and also the amount of data transferred and processing etc., it still gives an impression of the capabilities of Web Sockets, and the improvement compared to HTTP request/response.

Other studies of Web Sockets A simple collaboration drawing application was developed[110] for testing Web Sockets on real-time and collaboration application purposes. The results indicate that Web Sockets outperform other standards-based technologies, and that Web Sockets has made the web a reliable platform for real-time systems.

6.4. Web Workers

JavaScript was not designed for running in multi-threaded environments, but Web Workers were designed to solve this – each Worker runs in a separate thread. There are lots of software that can benefit from running multiple processes that are time-consuming and would otherwise freeze the web UI in the GIS domain. An obvious gain would be saving resources by running e.g. a large Delaunay-triangulation algorithm on a local machine with multiple, otherwise idle, cores.

Processes that need to communicate over the network, and need to wait for its request to complete before returning the result, would freeze the UI in a single-threaded application. This is especially prevalent in GIS applications, that often need to query a server for a tiny subset of its geographical data. The need to keep the data in a central location might be for licensing, storage or computational issues, but the fact is that web GIS applications need to accommodate this.

Web Workers avoid this by separating the process, and thus decrease the percieved latency – the task may not be processed faster in this scenario than without Web Workers, since the actual work is done on the server, but since it is non-blocking with Web Workers, it is *perceived* as faster (also freeing the user to du other things in the ui).

A third way to take advantage of the Web Worker API is to distribute resource demanding tasks from server to the clients – distributed computing. A real-time web application was implemented[156] to test the performance gain with Web Workers on both low-end (consumer) and high-end (commercial) server hardware (see Table 1).

	low-end server	high-end server
CPU	Intel A110@800 MHz	2 x Intel Xeon(R) E5345@2.33 GHz
RAM	1 GB	4 GB
OS	Fedora 12	Fedora 11

Table 1: Specifications of the servers used in the study

The system was a game with characters distributed in a shared world, and each client would update its view through the server. This application was implemented in two ways, one where the server did all the calculations, and a second where the server distributed each request back to the client to process, with required information (information about the other characters). Requests were sent from the clients every 500ms, and there were an average of 18 non-playable characters visible for each client at all times.

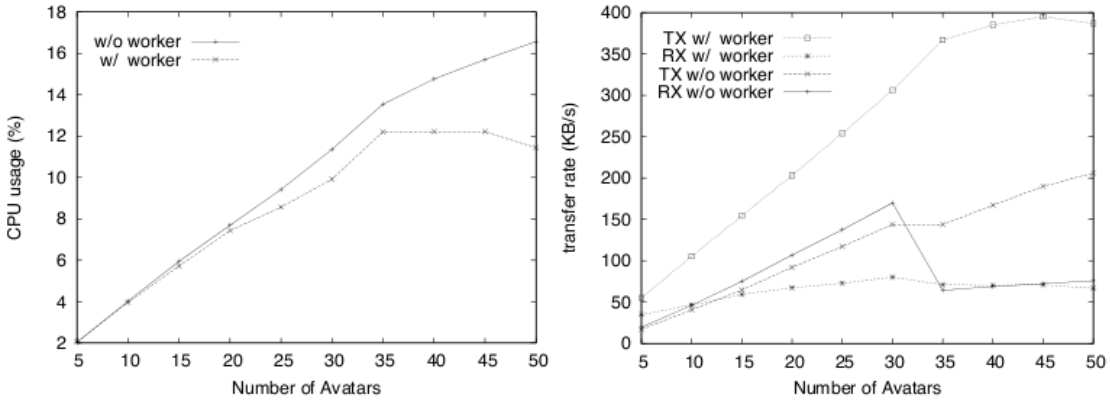


Figure 30: Figures that show network and CPU usage on the high-end server (from [156])

Results (see Figure 30) show that even with the low-end server, the latency is reduced with 10% when using web workers. Although the use of Web Workers places higher load on the network (because of all the extra information that is transferred to the clients), the amount of data transferred is low, and the savings in CPU usage with Web Workers are more of a bottleneck than the transfer rate limit from server to client (20 concurrent players consumed a total of 130kB/s, or 1Mb/s).

The results with the high-end server show a noticeable decrease in CPU usage when distributing the load with Web Workers – with 50 clients, the load for using and not using Web Workers is 11% and 17%, respectively. The transfer rate increases with Web Workers in the same manner as the low-end server, which is expected.

7. Can HTML5 serve the requirements of future GIS applications?

Early in 2011, the WHATWG group announced[157] that the HTML specification will just be known as "HTML". This means that the WHATWG HTML specification[158] is now a "living standard", and removes the artificial barrier for browser vendors to delay implementations because of the new version not being finished (actually, looking at how HTML5 was and is adopted, this has been going on for some time).

One needs to keep in mind, when thinking of HTML5 as a technology, that it is not limiting in the way that e.g. Adobe Flash is. HTML5 is a part of the open web, and while it standardizes a lot of technology previously hard to develop and maintain across browsers, use of HTML5 encourages use of external JavaScript libraries to implement the features that HTML5 itself does not cover. With closed technologies such as Flash, it is not as easy to rely on external resources.

The future of HTML5 – or just HTML – (GIS) applications therefore gains from the advancement of web technologies in general, and not only the specification itself. New JavaScript libraries and frameworks that ease development, or use optimized algorithms; JavaScript engines with increased performance or new JIT compiler optimizations; existing graphical user interface frameworks that adds support for rendering on the web; how and how fast the web browser vendors implement support for new technologies, and also hardware acceleration, are all influencing the degree of success that HTML5 will have in providing GIS applications on the web.

