TECHNISCHE UNIVERSITÄT DRESDEN

Department of Computer Science Institute for Systems Architecture, Chair of Computer Networks

Master Thesis

GRAPHICAL DISCUSSION SYSTEM

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Matriculation number: 3942792
Matriculation year: 2013

to achieve the academic degree

Master of Science (M.Sc.)

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Submitted on: 18th February 2015

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MASTER THESIS ASSIGNMENT

TOPIC: Graphical Discussion System

Name (sur, given):	Chen, Kaijun	Degree Programme:	Master Informatik (PO 2010)
Matriculation No:	5942792	Project/Focus:	Tech-enhanced Learning
Responsible Professor:	Prof. Dr. rer. nat. habil. Dr. h. c. Alexander Schill		
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Start:	8 January 2016	Due:	17 June 2016

GOAL

At the Chair of Computer Networks a teaching and learning platform has been developed. Currently, its features include a text-based discussion system as well as a virtual interac-tive whiteboard system.

The goal of this assignment paper is to combine both systems into one graphical discussion system that allows for textual as well as graphical discussions. Contributions need to be quotable as is custom in forum systems, however allowing to not only annotate graphical contribution like images, but actually enabling modification of quoted graphical contents. Additionally, any contribution (textual as well as graphical) should be manageable by means of graphic interaction, especially drag & drop gestures with mouse as well as finger tips.

In order to achieve the goal, all aspects of modern web technologies need to be considered, especially HTML 5. Additionally, a feasible concept for storing of contributions and their relations is required on the server. The data model must respect possible future additions, especially storing of client-side private keys for encryption within the local browser storage.

Existing solutions and concepts must be investigated and assessed before conceiving a concept for the desired graphical discussion system. Afterwards, a proof-of-concept implementation is mandatory.

An evaluation of the graphical discussion system should be executed, focussing on usability aspects as well as the capabilities of the conceived data model.

Prof. Dr. rer. nat. habil. Dr. h. c. Alexander Schill
(responsible professor)

FOCUSES

- Investigation of related work and current state of research,
- definition of requirements and criteria for quantitative design,
- conception of an evaluation method,
- implementation of proof-of-concept components, and
- evaluation and assessment of the results.

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Statement of authorship

I hereby certify that I have authored this Master Thesis entitled *Graphical Discussion System* independently and without undue assistance from third parties. No other than the resources and references indicated in this thesis have been used. I have marked both literal and accordingly adopted quotations as such. They were no additional persons involved in the spiritual preparation of the present thesis. I am aware that violations of this declaration may lead to subsequent withdrawal of the degree.

Dresden, 18th February 2015

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ABSTRACT

A discussion of the teaching content or the educational material is always essential for both tutors and students in the teaching activities. In traditional way, a discussion can only be performed normally after courses also requires the absence of the students as well as the tutors.

The traditional approach of discussing shows its limitations. Inefficiency in knowledge acquisition: not all the students have the same question and the tutor is able to offer explanation for only one question at same time; time-consumption: ; low interactivity:

Thus, a discuss system with intense interactivity as well as in crowdsourcing way is highly needed. To achieve high interactivity, a discuss system with graphical tool and real-time data communication is proposed. Students are able to contribute their questions and answers to get to the bottom of his deficiencies of teaching content and the educational material. And students who has the same questions can instantly acquire the best solution which is recommended and approved by the community.

In order to validate and evaluate the concepts of this approach, an implementation of the proposed solution is developed on top of modern web technologies. Moreover, a usability questionnaire survey is proposed and delivered for a quantized evaluation of the client application. The performance of this application is also evaluated at the same time through the created simulation scenarios.

CONTENTS

1. INTRODUCTION

With the rapid development and popularization of internet and technology, the traditional educational activities are moving to the online platforms. MooCs like ..... have taken the responsibilities and ... to .

Tell some histories!

1.1. MOTIVATION

What's the situation now?

Pain?

1.2. GOALS AND RESEARCH QUESTIONS

What's the features of the new system?

What's the problems/question am i solving?

1.3. THESIS OUTLINE

Outline

2. STATE OF THE ART

The following chapter gives an overview of state of the art. To achieve the high interactivity and responsiveness in the graphical discussion system, a lot of modern web technologies should be applied.

However, there are always plenty of alternatives for each technology which could differ from system to system. So it is important to investigate and analyse the existing solutions and capture an overview about different alternatives of technologies. It's is also vital to understand the benifit and drawback of the technologies used. In addition, a

First of all, the general modern web technology and development workflow will be introduced, which goes through our whole development and has a great impact on the development efficiency. The next part describes the different graphical technologies on web, and which fits our system best. Then an overview of the real-time communication technologies is illustrated and evaluated. At last, a collection of modern technologies applied within the back-end server is listed.

2.1. MODERN WEB DEVELOPMENT

2.1.1. EVOLUTION

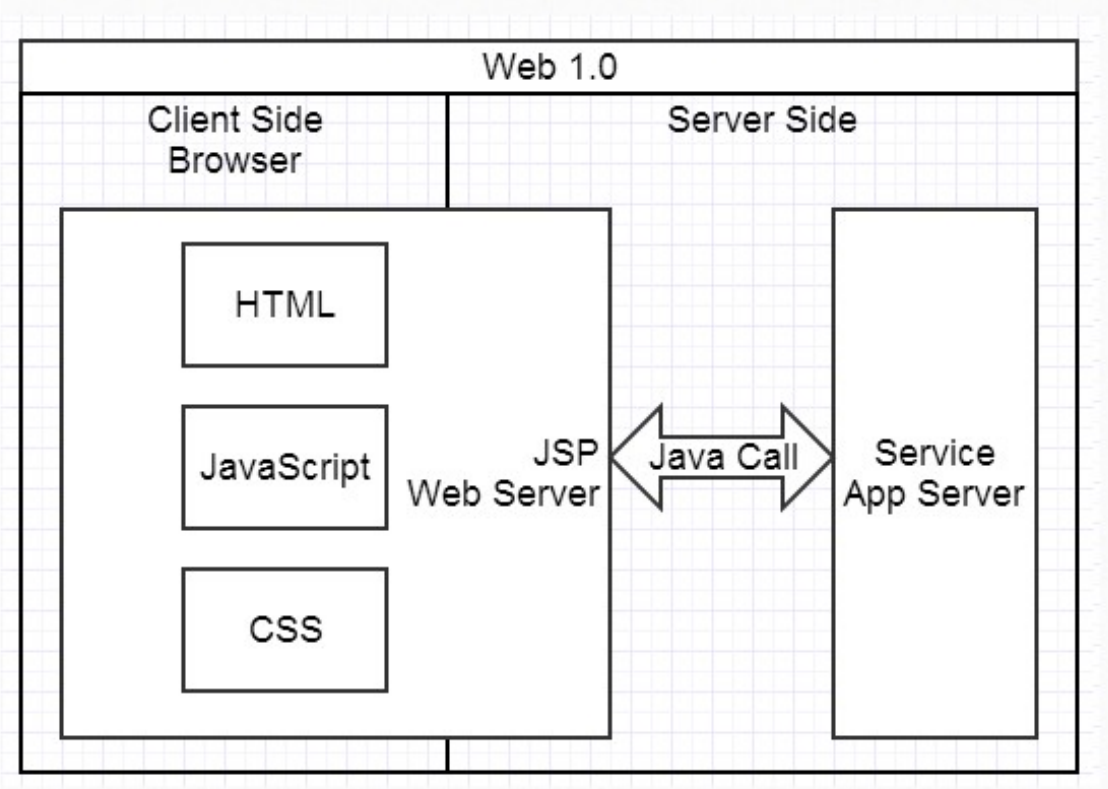
With the increasing complexity of a web app and high demand of agile development, people are always thinking about how to improve patterns of the workflow in web development as well as the architecture of a web app. To achieve better scalability, maintainability and ubiquity of a web app, the architecture of an entire web app has been envolving in the past several years .

EARLY AGE

At the early age of web development, the backend did all jobs for both client side(browser) and server side, such as rendering, calling system service, composing data, etc. Figure 2.1 shows the overview of web architecture: The advantage of this pattern is clear: The development and deployment are simple and straightforward, if the bussiness logic doesn't become complexer. But with the increasing complexity of the product, the problems shows up:

1. Development of frontend heavily depends on the whore development environment. Developers have to start up all the tools and services for testing and debugging only some small changes on view. In most cases, the frontend developer who isn't familar with the backend needs help while intergrating the new views into the system. Not

Figure 2.1.: Web architecture in early age



only the efficiency of development, but also the cost of communication between frontend developer and backend developer are huge problems.

2. The own responsibility of front-end and back-end mess up, which could be expressed by the commingled codes from different layers, for example there is no clear boundry from data processing tp data representing. The maintainability of the project becomes worse and worse with the increasing complexity.

It's really significant to improve the maintainability of code, as well as the efficiency and resrationality of division of work from both front-end and back-end in the whole web development phase. In the section below, a evolution of the technical architecture will reveal how these problems are solved.

WEB 2.0

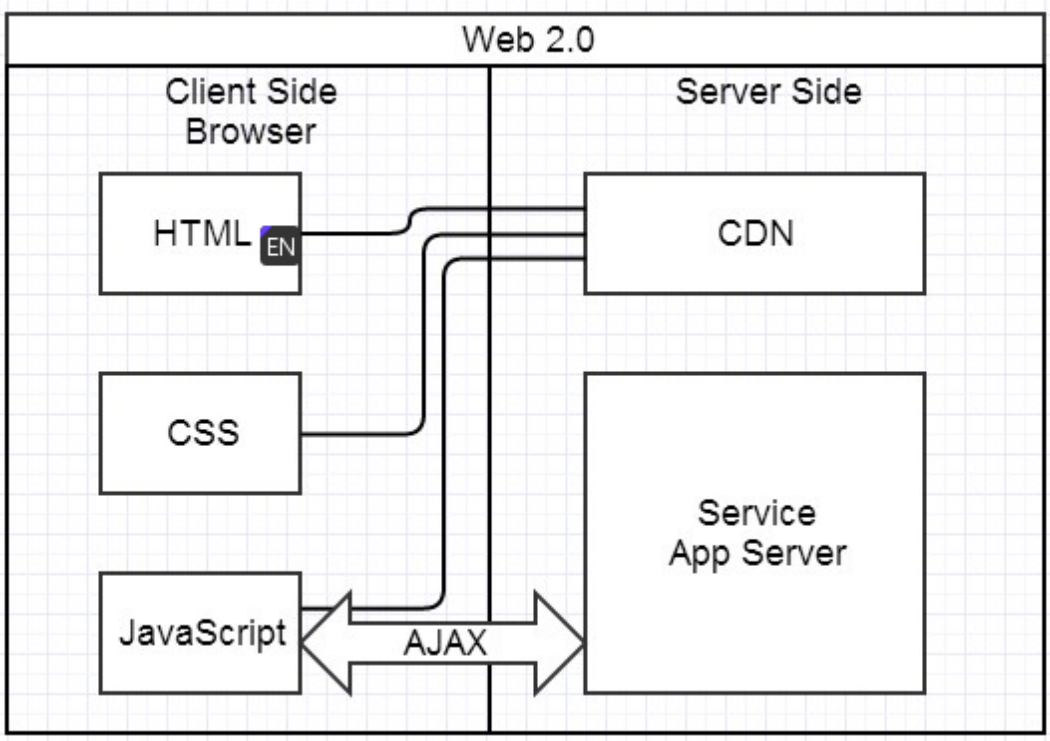
Along with the birth of Gmail[1] in 2004, which is noted for its pioneering use of Ajax, the web application started to behave more interactively. Browser began to take over the job of data fetching, processing, rendering, such a sequence of workflow which could only be done by the server side formerly.

The architecture in Web 2.0 generation is presented in figure 2.2.

By using Ajax, the client has the ability to fetching data stream asynchronously, after which the client will consume the data and render it into the specific section of view. Usability was dramatically improved, because the entired view represented to users will

[1] https://mail.google.com/

Figure 2.2.: Web 2.0 architecture



not be refreshed and the front-end is able to process and render data in its own intension, which means more flexible control of the consumption of data.

SINGLE PAGE APP

With the evolution of web technologies and promotion of these technologies in modern browswers by brower vendors, a new web development model called SPA was proposed and caught the developers' eye. The back-end is no more responsible for rendering and view controling, it only take charge of providing services for the front-end.

The structure in figure 2.3 shows that the client side has the full control of view rendering and data consumption after data acquisition through web services which is released by back-end with promised protocol. All rendering tasks was stripped off from the server side, which means that the server side achieves more efficiency and concentrate more on the core bussiness logics.

But more responsibility in front-end means more complexity. How to reduce the complexity and increace the maintainability of a front-end project becomes a significant problem. Developers come up with an new envolved variant of SPA as demonstrated in figure 2.4.

In general, the architecture is componentized and layered into template, controller and model. Each component is isolated and has its own view as well as correlated logics. Front-end frameworks like EmberJS, AngularJS, ReactJS are providing such a approach and development pattern for developers to build modern web apps. With this approach, a giant and complex front-end app is broken up into fine grained components, therefore, components are easy to reuse if the components are well abstrated in a proper way. In addition, the maintaince of each component is also effortless.

Figure 2.3.: SPA architecture

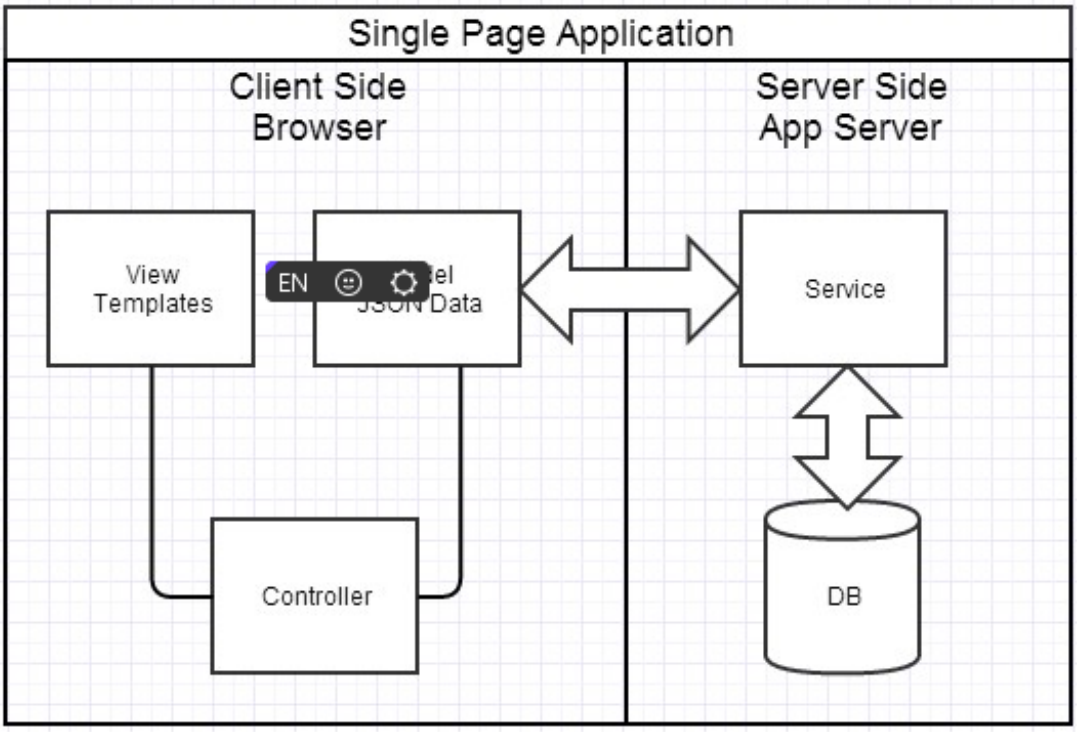
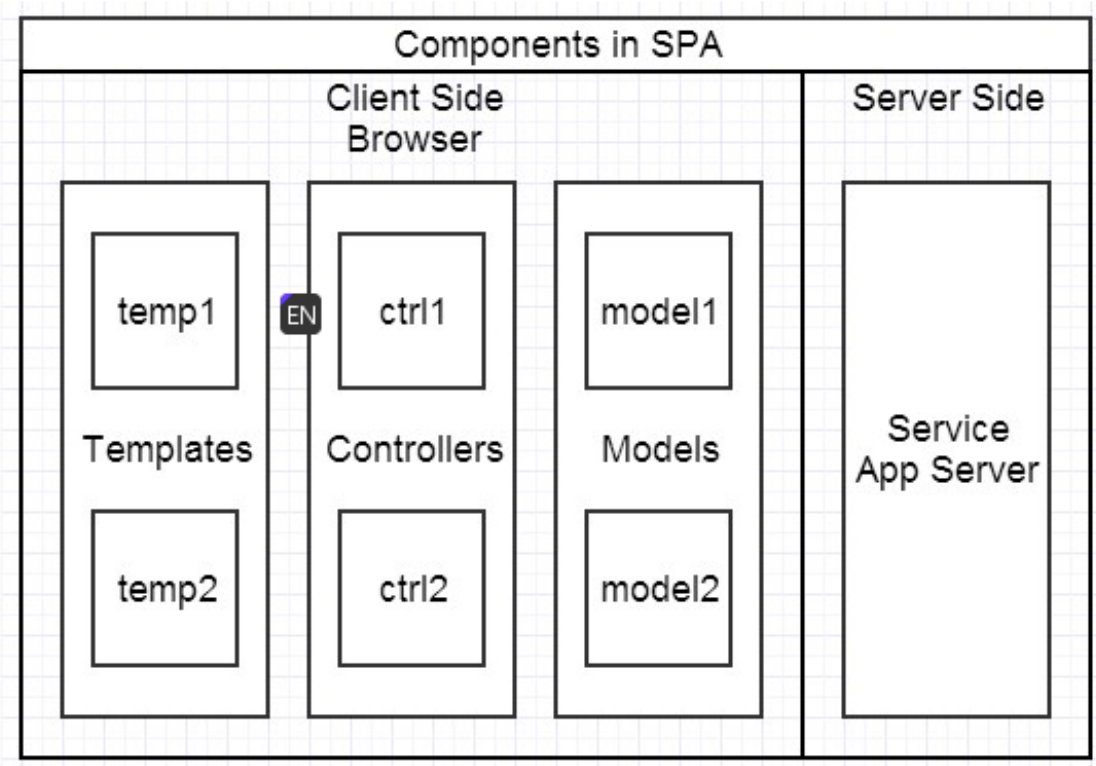