Additionally, by trying to add support for the web and HTML5 into an existing user interface framework, the GTK+ Broadway project[159][160], which renders applications written with the GTK+ framework in a HTML5 canvas element, any existing GIS application written with GTK+[161] – such as the libchamplain mapping widget – will "automatically" also become a web application. It is a very interesting approach which makes a desktop application web capable without a complete rewrite to HTML5, but although applications such as the LibreOffice productivity suite[162] are already planning running on GTK+ Broadway[163], GTK+ Broadway is not currently ready for production use. Depending of the success of GTK+ Broadway, other frameworks and GIS applications such as QT[164] and Quantum GIS[165] may follow this approach too.

In the end, the driving factor is the demand for accessing GIS web applications in a browser. With great demand, innovation and improved performance will follow – although performance is a barrier right now, it will probably improve rapidly. Cross-compatibility between browsers, and browser vendors willingness to cooperate, is more critical, because the goal of HTML5 as a common platform – in the author's opinion HTML5's perhaps strongest argument – will not work without the compatibility this requires. If HTML5 continues to evolve into an effective solution for any application that needs to work on multiple platforms, it certainly should have a bright future for application development in the GIS domain.

8. Conclusion

With the new HTML5 standard, the open web has taken a major step forward for providing developers and companies with the means necessary to create GIS applications that may compete with their desktop-bound counterparts. While third-party plugins like Adobe Flash and Microsoft Silverlight are years ahead in terms of maturity, HTML5 lays a solid foundation for the future open web, and existing GIS applications that use HTML5 technologies are impressive both with regards to their performance, and their user interfaces.

While the Web Sockets API shows a tremendous decrease in redundant bandwidth usage, and low enough latency for real-time application use, other parts of HTML5 are clearly at a very early adoption phase, and not supported across major browsers. However, the opportunity HTML5 provides by being a common platform that is independent of operative systems, and only rely on a recent web browser, is why HTML5 in the authors opinion should – and will – be adopted by major GIS application vendors, either now or as the standard progresses, and HTML5 matures.

The increase in mobile device usage, and thus multiple operative systems with large market shares, increase demand for a solution where a single application can be deployed to multiple devices, independent of the type of device. HTML5 only relies on a web browser, and is perfect for this scenario, which is a common situation in the GIS domain with location-aware applications, or any application that targets mobile devices. This major selling point of HTML5 looks very promising, and might make or break the large scale adoption of HTML5 as a choice for large application vendors.

There is need for further work on various applications of the HTML5 elements, and more research on performance and possibilities in realistic GIS environments (mapping applications, GIS systems etc.). Since the HTML5 – and its "successor" HTML – is a moving target, there is additionally a need to assess the standard's support across browsers as it progresses and matures. Although there are not a high number of GIS applications made with HTML5 available, many will emerge as the standard gets older and more widespread, and research on the implementations of GIS applications on the web with HTML5 is also needed.

It will be interesting to monitor the adoption rate as HTML5 matures. In the author's opinion, HTML5 is a technology that is a solution to a problem that an increasing number of application vendors that target multiple (and mobile) devices encounter. How attractive HTML is and will become for these companies, will decide if HTML5 gets a major or minor role for application development in the future, and whether e.g desktop GIS applications will move to the web. The author believes GIS applications and location awareness will increase even more, and that this will happen with HTML5 as the underlying technology.

Appendices

A. HTML5 Support in Web Browsers

At the time of writing this paper, HTML5 is still a "young" standard. The support for different parts of HTML5 varies for each browser, and its status should be examined for every web browsers the developer intends to target. The support status changes at such a rapid phase, that instead of providing a static (and quickly outdated) status report in this paper, one is encouraged to use online sources instead. Sites such as html5test.com[62], html5readiness.com[63] and caniuse.com[64] provides an up to date overview of browsers with HTML5 support.

In the wake of lacking support and implementation across browsers, a handful of tools have appeared to check if specific features are supported in the browser – the most popular is probably Modernizr[61]. Libraries that backport several features for use in aging browsers are also available, a great win for companies on the fence because of lacking support. Use of such tools in encouraged if supporting legacy browsers is a priority.

B. Code Examples

Code Example 18: WFS GetFeature Response

```
<?xml version="1.0" encoding="UTF-8"?>
<wfs:FeatureCollection
      xmlns="http://www.opengis.net/wfs"
      xmlns:wfs="http://www.opengis.net/wfs"
      xmlns:topp="http://www.openplans.org/topp"
      xmlns:gml="http://www.opengis.net/gml"
      xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"

  xsi:schemaLocation="http://www.openplans.org/topp
      http://localhost:8080/geoserver/wfs?service=WFS&amp;version=1.0.0
      &amp;request=DescribeFeatureType&amp;typeName=topp:archsites
      http://www.opengis.net/wfs
      http://localhost:8080/geoserver/schemas/wfs/1.0.0/WFS-basic.xsd">

<gml:boundedBy>
<gml:Box srsName="http://www.opengis.net/gml/srs/epsg.xml#900913">
  <gml:coordinates
        xmlns:gml="http://www.opengis.net/gml"
        decimal="." cs="," ts=" ">
     63.414751,10.406435 63.414914,10.406263
  </gml:coordinates>
</gml:Box>
</gml:boundedBy>

<gml:featureMember>
<building:features fid="Feature1">
  <building:name>Sample Building</building:name>
  <building:geometry>
    <gml:Point srsName="http://www.opengis.net/gml/srs/epsg.xml#900913">
      <gml:coordinates
            xmlns:gml="http://www.opengis.net/gml"
            decimal="." cs="," ts=" ">
        63.414876,10.406321
      </gml:coordinates>
    </gml:Point>
  </building:geometry>
</building:features>
</gml:featureMember>

</wfs:FeatureCollection>
```

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