Figure 2.4.: Components in SPA



TRADE-OFF

In summarize, a single-page app has a lot of benefits:

1. Rational seperation of works from front-end and back-end: client takes charge of view rendering and data representation, as well as slight data processing if needed; the server focus on providing services of the core logics, persistance of data, and also computational tasks.
2. High interactivity and user experience in client side: asynchronous data fetching and view rendering implies no more need of hard reloading the page which user is viewing and the current states of the page could also be preserved.
3. Efficiency in server side: rendering tasks are stripped off from server side.
4. Ubiquity: with the seperation of services provided by server side, not only the web browser but also other clients in other platforms such as Android, iOS apps are able to access and comsume the services.

But SPA also has its deficiencies:

1. SEO unfriendly: because the page are not directly rendered by server side, and the web crawlers are not able to run JavaScript codes like a browser does, the site could not be crawled properly under normal circumstances. So if SEO results really matter for the app, SPA is obviously not the best choice.
2. Excessive http connections: all the data is acquired from different services through diversed APIs, thus multiple HTTP connections are established and performed parallelly, whose initial time of connections for partial data could be much more than a single connection in the traditional way. So it's highly needed to merge the services and find a balance between data model complexity and time consumption.

2.1.2. RESTFUL INTERFACE

REST is a simple way to organize interactions between independent systems. It's been growing in popularity since 2005, and inspires the design of services, such as the Twitter API. This is due to the fact that REST allows you to interact with minimal overhead with clients as diverse as mobile phones and other websites. In theory, REST is not tied to the web, but it's almost always implemented as such, and was inspired by HTTP. As a result, REST can be used wherever HTTP can.

The alternative is building relatively complex conventions on top of HTTP. Often, this takes the shape of entire new XML-based languages. The most illustrious example is SOAP. You have to learn a completely new set of conventions, but you never use HTTP to its fullest power. Because REST has been inspired by HTTP and plays to its strengths, it is the best way to learn how HTTP works.

URLS

URLs are how you identify the things that you want to operate on. We say that each URL identifies a resource. These are exactly the same URLs which are assigned to web pages. In fact, a web page is a type of resource. Let's take a more exotic example, and consider our sample application, which manages the list of a company's clients:

- /clients: will identify all clients

- /clients/jim: will identify the client, named 'Jim', assuming that he is the only one with that name.

In these examples, we do not generally include the hostname in the URL, as it is irrelevant from the standpoint of how the interface is organized. Nevertheless, the hostname is important to ensure that the resource identifier is unique all over the web. We often say you send the request for a resource to a host.

Finally, URLs should be as precise as needed; everything needed to uniquely identify a resource should be in the URL. You should not need to include data identifying the resource in the request. This way, URLs act as a complete map of all the data your application handles.

HTTP VERBS

HTTP verbs tell the server what to do with the data identified by the URL. The request can optionally contain additional information in its body, which might be required to perform the operation - for instance, data you want to store with the resource.

If you've ever created HTML forms, you'll be familiar with two of the most important HTTP verbs: GET and POST. But there are far more HTTP verbs available. The most important ones for building RESTful API are GET, POST, PUT and DELETE. Other methods are available, such as HEAD and OPTIONS, but they are more rare (if you want to know about all other HTTP methods, the official source is IETF).

2.2. GRAPHICS ON THE WEB

2.2.1. CANVAS

The canvas element is an element defined in HTML code using width and height attributes. The real power of the canvas element, however, is accomplished by taking advantage of the HTML5 Canvas API. This API is used by writing JavaScript that can access the canvas area through a full set of drawing functions, thus allowing for dynamically generated graphics.

Every HTML5 canvas element must have a context. The context defines what HTML5 Canvas API you'll be using. The 2d context is used for drawing 2D graphics and manipulating bitmap images. The 3d context is used for 3D graphics creation and manipulation. The latter is actually called WebGL and it's based on OpenGL ES.

The Canvas coordinate system, however, places the origin at the upper-left corner of the canvas, with X coordinates increasing to the right and Y coordinates increasing toward the bottom of the canvas. So unlike a standard Cartesian coordinate space, the Canvas space doesn't have visible negative points. Using negative coordinates won't cause your application to fail, but objects positioned using negative coordinate points won't appear on the page.

2.2.2. SVG

SVG is an XML language, similar to XHTML, which can be used to draw graphics, such as the ones shown to the right. It can be used to create an image either by specifying all the lines and shapes necessary, by modifying already existing raster images, or by a combination of both. The image and its components can also be transformed, composited together, or filtered to change their appearance completely.

SVG came about in 1999 after several competing formats had been submitted to the W3C and failed to be fully ratified. While the specification has been around for quite a while, browser adoption has been fairly slow, and so there is not a lot of SVG content

being used on the web right now (as of 2009). Even the implementations that are available often are not as fast as competing technologies like HTML5 Canvas or Adobe Flash as a full application interface. SVG does offer benefits over both implementations, some of which include having a DOM interface available for it, and not requiring third-party extensions. Whether or not to use it often depends on your specific use case.

HTML provides elements for defining headers, paragraphs, tables, and so on. In much the same way SVG provides elements for circles, rectangles, and simple and complex curves. A simple SVG document consists of nothing more than the <svg> root element and several basic shapes that build a graphic together. In addition there is the <g> element, which is used to group several basic shapes together.

There are a number of drawing applications available such as Inkscape which are free and use SVG as their native file format. However, this tutorial will rely on the trusty XML or text editor (your choice). The idea is to teach the internals of SVG to those who want to understand it, and that is best done by dirtying your hands with a bit of markup. You should note your final goal though. Not all SVG viewers are equal and so there is a good chance that something written for one app will not display exactly the same in another, simply because they support different levels of the SVG specification or another specification that you are using along with SVG (that is, JavaScript or CSS).

SVG is supported in all modern browsers and even a couple versions back in some cases. A fairly complete browser support table can be found on Can I use. Firefox has supported some SVG content since version 1.5, and that support level has been growing with each release since. Hopefully, along with the tutorial here, MDN can help developers keep up with the differences between Gecko and some of the other major implementations.

2.2.3. COMPARISION

HTML5 Canvas is simply a drawing surface for a bit-map. You set up to draw (Say with a color and line thickness), draw that thing, and then the Canvas has no knowledge of that thing: It doesn't know where it is or what it is that you've just drawn, it's just pixels. If you want to draw rectangles and have them move around or be selectable then you have to code all of that from scratch, including the code to remember that you drew them.

SVG on the other hand must maintain references to each object that it renders. Every SVG/VML element you create is a real element in the DOM. By default this allows you to keep much better track of the elements you create and makes dealing with things like mouse events easier by default, but it slows down significantly when there are a large number of objects

Those SVG DOM references mean that some of the footwork of dealing with the things you draw is done for you. And SVG is faster when rendering really large objects, but slower when rendering many objects.

A game would probably be faster in Canvas. A huge map program would probably be faster in SVG. If you do want to use Canvas, I have some tutorials on getting movable objects up and running here.

Canvas would be better for faster things and heavy bitmap manipulation (like animation), but will take more code if you want lots of interactivity.

I've run a bunch of numbers on HTML DIV-made drawing versus Canvas-made drawing. I could make a huge post about the benefits of each, but I will give some of the relevant results of my tests to consider for your specific application:

I made Canvas and HTML DIV test pages, both had movable "nodes." Canvas nodes were objects I created and kept track of in Javascript. HTML nodes were movable Divs.

I added 100,000 nodes to each of my two tests. They performed quite differently:

The HTML test tab took forever to load (timed at slightly under 5 minutes, chrome asked

to kill the page the first time). Chrome's task manager says that tab is taking up 168MB. It takes up 12-13% CPU time when I am looking at it, 0

The Canvas tab loaded in one second and takes up 30MB. It also takes up 13% of CPU time all of the time, regardless of whether or not one is looking at it. (2013 edit: They've mostly fixed that)

Dragging on the HTML page is smoother, which is expected by the design, since the current setup is to redraw EVERYTHING every 30 milliseconds in the Canvas test. There are plenty of optimizations to be had for Canvas for this. (canvas invalidation being the easiest, also clipping regions, selective redrawing, etc.. just depends on how much you feel like implementing)

There is no doubt you could get Canvas to be faster at object manipulation as the divs in that simple test, and of course far faster in the load time. Drawing/loading is faster in Canvas and has far more room for optimizations, too (ie, excluding things that are off-screen is very easy).

2.3. REAL-TIME COMMUNICATION

2.3.1. LONG POLL

Creates connection to server like AJAX does, but keep-alive connection open for some time (not long though), during connection open client can receive data from server. Client have to reconnect periodically after connection is closed due to timeouts or data eof. On server side it is still treated like HTTP request same as AJAX, except the answer on request will happen now or some time in the future defined by application logic. Supported in all major browsers.

2.3.2. WEBSOCKETS

Create TCP connection to server, and keep it as long as needed. Server or client can easily close it. Client goes through HTTP compatible handshake process, if it succeeds, then server and client can exchange data both directions at any time. It is very efficient if application requires frequent data exchange in both ways. WebSockets do have data framing that includes masking for each message sent from client to server so data is simply encrypted.

2.3.3. WEBRTC

Transport to establish communication between clients and is transport-agnostic so uses UDP, TCP or even more abstract layers. By design it allows to transport data in reliable as well as unreliable ways. This is generally used for high volume data transfer such as video/audio streaming where reliability - is secondary and few frames or reduction in quality progression can be sacrificed in favour of response time and at least delivering something. Both sides (peers) can push data to each other independently. While it can be used totally independent from any centralised servers it still require some way of exchanging endPoints data, where in most cases developers still use centralised servers to "link" peers. This is required only to exchange essential data for connection establishing - after connection is established server on aside is not required.

2.3.4. ADVANTAGES

Main advantage of WebSockets for server, is that it is not HTTP request (after handshake), but proper message based communication protocol. That allows you to achieve huge per-

formance and architecture advantages. For example in node.js you can share the same memory for different socket connections, so that way they can access shared variables. So you don't need to use database as exchange point in the middle (like with AJAX or Long Polling and for example PHP). You can store data in RAM, or even republish between sockets straight away.

2.3.5. SECURITY CONSIDERATIONS

People often are concerned regarding security of WebSockets. Reality is that it makes little difference or even puts WebSockets as better option. First of all with AJAX there is a higher chance of MITM as each request is new TCP connection and traversing through internet infrastructure. With WebSockets, once it's connected it is far more challenging to intercept in between, with additionally enforced frame masking when data is streamed from client to server as well as additional compression, that requires more effort to probe data. All modern protocols support both: HTTP and HTTPS (encrypted).

2.4. FRONT-END TECHNOLOGIES

2.4.1. EMBER.JS

Ember.js is a popular framework that utilizes a MVC framework composed of views in the form of handlebars templates. In this section, note that there is a bit of work to do in order to facilitate the integration of the templates, models, and controllers. This is not to say that Ember.js is a bad framework, because modification is a byproduct of such a framework.

In Listing 1-1, which is the body of the TodoMVC Ember.js example, you see that the markup consists of two handlebars templates for the to-do list and the to-dos.

Along with these there are three controllers—an app.js entry point, a router, and a todo input view component. That seems like a lot of files, but in a production environment, that would be minimized. Note the separation of the controllers and views. The views, including the to-do list view shown in Listing 1-2, are quite verbose and make it easy to determine what the code does.

This is a clear example and works as a readable view. There are several properties that are dictated from the controller as you would expect. The controller is named in the router.js file, which also names the view to be used. This controller is shown in the Listing 1-3.

You can see that this TodosListController takes a model of to-dos and adds some properties along with the itemController of 'todo'. This todo controller is actually where most of the JavaScript resides that dictates the actions and conditionals that are visible in the view you saw earlier in this section. As someone who is familiar with Ember. js, this is a well defined and organized example of what Ember.js can do. It is however quite different than React, which you will see soon enough. First, let's examine a bit of the AngularJS TodoMVC example.

2.4.2. ANGULARJS

AngularJS is perhaps the world's most popular MV* framework. It is extremely simple to get started and has the backing of Google along with many developers who have jumped in and created great tutorials, books, and blog posts. It is of course not the same framework as React, which you will soon see. Listing 1-4 shows the AngularJS TodoMVC application.

You can see already that compared to Ember.js, Angular is more declarative in nature in its templating. You can also see that there are concepts like controllers, directives, and services that are tied to this application. The todoCtrl file holds the controller values that

power this view. The next example, shown in Listing 1-5, is just a snippet of this file, but you can see how it works.

This example showcases the todoCtrl and shows how it builds a $scope mechanism that then allows you to attach methods and properties to your AngularJS view. The next section dives into React and explains how it acts on a user interface in a different way than Ember.js and AngularJS do.

2.4.3. REACT

As you saw in the other examples, there is a basic structure to the TodoMVC applications that makes them an easy choice for demonstrating differences. Ember.js and AngularJS are two popular frameworks that I think help demonstrate that React is not an MV* framework and just a basic JavaScript framework for building user interfaces. This section details the React example and shows you how to structure a React app from the component level, and then works backward to explain how the components are composed. And now, many pages into a book about React, you finally get to see React code in Listing 1-6.

In this example, you see the rendering of the TodoItem component, which is a subcomponent of the TodoApp. This is simply a component that handles the individual list 14

items that are contained in the TodoApp. This is split off into its own component because it represents its own set of interactions in the application. It can handle editing as well as marking if the item is completed or not. Since this functionality doesn't necessarily need to know or interact with the rest of the application, it is built as a standalone component. It may have been just as easy to add to the TodoApp itself initially, but in the world of React, as you will see later, it is often better to make things more modular. This is because in the future the maintenance costs will be recouped by utilizing this logical separation of interactions. Now you understand at a high level how interactions can often be contained in subcomponents in a React application. The code of the TodoApp render function shows that the TodoItem exists as a subcomponent and shows that the TodoFooter, contained in a JSX by itself, houses its own interactions. The next important concept is to focus on how these subcomponents are reassembled. The TodoItems are added to an unordered list that is contained in a variable called main, which returns the JSX markup for the main section of the TodoApp. Similarly the footer variable contains the TodoFooter component. These two variables, footer and main, are added to the return value of the TodoApp, which you see at the end of the example. These variables are accessed in JSX by using curly braces so you see them as follows:

2.4.4. WHY REACT.JS

In many cases when you learn something, you first need to realize what the thing is that you are learning. In the case of React, it can be helpful to learn which concepts are not parts of the React framework. This will help you understand which standard practices you have learned need to be unlearned, or at least need to be set aside, in order to fully understand the concepts of a new framework such as React. So what is it that makes React different and why is it important?

Many argue that React is a full-scale JavaScript framework on a level that compares to other frameworks such as Backbone, Knockout.js, AngularJS, Ember, CanJS, Dojo, or any of the numerous MVC frameworks that exist. Figure 1-1 shows an example of a typical MVC framework.

Figure 1-1 shows the basics of each of the components in a Model-View-Controller architecture. The model handles the state of the application and sends state-changing events to the view. The view is the user-facing look and interaction interface to the end user. The view can send events to the controller, and in some cases to the model. The controller

is the main dispatcher of events, which can be sent to the model, to update state, and the view to update the presentation. You may note that this is a generic representation of what an MVC architecture is, and in reality there are so many variants and customized implementations that there is no single MVC architecture. The point isn't to state what an MVC structure looks like, but to point out what React is not.

This MVC structure is actually not a fair assessment of what React is or intends to be. That is because React is one particular piece of what these frameworks present. React is in its simplest form, just the view of these MVC, MVVM, or MV* frameworks. As you saw in the previous section, React is a way to describe the user interface of an application and a mechanism to change that over time as data changes. React is made with declarative components that describe an interface. React uses no observable data binding when building an application. React is also easy to manipulate, because you can take the components you create and combine them to make custom components that work as you expect every time because it can scale. React can scale better than other frameworks because of the principles that drove it from its creation. When creating React interfaces, you structure them in such as way that they are built out of multiple components.

Let's pause for a minute and examine the most basic structure of several frameworks and then compare them to React in order to highlight the differences. For each of the frameworks, you will examine the most basic to-do list applications as they are created for the http://todomvc.com web site. I am not going to deride other frameworks because they all serve a purpose. Instead I attempt to demonstrate how React is structured compared to the others. I showcase just the important parts to highlight and limit a complete recreation of the application here. If you want to see the full examples, the links to the source are included. Try not to become too focused on the implementation details of any of these examples, including the React example, because as you progress through this book the concepts will be covered thoroughly and will help you understand what is going on completely.

2.5. CONCLUSION

TBD

3. REQUIREMENTS

Before starting to concept the graphical discuss system, it's necessary to analyse requirements and objectives behind the origin motivation in the first place. It should be defined at first, what kind of functionalities should be achieved and how the system behaves.

3.1. BASIC FUNCTIONALITIES

As a graphical discuss system for the educational purpose, the system should contain basic functionalities on the prototype of a forum which could be organized by classes. So class management, question management and answer management are the three essential parameters to be designed at the start.

3.1.1. COURSE MANAGEMENT

Each question should have a certain domain of its content, so the questions are organized by classes initially. The features of course management should be:

1. Create Course: The user who is identified as a tutor is able to create course and maintain the course he created. While creating the course, the tutor can define the name of the course and upload an image as a background of the course for better recognization. In addition, concret description of the course could also be added to the description area.

2. Search Course: After a course is created, a corresponding unique identifier code for the course will be generated at the same time. The students are able to find the course through the identifier code.

3. Favor Course: If a student is interest to a certain course, he is capable to add the course to his favor list so that it's easy to find and access the course he liked later.

3.1.2. QUESTION MANAGEMENT

1. Submit/Edit/Withdraw Question: The student who has confusion with the teaching content can submit his own question with detailed description in a certain course. The user is also permitted to edit the question if he want to add more precise informations or modify the unclarity he made to the question. Withdrawing of his own question is also possible, but only when there're no contributes made to the question.

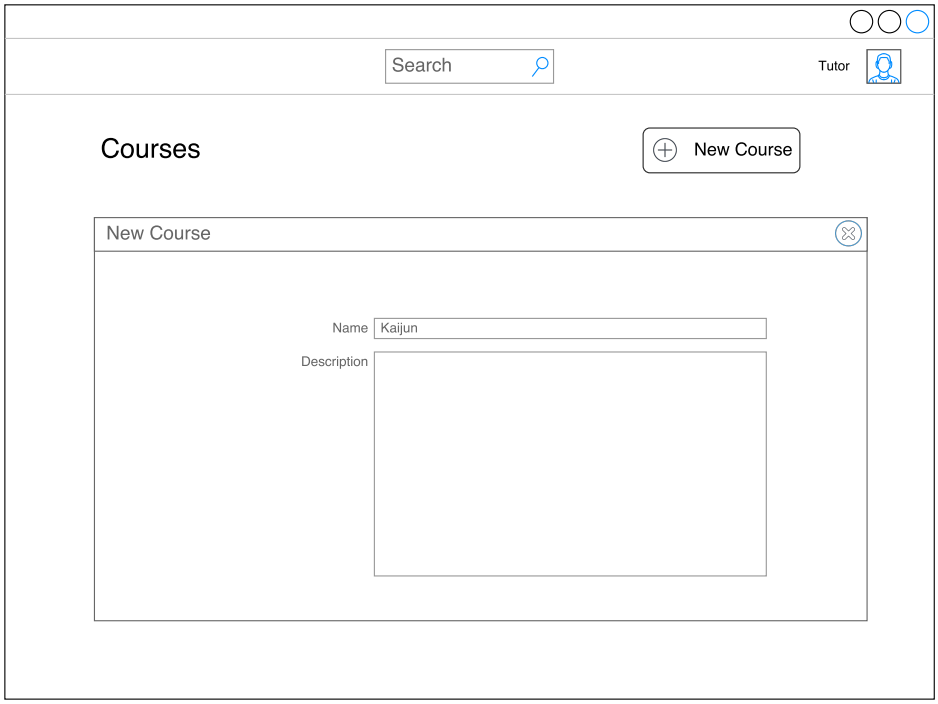


Figure 3.1.: Submit a new course

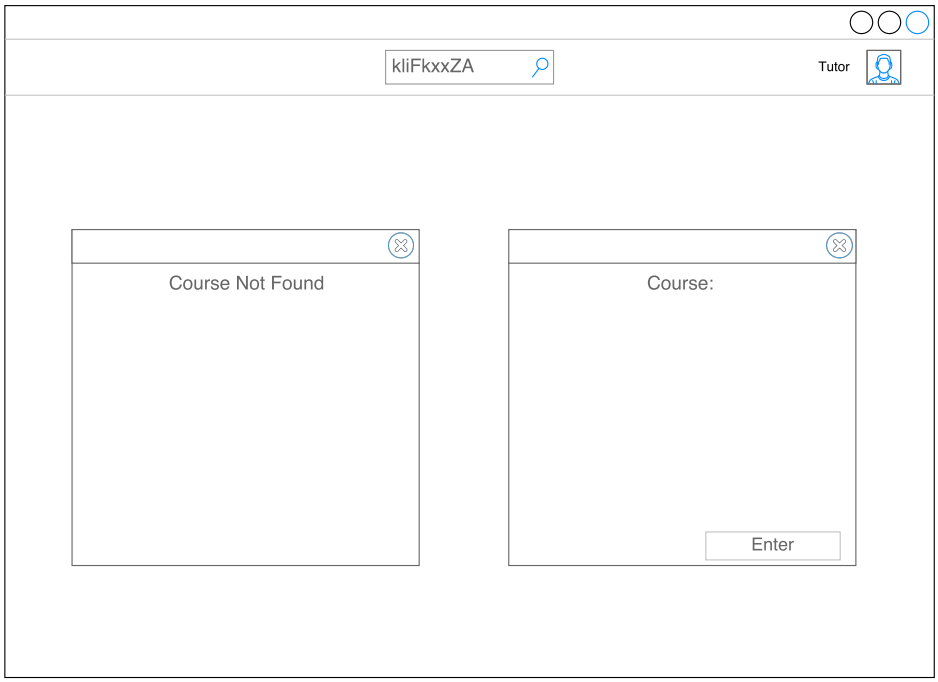


Figure 3.2.: Search course with code

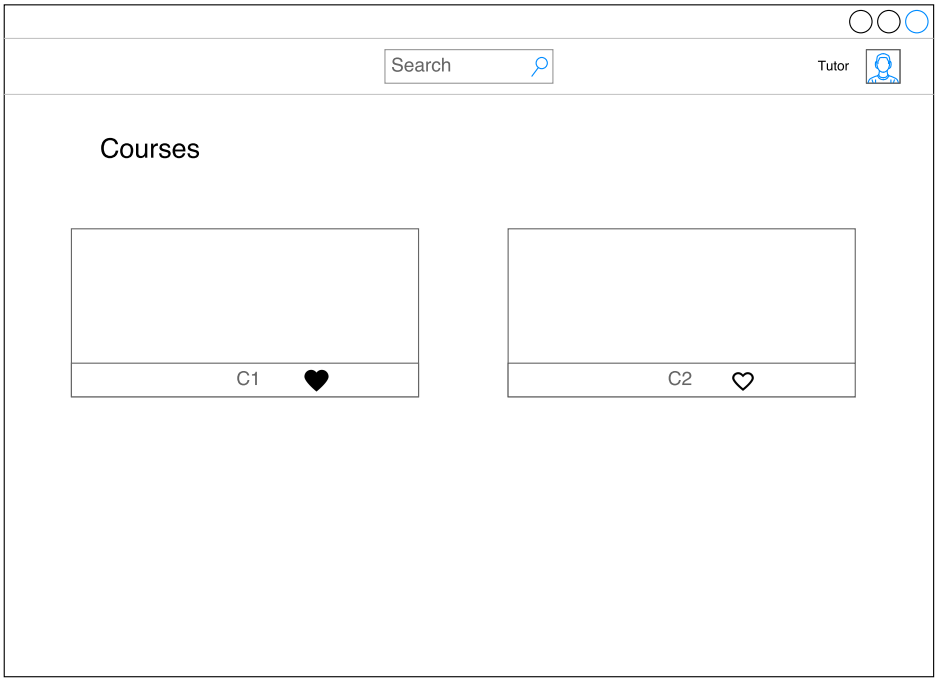


Figure 3.3.: Favor course

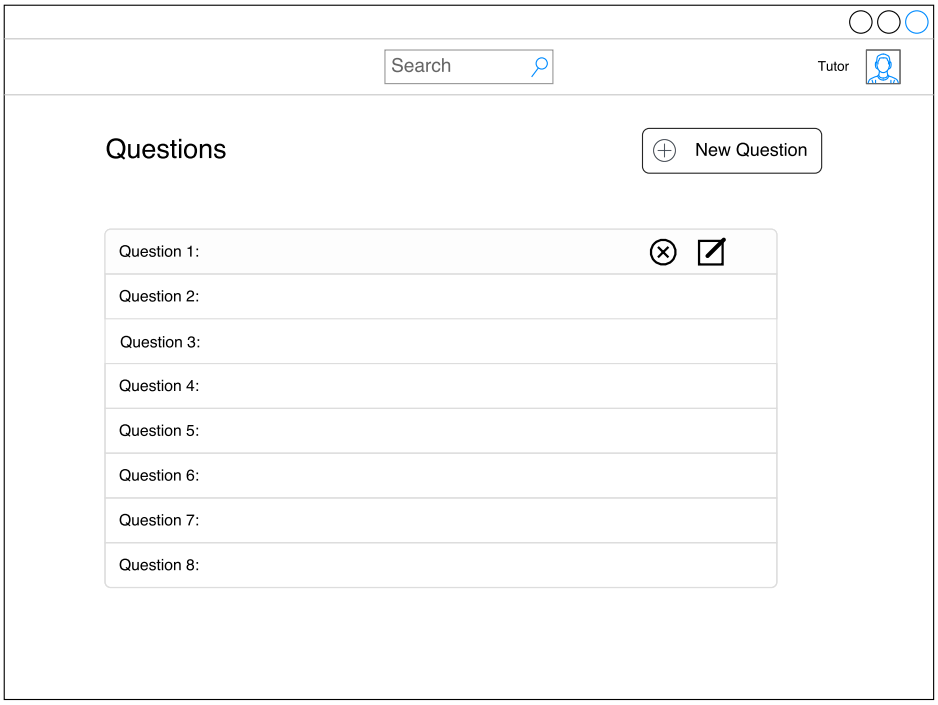


Figure 3.4.: Submit a new question; withdraw or modify own question

2. **Upvote/Downvote Question**: An assessment of a question is decisive for building a better community with high-quality contents. So the user is able to upvote or downvote of a question and determine if the question is helpful for other members in the community or not.

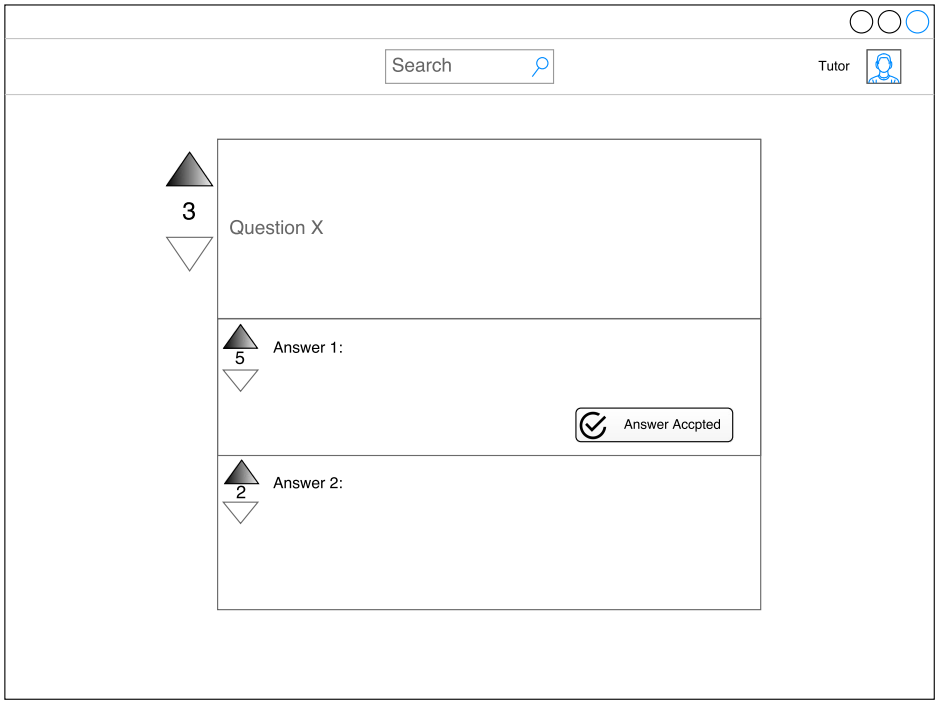


Figure 3.5.: Upvote/Downvote a question or answer

3. **Favor Question**: If the student consider the question as a helpful and useful content and want to review this question in the future, he can favor the question and locate it in a certain list.

4. **Accept Answer**: The owner of the question has the right to accept the most useful answer in his opion which will be shown up at the top of the answer list.

3.1.3. ANSWER MANAGEMENT

1. **Submit/Modify/Remove Answer**: User who has experence with the question can submit his answer to the question. After the submission, the modification or removal of the user's own question is possible.

2. **Upvote/Downvote Answer**: As mentioned above in section of question functionality, a similar idea of assessment should also be applied to answers. Answer with higher vote will be listed at first.

3. **Quote Answer**: Answers are able to be quoted so that the user can supplement informations on the top of original post or point out the deficiency of the contribute.

3.2. HIGH INTERATIVITY

Building with the basic functionalities is far not enough. To fit the system for educational purpose and improve the interactivity for arousing enthusiasm of students, a drawing tool and realtime functionality should be intergrated into the system.

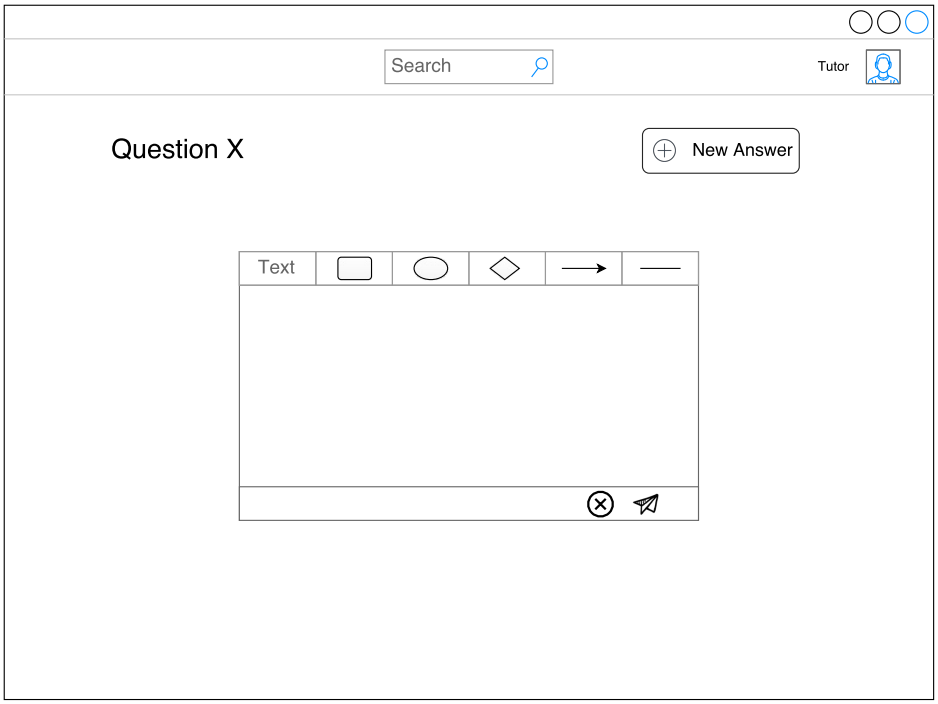


Figure 3.6.: Submit a new answer

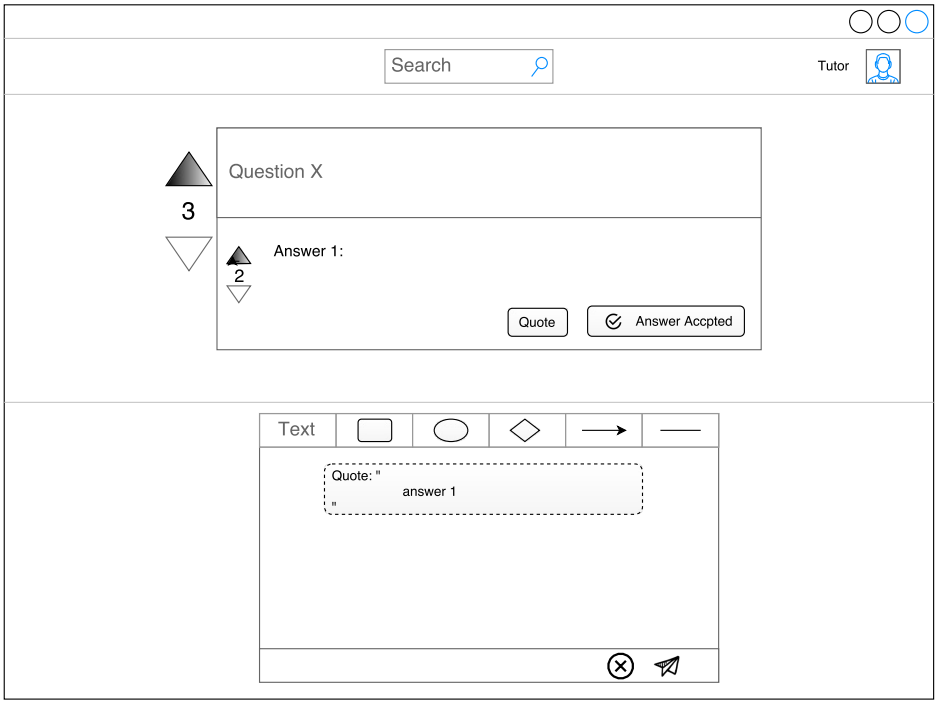


Figure 3.7.: Quote an answer

3.2.1. DRAWING TOOL

Normally, some of the thoughts can't be simply expressed by textual description, so a drawing tool should be designed to enables the user to compose not only text but also different components such like rectangle, circle, line and so on, which helps the user to express his question more precisely. The ideal drawing tool should have following features:

1. Drawing Diverse Components: Not only text but also diverse components could be drawn while posting a contribution. Styling of a component such as size tuning, color changing is also the essential, which will helps emphasize the important part the user expressing.
2. Drawing History: During drawing, the user might make mistakes or change mind after placing a component or text. So a history list of drawing actions bundled with undo and redo functionalities will dramatically improve the usability of drawing process.

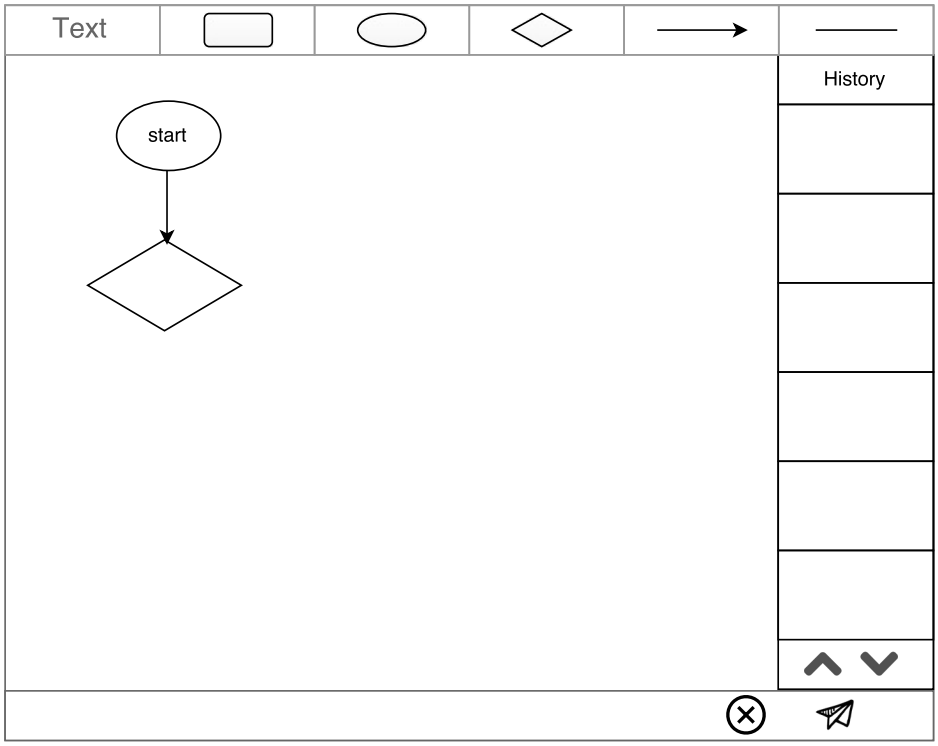


Figure 3.8.: Drawing editor with drawing history

3.2.2. REALTIME

How to ease the approach of content acquisition and improve the interactivity for arousing enthusiasm of students, is also a key point while designing the discuss system. So two major realtime functionalities are featured as follow:

1. Realtime Question List: Without requesting the question list initiatively, all new questions posted by other users will be pushed to user automatically. The user doesn't have to concern himself with acquisition of the new content anymore.
2. Realtime Answer Ordering: Without refreshing the page, the answers will be re-ordered as new vote action is triggered.

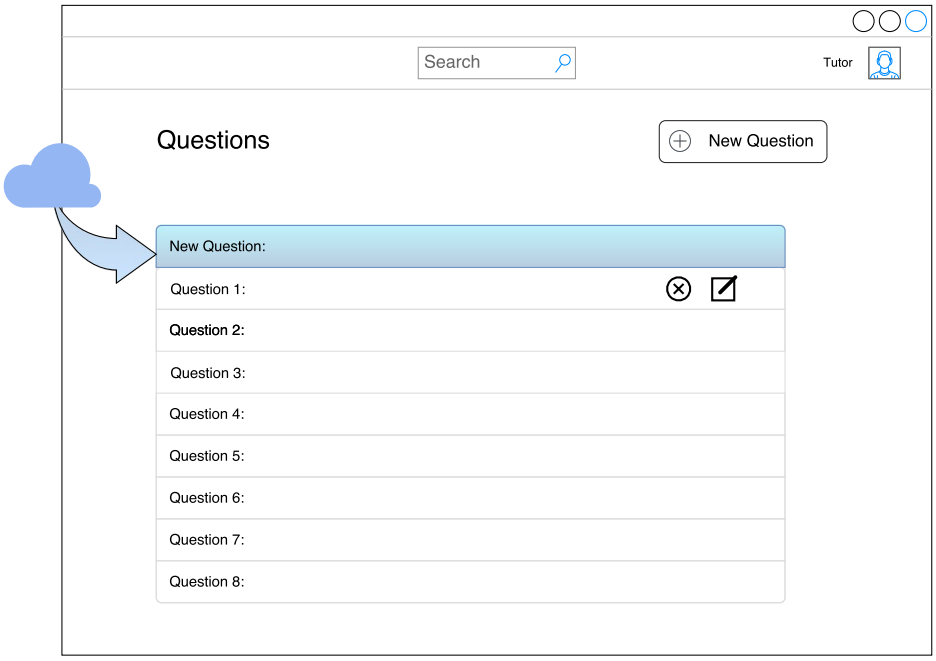


Figure 3.9.: Notify with new question automatically

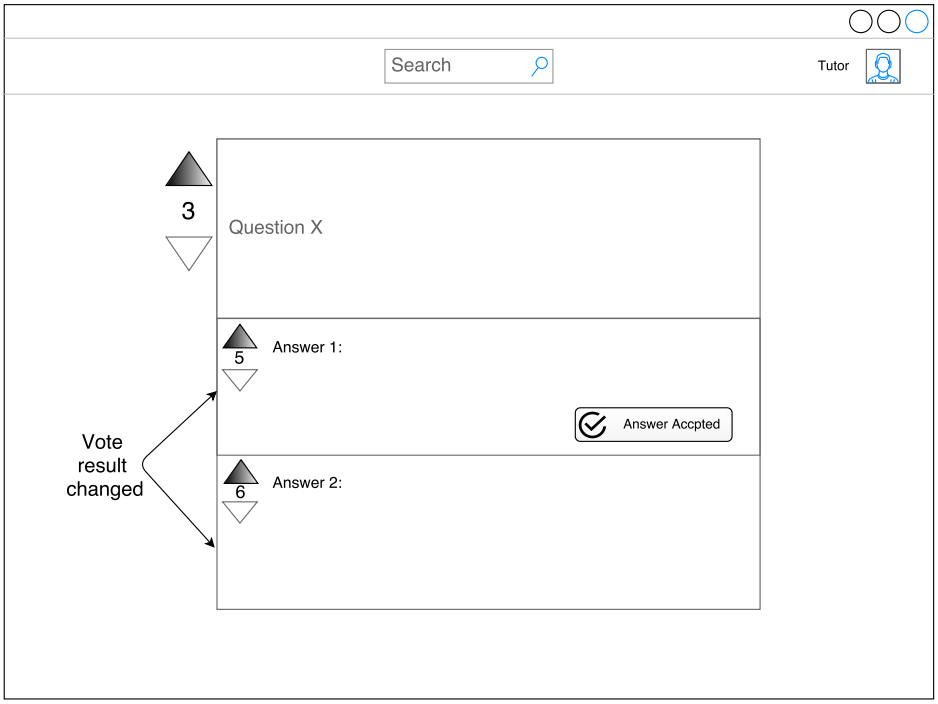


Figure 3.10.: Anto re-order answer if vote contributions changed

4. CONCEPTION

!!! In this chapter a conception of the discuss system including both client and server side will be described. In the first section, all the essential requirements are presented. After that, the general conception or workflow of the application will be proposed. The more concrete details and definitions of the conception will also be outlined. In addition, the focal points behind the conception and the proper solutions of the difficulties will be illustrated.

4.1. GENERAL CONCEPT

Before the whole conception of the system, a general conceptual architecture of the system should be defined initially. In order to help understanding how the system works, the primary data flow between different domains will also be described.

4.1.1. ARCHITECTURE

According to the analysis result of Single-Page-App in chapter 2, and considering the demand on high interactivity and ubiquity as well as scalability in the graphical discuss system, leveraging SPA architecture will benefit a lot and accelerate the implementation of the system.

In general, the entire system will be divided into two parts: namely client and server-side. Each side is basically full independent to the other and has its own responsibility.

- Client: The client is totally responsible for initial view rendering and view re-rendering as the view model changes.
- Server: The server is in charge of core business logic, data processing, data persistence and also provides the client interfaces for data acquisition.

General architecture of the system is described in figure 4.1, the only bridge between the client and server-side is data transmission service. Complete separation of both sides will also accelerate the development flow in implementation phase. Once the protocol of data transmission services is fully confirmed and defined, development of each side is able to performed parallelly. Furthermore, technical choices on both sides are more flexible. Both sides are able to apply the technologies which fit them most without coupling to each other, the only thing they should obey is to follow the protocol of data transmission.

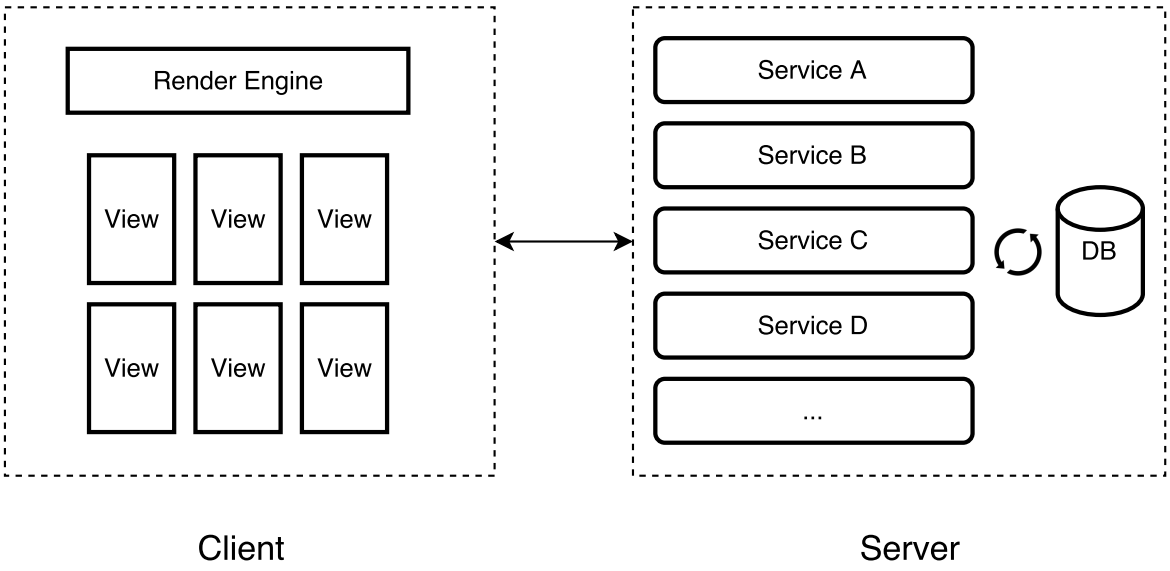


Figure 4.1.: General architecture in conception

4.1.2. COMMUNICATION

As mentioned above in section 4.1.1, data communication is the only coupling factor in the general architecture. In this system, there exist two different type of protocols: standard HTTP using REST architecture and WebSocket with persistent connection. Each data transmission protocol has its own responsibility and usage scenario.

- HTTP with REST architecture: Data which is requested initiatively is transferred over HTTP. The HTTP connection will be closed as soon as the data is successfully transferred.
- WebSocket with persistent connection: Reactive data with realtime need is transferred over WebSocket. After the persistent connection is established, client are able to receive the data at the first moment as the state of data is updated.

As figure 4.2 shows, in case data for view model is acquired from server despite transferred over HTTP or WebSocket, the views are re-rendered. Comparing with HTTP, the specialty of data acquisition over WebSocket is: a listener for specific resource with unified process of data processing and automatic view re-rendering will be created.

4.2. DATA

Definition In this section, data modelling of the system including definitions of data domain, data fields for each domain, and relation between domains will be performed in the first place. In the following subsection, APIs corresponding to related operations on data models will be assigned.

4.2.1. GENERAL DATA MODEL

DATA DOMAIN

In general, data in the system could be divided into 4 primary domains:

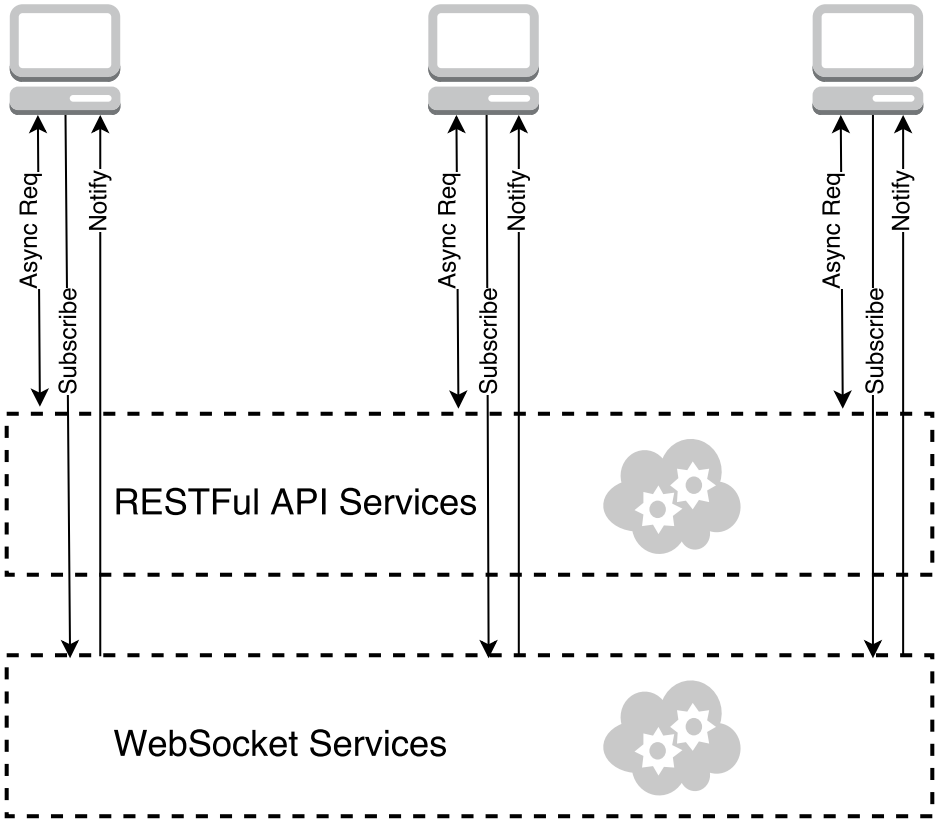


Figure 4.2.: General data communication

- **User**: personal information as well as user identifier for accessing the system.
- **Course**: a container with own course information as well as collection of questions classified to this context.
- **Question**: data with information of questions submitted by users.
- **Answer**: data with information of answers, also has graphical data within the data model.

Users are able to assess the contributions made by other users and mark it as useful or useless, which will affect the contributions' oder priority while rendering the views. Voters should also be aware of what kind of vote he has marked to the contribution. Therefore, additional 2 data models **VoteAnswer** and **VoteQuestion** should also be considered.

The relation between domains is illustrated in the following figure 4.3. Each data modal has an unique identifier, which is referenced in another data model when they have a connection.

DATA FIELDS

More detailed definition and description of fields in each data model should be made for a better understanding of the structure as well as behaviour of a data model. Tabel ?? describes key fields of general domains.

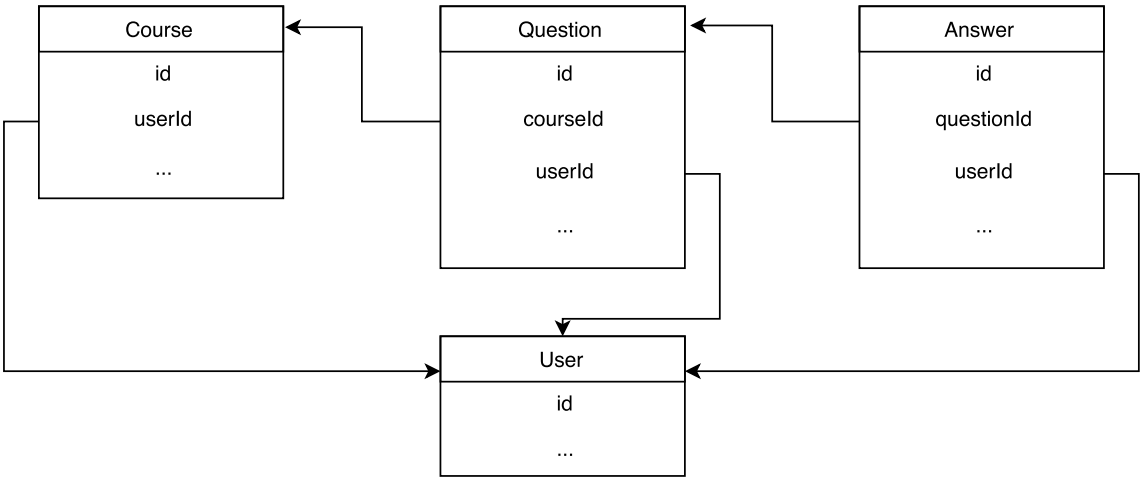


Figure 4.3.: Relations between data domains

Domain	Field	Description
User	email	unique identifier of an user for authentification, also as contact way to user.
	password	string for user authentication to prove identity or access approval
	username	user identifier shown to other users
	isTutor	flag which determines if the user is a student or tutor
Course	name	name of the course
	desc	description of the course
	creator	id of the user(tutor) who created this course
	code	unique code for quick search purpose which is generated automatically as the course is created
Question	title	title of the question
	content	content of the question
	course	id of the the course to which the question belongs
	vote	vote count of the question
	creator	id of the user who submitted this question
Answer	content	content of the answer
	question	id of the question for which the answer is made
	quoted	id of the original question which is quoted
	vote	vote count of the answer
	creator	id of the submitter
Vote	type	enum values of up-voting or down-voting actions
	handler	id of the hander
	question/answer	id of the question/answer to which the vote action is applied

Table 4.1.: Fields for Each Data Domain

4.2.2. RESTFUL API DEFINITIONS

As mentioned in section xxx, RESTful architecture is a an excellent technical choice for data transferring. Because of its simplicity and clear semantic description of HTTP methods comparing to other protocols such like SOAP, it will dramatically simplify and clarify our data transmission services.

MAPPING OF HTTP METHODS TO DATA MODEL BEHAVIOUR

The data model defined above can directly map to the definition of resources in RESTful. The HTTP methods on each resource domain can also represent the data model behaviours, *User Model* is taken as an example:

Method	Operation of data model collection
GET	Query and return a specific user from user model collection.
POST	Create a new user entry and insert into user model collection.
PUT	Update a specific user in user model collection.
DELETE	Delete a specific user in user model collection.

Table 4.2.: HTTP methods on User resource

In table ??, resource entry in persistent storage can be executed with specific action while requesting resource URI through different HTTP methods. A semantic description of connection between CRUD and HTTP methods on RESTful will make the data transmission services more understandable and unified.

GENERAL RESTFUL API DEFINITIONS

Requesting a specific resource can only succeed through its URI, through which the client and server-side could connect to each other actually. Therefore, a definition of APIs which describes URI of the resources and its functional responsibility should be proposed in the first place.

- User Authentication: the major actions of user authentication include signup, login, logout. To protect the user information, POST method which doesn't expose information via the URL, is highly recommended.

URI	Method	Description
/auth/login	POST	User login action, request with login information.
/auth/signup	POST	User signup action, request with registration information.
/auth/logout	GET	User logout action, no data submission is needed.

Table 4.3.: User Auth APIs

- Courses: acquisition of courses and new submission of a course is possible. In addition, CRUD operations on a specific course should also be achieved through a single URI with various HTTP methods.

- Questions: in a real sense question resource is attached to course resource. According to the best practise of RESTful API design [reference xxx], question resource could be touched under course URI, */courses/:courseId/questions/:questionId*. But in

URI	Method	Description
/courses	GET/POST	request the whole collection of courses; create course with data submitted
/courses/:courseId	GET/PUT/DELETE	request, modify, remove specific entry of course

Table 4.4.: Course Resource APIs

the real world, question resource has its own collection, and *questionId* is the unique identifier, through which a specific question entry could be selected without using *courseId*. So an optimized conception is simply using */questions* as URI instead. And pass *courseId* as a query parameter while requesting collection of question entries under a specific course.

URI	Method	Description
/questions?courseId=:id	GET/POST	request the whole collection of questions belonging to a specific course; create question under a specific course
/questions/:id	GET/PUT/DELETE	request, modify, remove specific entry of question
/questions/:id/vote/:type	POST	vote actions with different vote types applied to specific question

Table 4.5.: Question Resource APIs

- Answers: the general API design of answer is totally same as the approach applied in question resource. A independent API for voting functionality should also be designed. And multiple possibilities of vote types could also be passed through the API.

URI	Method	Description
/answers?questionId=:id	GET/POST	request the whole collection of answers belonging to a specific question; create answer under a specific question
/answers/:id	GET/PUT/DELETE	request, modify, remove specific entry of answer
/answers/:id/vote/:type	POST	vote actions with different vote types applied to specific answer

Table 4.6.: Answer Resource APIs

Once all APIs with different HTTP methods are defined, a more concrete data structure over the APIs between two sides should be promised and confirmed. By following defined APIs and promised data structure, developments on both client and server-side could be executed parallelly.

4.2.3. WEBSOCKET DEFINITIONS

As the requirements defined in section 3, users could be informed as new question is posted or the order of answers with rating priority changes. Basically, only two different

types of listeners are needed in this case: one for listening to the new questions under a specific class and one for responsive order of answers under a specific question. With WebSocket, URI should also be defined as an identifier for the persistent connection between client and server. And different events within a connection of one URI should also be designed. Table 4.7 defines these two WebSocket specifications.

URI	Event	Response
/ws/courses/	questions-changed	data of new question posted by others
/ws/questions/	answers-changed	data of answers in new order

Table 4.7.: Answer Resource APIs

Definition

4.3. GRAPHICAL DATA SERIALIZATION

Graphical content is the most efficient and intuitive way to deliver the explanation of an answer to other users comparing with pure textual content. In this section, Choices for graphical technologies on the Web will be analysed in order to figure out which is the ideal and fit the graphical discussion system most. And a feasible approach of storing graphical data will be proposed. At last, a drawing tool will also be designed to offer user interfaces for drawing elements on the drawing board.

4.3.1. CANVAS OVER SVG

It seems that both Canvas and SVG are good candidates as a graphic technology for the graphic discussion system. Both of them provides native methods to render rich varieties of elements like path, circle, rectangle and so on. Which would be a better choice above the context of discussion system, should be analysed at first.

EFFICIENCY

As mentioned in section 2.2.3, the rendering efficiency is the primary deficiency happening to SVG.

And graphic technologies are not only simply used for rendering a static graphical content in the system. Dragging, resizing or deleting an element are the basic features of a drawing tool, which provides input of graphical content. All these features are only able to be accomplished by re-rendering the elements on the drawing board.

Considering that all contributions in the system are made with graphical contents, efficiency plays a significant role especially on mobile devices with old hardware. Choosing Canvas will give users better usability while viewing the contributions as well as using the efficient drawing tool without janky feeling.

EXTENSIBILITY

TDB

4.3.2. STORABLE AND REVERSIBLE CANVAS DATA

A focus point in the thesis is how to store the graphical content submitted by users. In the traditional way, graphical data could only be stored either in file system or in the database with encoded format, for example Base64 encoded images.

DEFICIENCY OF CANVAS - STORABLE IMAGE DATA

Canvas provides a native method called *getImageData()* to export the whole Canvas context including the size of Canvas and pixels on Canvas to an image data. The image data exported by canvas represents the underlying pixel data with the format of *Uint8ClampedArray*. The *Uint8ClampedArray* typed array represents an array of 8-bit unsigned integers clamped to 0-255 [reference], which implies the position of the pixel as the index of array and the color of pixel as value from 0 to 255. A example is taken in figure 4.4 shows a Canvas with size of 100x100 and its simplified ImageData.

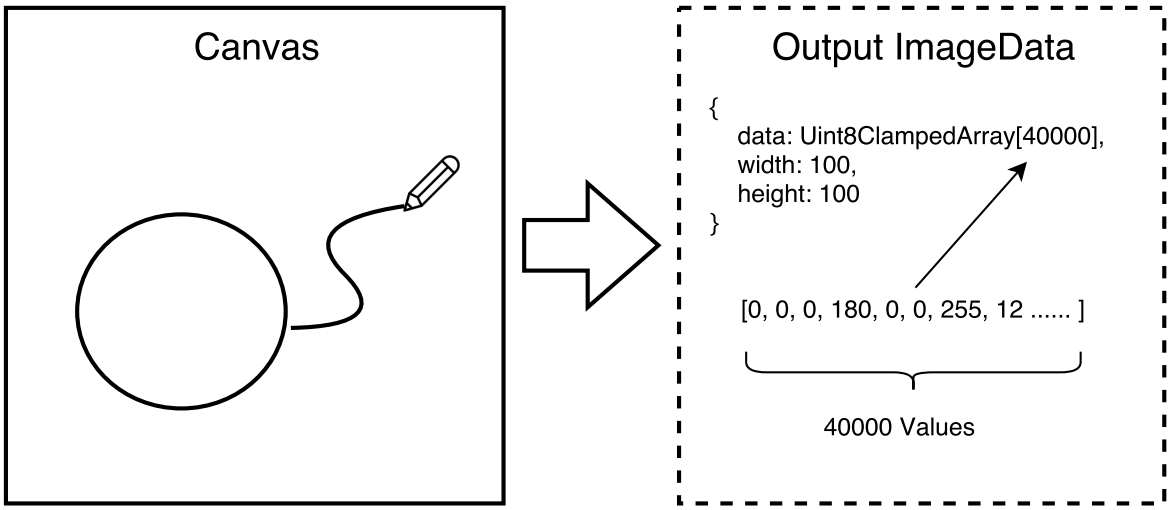


Figure 4.4.: Canvas to native ImageData

Restoring with the exported ImageData is also possible in Canvas by using its native method called *putImageData()*. Basically, the concept of *putImageData()* is traversing the ImageData exported by Canvas, and re-drawing each pixel at the position according to the index in the *Uint8ClampedArray* and applying the color to the pixel based on the value from 0 to 255 stored in the array.

Natively exported result of image data could basically meet the storing demand, however, the data redundancy in the native exported format representing the properties of each pixel is still very huge. Storing such kind of data will cause high demand on storage space when plenty of graphical contributions are made in there system.

Additionally, it is expected that users are able to remove, resize and modify the elements in the canvas while quoting others' contributions. However, natively exported result of image data could only describe each pixel but not each element on the Canvas, which means modification on the elements is not possible even though the whole canvas could be reproduced with graphical content by others.

Therefore, a workable solution should be concepted and new data model describing the graphical content in Canvas should be designed to meet the demands mentioned above.

SOLUTION - OBJECTIFICATION OF ELEMENTS IN CANVAS

Even though Canvas has native methods to draw different shapes of elements, but Canvas only render them pixel by pixel, it knows nothing of the shapes that are drawn. Therefore, removal or modification of a already drawn element is not possible. In this condition, a feasible solution is to wrap the Canvas and objectify the original elements which could be stored and persisted in a stack. Furthermore, the wrapper on Canvas should also provide methods to render, modify, remove the custom elements.

The general conception of the wrapped Canvas is illustrated in figure 4.5.

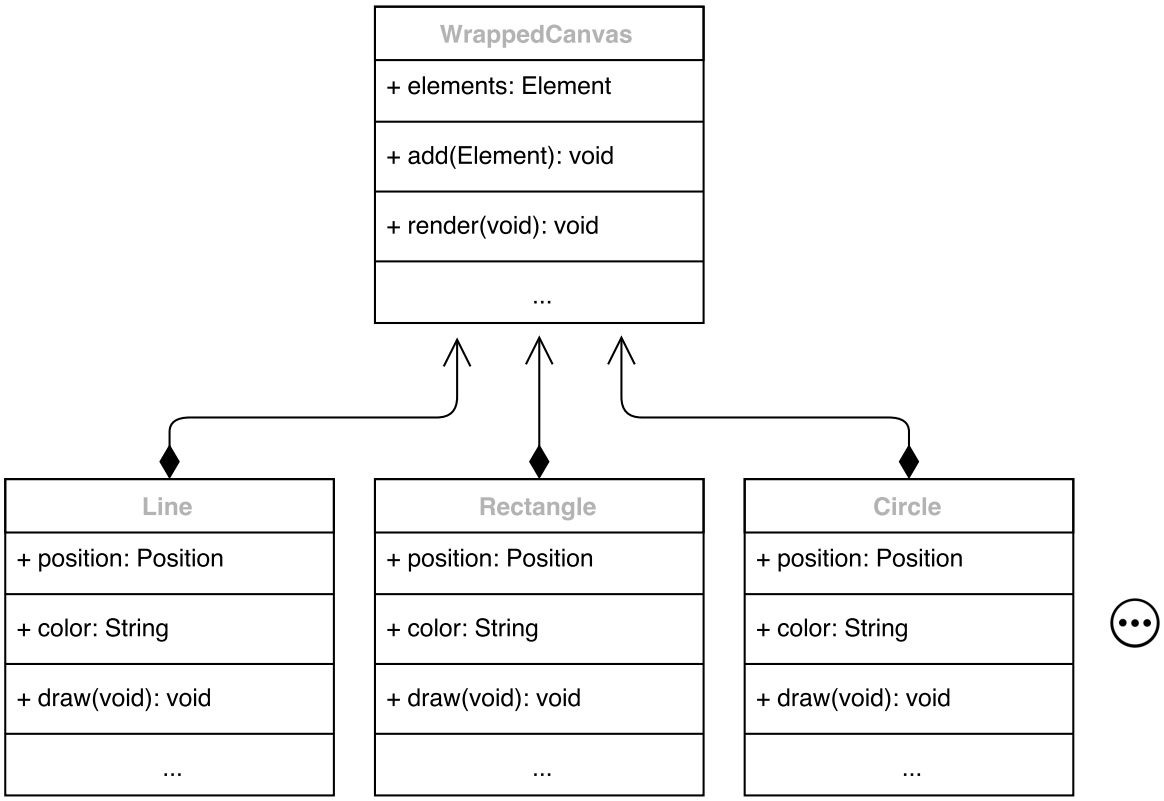


Figure 4.5.: Concept of wrapped Canvas

The wrapped Canvas has a list of objectified elements which are visible on Canvas. Now there are new definitions for rendering, modification of an objectified element:

- Rendering Canvas: the list of elements maintained by wrapped Canvas will be traversed and each element will be rendered by calling the native drawing method of Canvas. Position and style of the element in Canvas refer to the properties of its object.
- Modification or Removal: In case the methods for modifying or removing provided by element object in wrapped Canvas are fired, the whole Canvas will be re-rendered in the same way of rendering the Canvas initially.

Now rendering means that the list of elements maintained by wrapped canvas is traversed and each elements are

DATA MODEL EXPORTED BY WRAPPED CANVAS

Since the wrapped Canvas maintains a list of objects for elements, which also contain the properties such as position, color, size and so on, so the exporting of image data is now

really simple. A composition of all objectified elements' properties is already enough to describe the whole canvas. Figure 4.6 reveals the approach and data model output from wrapped canvas.

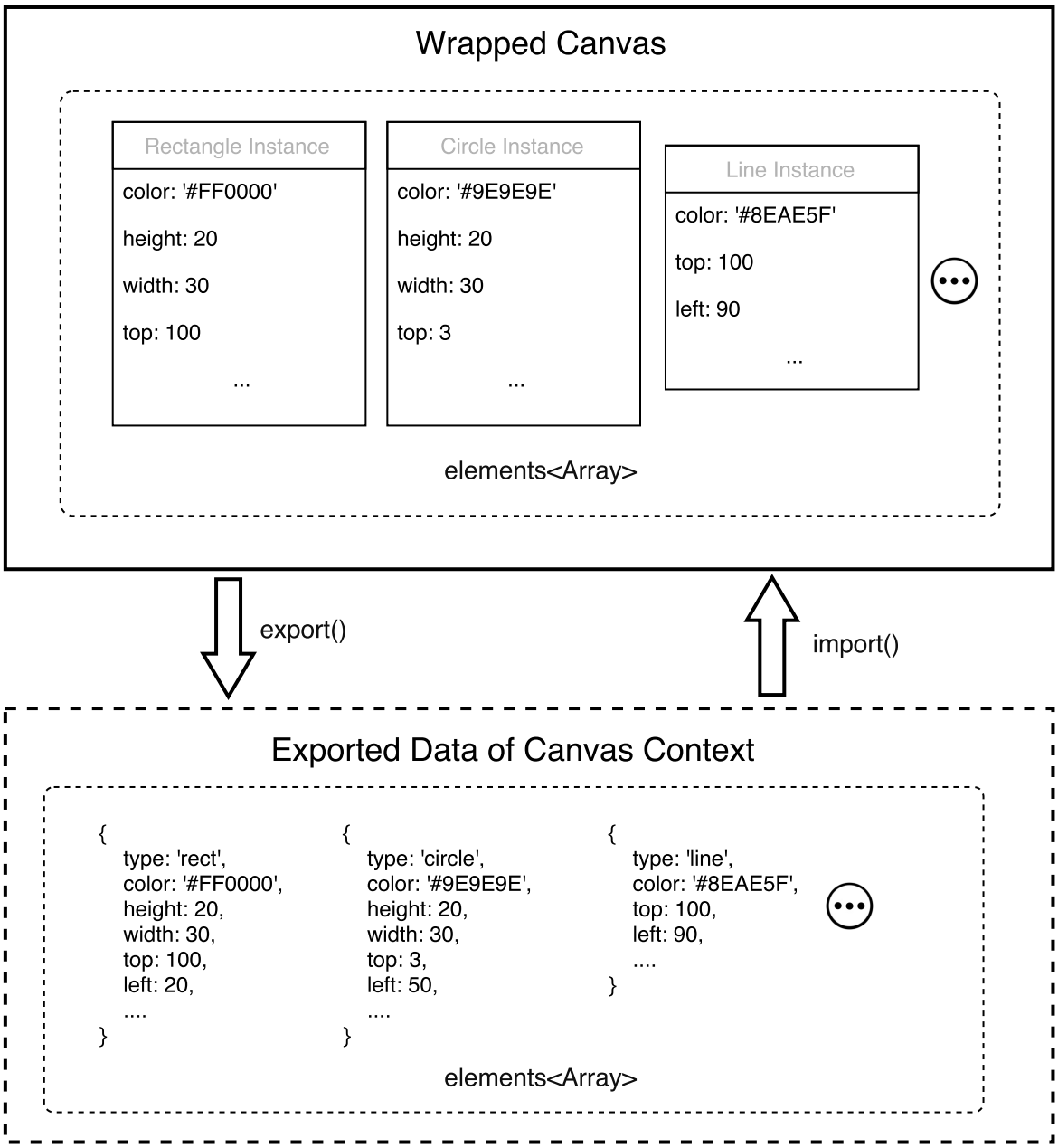


Figure 4.6.: Export and import of Canvas context with objectified elements

After converting all elements in wrapped canvas, the new data model is much more efficient for storing comparing to the raw image data. The wrapped Canvas will also provides a method to restore the output data, create new objectified elements by giving the properties of the data model, and re-render the elements into original Canvas pixel by pixel. With this approach, the feature of modification on elements while quoting other contributions could also be achieved.

4.3.3. DRAWING TOOL

After the conception of a feasible wrapped canvas as base of the container for all elements, a drawing tool which provides user interfaces to draw variable shapes as well as texts should be designed in the next step.

First of all, user interfaces for selecting different drawing mode like drawing circle, rectangle or line should be designed. Buttons for toggling various drawing modes are the best choice in this case.

Because drawing elements in different shapes has distinct behaviors, so listeners for each specific drawing mode should be defined. When the button for toggling drawing mode is clicked by user and specific drawing mode is activated, the correlative listener will be initiated. Clicking events or moving events of the mouse on Canvas will be captured and processed. Meanwhile, drawing behaviors are also performed according the mouse events fired by user.

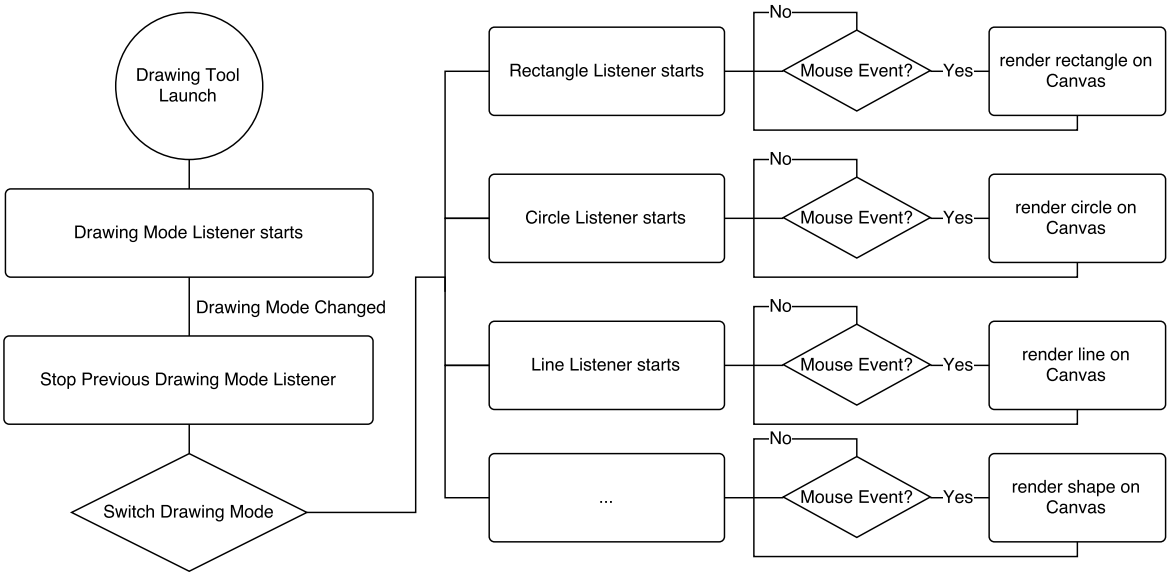


Figure 4.7.: Lifecycle of drawing tool

Figure 4.7 illustrated the conception of drawing tool with user interfaces and life cycle of event listeners for each drawing mode.

4.4. REAL-TIME DEMAND

Realtime communication as mentioned in subsection 4.1.2 are used for reactive data, which requires WebSocket for establishing persistent connections to enable the bi-directional communication between client and server.

All users are able to subscribe arbitrary course for new submission of a question as well as arbitrary question for updated order of answers, and server could also push realtime data to those users who has subscribed the resource with specific identifier. However, only two WebSocket services: */ws/courses* and */ws/questions* are defined as the entry points according to the definition in subsection 4.2.3. The approach how the server broadcast data precisely to the users who subscribe resources they require should be resolved.

A feasible solution is that the server maintains a list of user ids and resource ids subscribed by user. Afterwards, as a specific resource is updated, the server can get all users who has subscribed this resource from the maintained list using the resource's identifier.

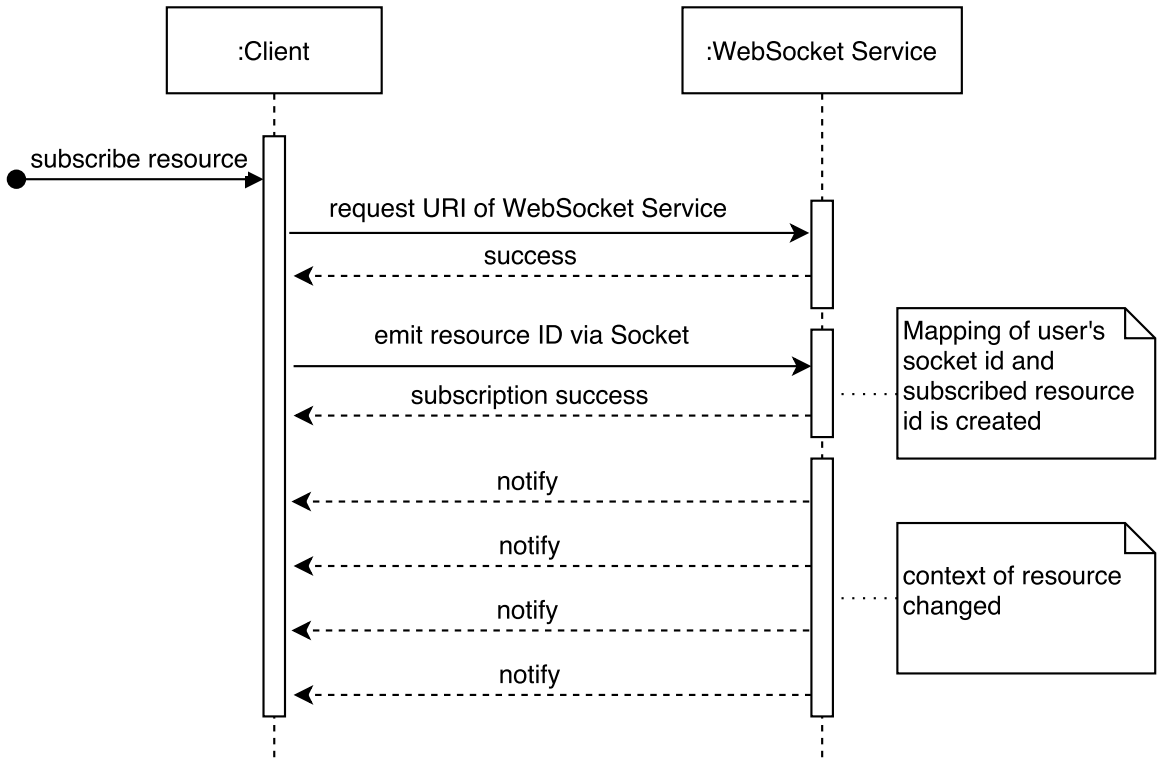


Figure 4.8.: Sequence diagram of establishing a WebSocket connection

Figure 4.8 represents the whole workflow of establishing the connection over WebSocket. In the first place, the server starts listening for requests over WebSocket protocol with specific URI. Then the user start a connection to server for subscribing the resource he requires. As soon as the connection is successfully established, the client will emit the resource id to the server side, and resource id from client will be mapped to the user id in a list maintained by the server.

After that, the server has the information of which user has subscribed which resource, and is able to emit realtime data precisely.

4.5. CONCLUSION

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5. IMPLEMENTATION

In this chapter, an prototype of graphical discussion system will be created and make use of the previously developed approach as a "proof of concept". Firstly, ... the application domain will be presented and also foreshadow the prototype funtionality. Afterwards, ... the development itself will take place, highlighting and documenting best practices in the subsequent sections.

5.1. GENERAL

On the whole, the implementation can be divided into two parts: client and server. Since they are fully separated, each part is considered and structured as a independent project. The implementation on client side is basically data fetching and template rendering, while data persistence and core business logic is implemented on the server side. For convenience, the graphical discuss system is named "Graphicuss", which stands for graphical plus discuss.

5.1.1. PLATFORM AND FRAMEWORK

To achieve a better performance of view rendering on client side running in browser, React.js[1] is taken as the front-end framework. Componentization, the main philosophy of ReactJS, also helps organize the views and view model logics. On the server side, ExpressJS[2] as a web framework is adopted for its efficiency and productivity of building RESTFul APIs.

Since both client and server projects are primarily implemented in JavaScript, NodeJS[3] is the single development environment for either project implementation or project management on both sides.

FILE STRUCTURE

To have a basic understanding of whole project including the server side and client side, a file structure of the project Graphicuss is listed in figure 5.1:

- client/: independent front-end project built on top of ReactJS
- server/: independent back-end project implemented by using ExpressJS

[1] https://facebook.github.io/react/
[2] http://expressjs.com/
[3] https://nodejs.org/

- **dist/**: compiled back-end project integrated with compiled and compressed static view files from front-end project
- **node_modules/**: source of referenced third party libraries
- **package.json**: definition of third party libraries for client and server side
- **webpack.config.json**: config of specific behaviours in automated development or building process

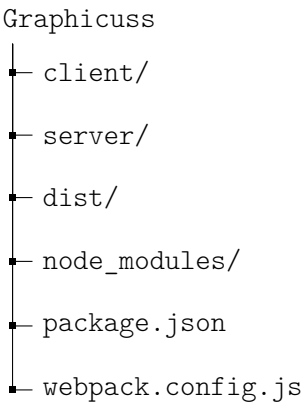

Figure 5.1.: Overview of Graphicuss' file structure

MODULE MANAGEMENT

NodeJS provides native module management which is called *npm*[4]. Third party libraries, which are published in the official remote repository, can be installed conveniently by only using npm's command line. There is also a list of names of all modules and dependencies in the file *package.json*. Installing all dependencies and modules can be simply achieved by using only one command line *npm install*, which will significantly ease the setting up process of the project freshly on a new machine.

5.1.2. ARCHITECTURE

An architectural overview of Graphicuss is illustrated in figure 5.2.

While the client starts requesting a specific URL for data from the server, a HTTP connection will be established. The server program receives the HTTP request and forwards it to its router, in which rules for matching URLs have been pre-defined. By analysing headers of HTTP request, router will check if the request matches any pre-defined rules.

Not only the URL but also the parameters passed by client, for example the identifier of a resource, could also be extracted from HTTP headers. Server runs correlate business logics according to the rule of matched URL and executes operations of databases for data persistence. Afterwards, results are returned from server.

As soon as the data is successfully returned, the HTTP connection will be closed. The client processes data acquired from server, and represents it by re-rendering views. So far, a entire request over HTTP is accomplished.

[4] https://www.npmjs.com

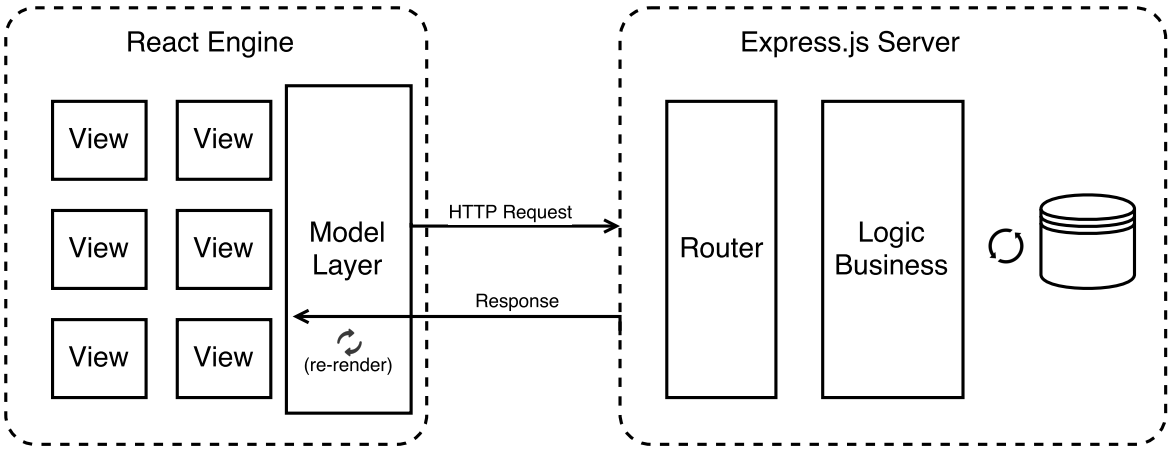

Figure 5.2.: General architecture

5.1.3. AUTOMATIZATION

To accelerate the developing as well as building process of the project, a automatization tool called *Webpack*[5] is used.

Webpack is a tool which could analyse the dependencies of the project and bundle modules with the app. In addition, it can also do tasks like compressing JavaScript codes to reduce the size of the client app, or compiling modern JavaScript as well as CSS codes to achieve the compatibility for old browsers.

AUTOMATED DEVELOPMENT PROCESS

To make the development of client app independent, it will start a dev server on its own for development purpose. However the dev server started by client app and the actual server are running on different ports. Which means that the communication between them will cause CORS problem.

CORS means, a resource makes a cross-origin HTTP request when it requests a resource from a different domain than the one which the first resource itself serves. For security reasons, browsers restrict cross-origin HTTP requests initiated from within scripts. [1]

Through configuring the dev server started by Webpack, a proxy could established to forward request to the actual back-end server. As figure 5.3 shows, the client is able now to request APIs under the same domain, and requests will go though the dev server, after that they are forwarded to the actual server.

AUTOMATED BUILDING PROCESS

For the client app, multiple tasks are executed during the building process by using Webpack: transforming modern JavaScript code, pre-processing the modern CSS code and bundling the static files. All these tasks will significantly reduce the size of client app and also improve the compatibility of the app.

Webpack also helps accelerate the building process by defining various automated building tasks. It will bundle all dependencies with the server app and client app. After processing on both sides, the final output of the files will be extracted into the *dist* directory mentioned in 5.1, which is now ready for deploying and serving. The whole building process is represented in figure 5.4.

[5] https://webpack.github.io/

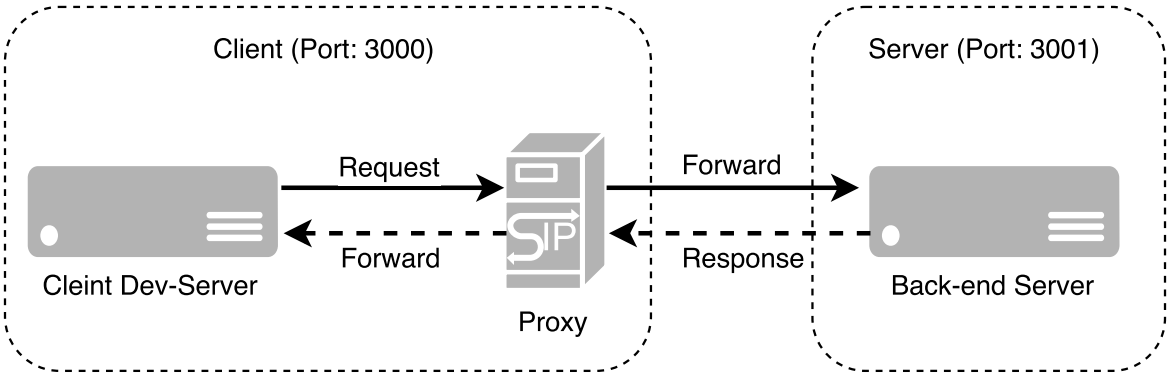

Figure 5.3.: Proxy for client development server

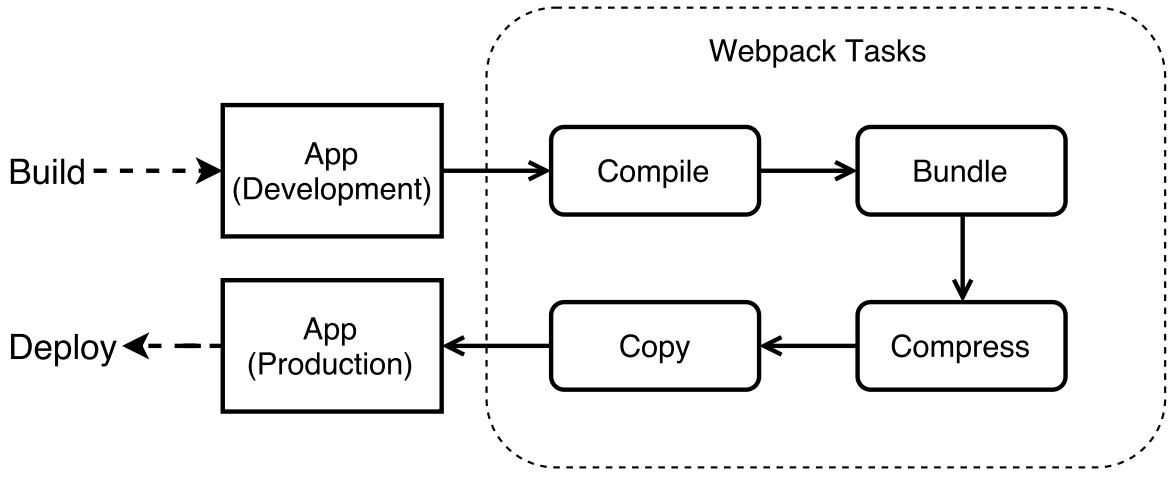

Figure 5.4.: Automated building process with Webpack

5.1.4. STORAGE STRUCTURE

In section 4.2, data domains and fields of data domains have already been defined.

For all persistence storage of data on the server side a MongoDB[6] database is used. In figure 5.5, more concrete definition of data model table is defined. MongoDB is a non-SQL database, which uses document oriented storage and JSON style data model. That will make it easy to implement as well as scale data models. In addition, An ORM framework called Mongoose[7] is also applied to the implementation, which encapsulates the native database operations of MongoDB. With help of the ORM framework, definition of schema and query on database will be quite simple.

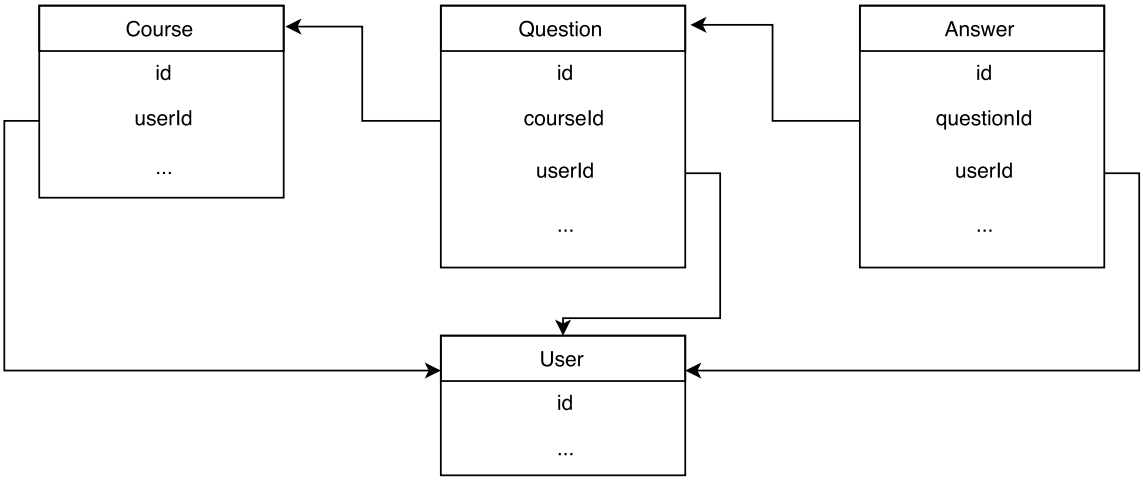

Figure 5.5.: Table of data model

5.2. SERVER OF GRAPHICUSS

5.2.1. ARCHITECTURE

MVC PATTERN & PROJECT STRUCTURE

To separate the different layers of model, view and controller, MVC pattern is used as the basic pattern of the architecture. In the model layer, all data model related concerns such as data shema definitions, data model validation as well as database operations are defined. And Controllers contain the core domain logics, process the data from model layer, and pass the result to view layer.

Since the templates are rendered on the client side, the view layer is just simply stripped. Therefore, basically the controllers response processed data to client side directly without rendering it to views. Figure 5.6 shows the overview of the server's file structure which is featured with MVC pattern.

- index.js: the entry point of the whole server app. It will create a server instance and set up configurations for the server. In addition, a connection from server instance to database will be established. After all configurations are done, the server instance will start listening port and waiting for the requests from client.
- config/index.js: config as well as constants for the server. It persists *apiConfig* for example the common prefix of API URL and version of the API. And config for

[6] https://www.mongodb.com/
[7] http://mongoosejs.com/

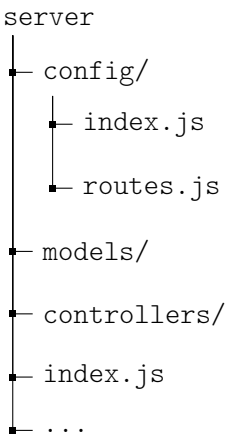

Figure 5.6.: Overview of server app's file structure

database including the database URL will be defined here as well. In addition, keys for encryption are also stored in the config file.

- **config/routes.js**: rules for URL matching. All URL matching rules are defined in this file. Controllers are referenced here and a dispatcher for router will be instantiated. If any request meets the defined rule, the request will be forward to a correlative controller.
- **controllers/***: controllers for processing specific requests.
- **models/***: data model definitions. Files under this directory are organized by different data domain.

ACHITECTURE OF SERVER

The figure 5.7 illustrates an overview of the server's architecture.

5.2.2. MODEL LAYER IMPLEMENTATION

In subsection 5.1.4 an overview of the storage structure has been described. In following subsections, more concrete implementation of data model layer is explained and example codes are represented.

DATA MODEL SCHEMA

Not only the fields of each data model are defined, but also data type of each field should also be restricted. Mongoose will check the type of fields within a data model according to the definitions before a record is inserted into the database.

```
1 import mongoose from 'mongoose'
2 const userSchema = mongoose.Schema({
3   username: String,
4   email: {type: String, lowercase: true, trim: true, unique: true},
5   password: {type: String, select: false},
6   faculty: {type: String, default: ''},
7   tutor: {type: Boolean, default: false},
8   admin: {type: Boolean, default: false}
9 }, {timestamps: true});
```

Listing 5.1: Example: user schema definition within Mongoose

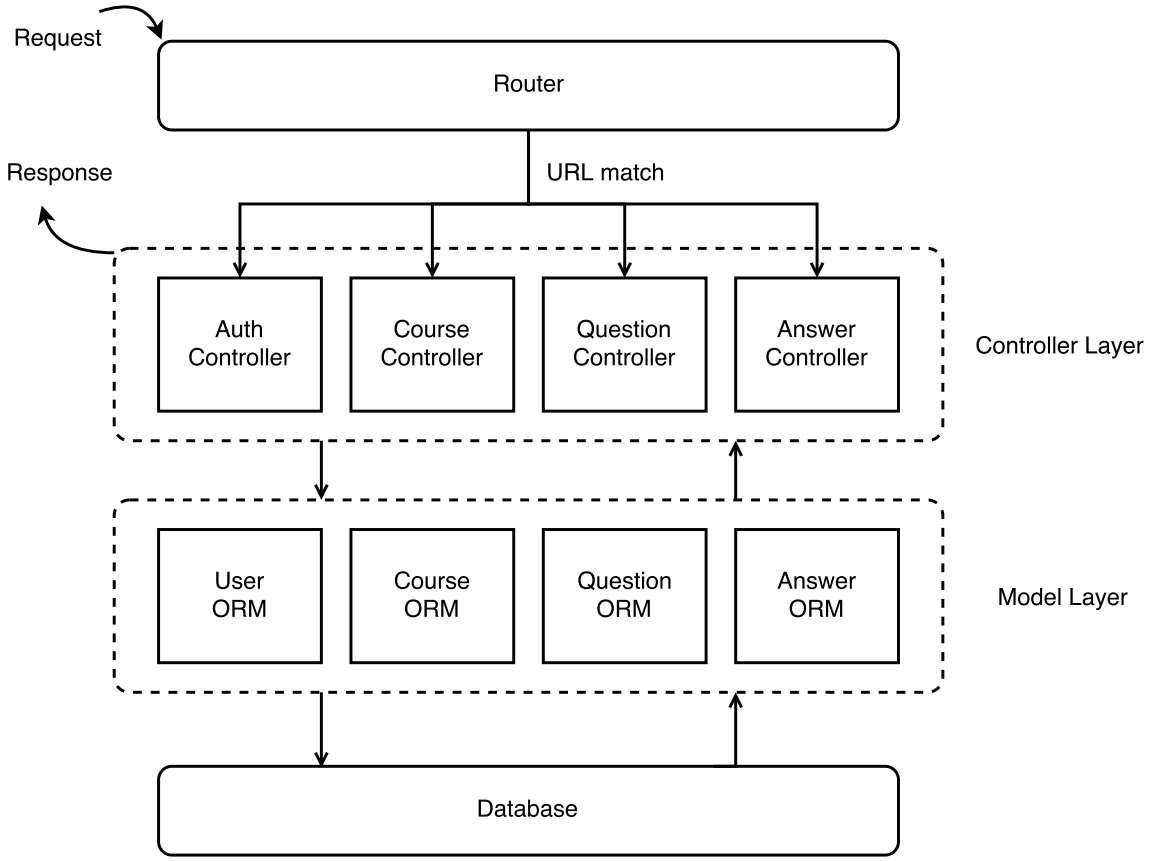

Figure 5.7.: Server architecture

Code list 5.1 takes *UserSchema* definition as an example. Fields like *username*, *email*, *password* and *faculty* are defined as *String* type. Fileds like *tutor* and *admin* are using Boolean type for determining the role of a user. In addition, default value of an field could also be given if record is added without value on this field. And Mongoose also provides a set of configurations for processing the entry inserted. In the example, setting *lowercase* on *email* will transform all characters to lowercase, while setting *trim* will stripped space symbols out of a string. Mongoose will not only validate the type of data model, but also check the uniqueness of the data field in the entire database if *unique* is set to *true*.

METHODS ON MODEL LAYER

In most cases, various operations are executed to acquire data from the database, modify data and even remove data in the database. Therefore, those data fetching or data processing tasks are implemented in the data model layer, which will also achieve the goal of seperation of concern. A example of *Course* data model is taken in the following code list 5.2.

```
1  courseSchema.statics.list = function() {
2    return this.find().sort('-createdAt').populate('creator').exec()
3  }
4  courseSchema.statics.load = function(_id) {
5    return this.findById(_id).populate('creator').exec()
6  }
7  courseSchema.method.edit = function(fields) {
8    return this.update(fields).exec()
9  }
10 courseSchema.method.remove = function() {
```

```
11    return this.remove().exec()
12  }
```

Listing 5.2: Example: user schema definition within Mongoose

Other data models like *Question* and *Answer* are quite same as *Course*. Method *list()* is defined for querying all records of a collection under the data domain. In addition, sorting and referencing other model with foreign key will also be done before returning the result. *load()* method is for querying a specific entry. Methods *edit()* and *remove()* means modification or removal of an entry in database.

5.2.3. AUTHENTICATION

The goal of authentication is confirming the identity of an user and controll the access of resources by checking the privilege of an user. So an authentication system is also designed for security reasons.

JWT BASED AUTHENTICATION

JSON Web Token (JWT) is an open standard (RFC 7519) that defines a compact and self-contained way for securely transmitting information between parties as a JSON object. This information can be verified and trusted because it is digitally signed. Reference!!!

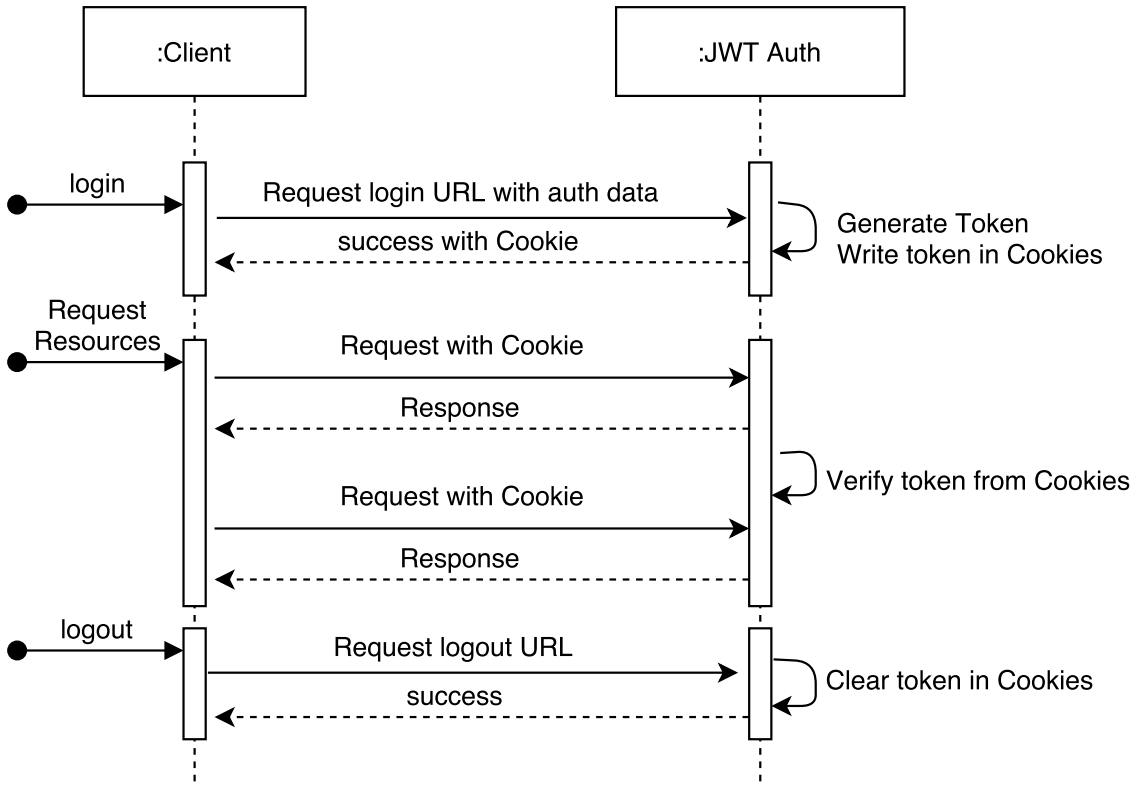

Figure 5.8.: JWT authentication process

The basic idea of JWT based Authentication in the server side of Graphicuss is shown in figure **??**. After that the user sends request to login with its identifier and password and the the authentication is successfully verified, JWT will encode the user information with a secret key to a token.

```
1  var token = jwt.sign(userInfo, authConfig.jwtSecret)
```

```
2  response.cookie('token', token);
```

Listing 5.3: JWT encodes user information with secret key

After that the authentication is successfully verified and Cookies are written with JWT token, every request started from the client side will be sent with Cookies. All the requests will go through the *authMiddleware* and the tokens inside Cookies from requests will be decoded with the secret key. With the payload of user information which is decoded from the token, server is able to deal with resources for the specific user.

```
1  jwt.verify(token, authConfig.jwtSecret, function(err, decoded) {
2    var userInfo = decode
3  })
```

Listing 5.4: JWT decodes user information with secret key

ROLE CONTROL & ACCESS CONTROL

As defined in section 5.1.4, each user has two fields called *tutor* and *admin*. An admin has full control of all resources while a tutor is able to create a course and manage all resources under his course. Same as a normal user without any privileges, he could only maintain resources submitted by himself.

So a *if* statement will be executed before the operations on resources in order to determine the role of the user, or to verify if an user has the access to the specific resource.

5.2.4. WEBSOCKET IMPLEMENTATION

For the implementation of real-time functionality, a library called Socket.io[8] which a fast and reliable real-time engine is used.

As described in section 4.4, at the start of server, an instance of Socket.io will be created for listening for WebSocket requests within specific namespace. Following code list 5.5 shows the main process of listener created for real-time questions under a specific course.

```
1  var courseWS = io.of('/ws/courses/');
2  var courseSocketMap  = {};
3  courseWS.on('connection', function(socket){
4    socket.on('course-to-listen', function(courseId){
5      if(courseSocketMap[courseId]){
6        courseSocketMap[courseId].push(socket)
7      }
8      else{
9        courseSocketMap[courseId] = [socket]
10     }
11   });
12 });
13
14 courseWS.on('disconnection', function(socket){
15   Object.keys(courseSocketMap).forEach(function(courseId) {
16     var index = courseSocketMap[courseId].indexOf(socket)
17     if (index > -1) {
18       courseSocketMap[courseId].splice(index, 1);
19     }
20   });
21 });
22 /* --- Listening for Question is the same approach--- */
```

Listing 5.5: Server starts listening for requests over WebSocket protocol

[8] http://socket.io/

After the WebSocket listener is started, it will monitor the the event called *course-to-listen*. As it is triggered, *courseId* received from client will be mapped to the a list of socket objects which represent the users who are listening to this resource. After the client disconnets from the WebSocket, his socket object will be removed from the listening list.

```
1 var sockets = courseSocketMap[courseId];
2 sockets.forEach(function(socket){
3   socket.emit('questions-changed', newQuestions);
4 });
5 /* --- Listening for Question is the same approach--- */
```

Listing 5.6: Server starts listening for requests over WebSocket protocol

If the questions under the specific course are changed, all sockets which could be referenced from *courseSocketMap* by using the *courseId* will emit an event with payload of changed question resources. Those clients who has subscribed this course will be informed and receive the new questions passively. Code list 5.6 demonstrates the process.

The approach of real-time order of answers under a specific question is quite same as the approach mentioned above.

5.3. CLIENT OF GRAPHICUSS

5.3.1. ARCHITECTURE

For the implementation of the client application, *React.js* which aims to solve the challenges involved when developing web application with complex user interfaces, is applied. To have a better concept of how Graphicuss's client application is implemented, an overview of the file structure is listed in the figure 5.9.

PROJECT STRUCTURE

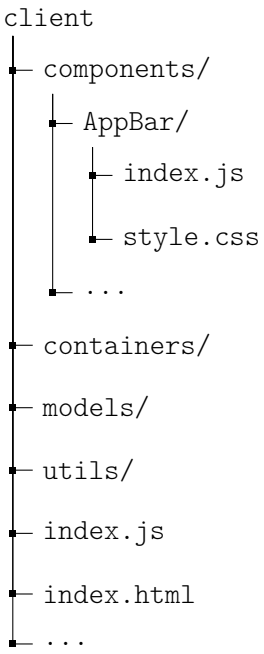

Figure 5.9.: Overview of client app's file structure

- **components/**: all components are defined by extending basic *React.Compoent*. Each custom component has an *index.js*, which processes the logics of view rendering and applies view model to the template. *style.css* defines the CSS style of the HTML DOMs within a component.
- **containers/**: containers are compositions of components.
- **models/**: in model directory, data models for the components are defined. In addition, the definition of APIs and processing after data acquisition also take place here.
- **index.js & index.html**: *index.js* is the entry point of the app, which will instantiate the React instance and render the views into a specific DOM defined in *index.html*

ACHITECTURE OF CLIENT

An overview of the client application's architecture is revealed in figure 5.10.

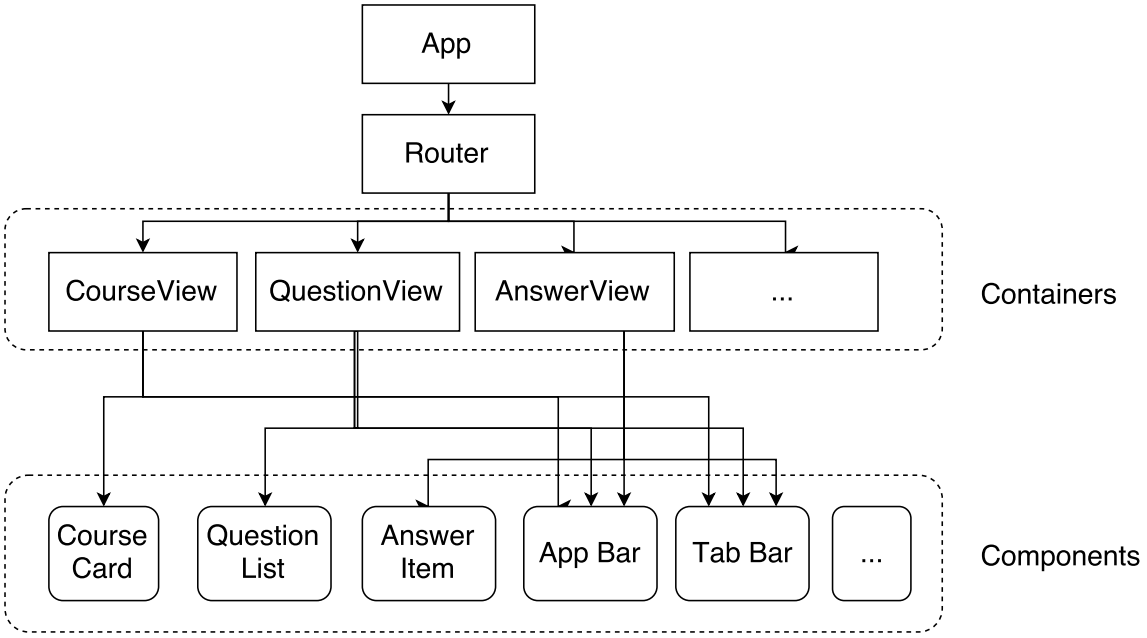

Figure 5.10.: Overview of client architecture

In the React application, *Router* is also regarded as a component, in which different matching rules of URL are defined. If the URL requested by user is matched, a correlate view will be rendered according to the definition of routes. Code list 5.7 shows the implementation of defining a *Router* component.

```
<Router history={history}>
  <Route path="/" component={App}>
    <Route path="auth" component={AuthView} />
    <Route path="courses" component={CoursesView} />
    <Route path="courses/:courseId" component={QuestionsView} />
    <Route path="questions/:questionId" component={AnswersView} />
  </Route>
</Router>
```

Listing 5.7: Router in client app

Containers such like *CourseView*, *QuestionsView* or *AnswersView* are compositions of components in fact. The way how component acquires view model is that the parent

component pass values to its child component by defining the properties of the child component. So the data flow starts from the root component and goes through every child components.

How to manage the data flow and control the rendering behaviour will be discussed later in the sub section 5.3.3.

5.3.2. COMPOSITION OF COMPONENTS

REACT COMPONENT

Defining a new *Component* with React.js must extent the *React.Component* class and implement the *render()* function, which will be called when the component is instantiated. Afterwards, the template as well as the composition of components are rendered to plain HTML. A simplfied example of building a *CourseView* component is represented in code list 5.8.

```
1  class CoursesView extends React.Component {
2    render() {
3      const courses = this.props.courses
4      return (
5        <div>
6          {
7            courses.map( (course) =>
8              <CourseCard course={course} key={course._id}></CourseCard>
9            )
10         }
11       </div>
12     );
13   }
14 }
```

Listing 5.8: Rendering *CourseView* with multiple *CourseCard* components

As mentioned above, the parent components pass data through as the properties of child components. Within the *CoursesView*, *courses* could be read from its properties which is defined while *CourseView* is composed. In the *render()* function of *CourseView*, *courses* are traversed and each single *course* will be passed into the *CourseCard* as its property. Which means, as *CourseView* is rendered, all *CourseCard* components within it will also call their own *render()* functions with the data model passed in. Data flows from top to bottom, likewise, views are rendered from parent to children components.

COMPOSITION

Components are the core of React. All each view and its view model of the client application is represented as a React Component. And the whole client app is actually a composition of React components. An example of *CoursesView* is taken in figure 5.11.

At the top of the view is a component called *AppBar*, which is also composed with another component *SearchBox*. *ContentSection* is a container for the main content, which will be replaced and re-rendered if the context of router changes. In this example, the route */courses* is applied, and the component *CourseView* is rendered into *ContentSection*.

CourseView is also a composition of components: a list of *CourseCard* components and also other components such as submit button component and popover component for creating new course.

In principle, building other views is the same approach. Composition of components constructs the all views. With fine-grained components, the client app becomes much extensible and maintainable.

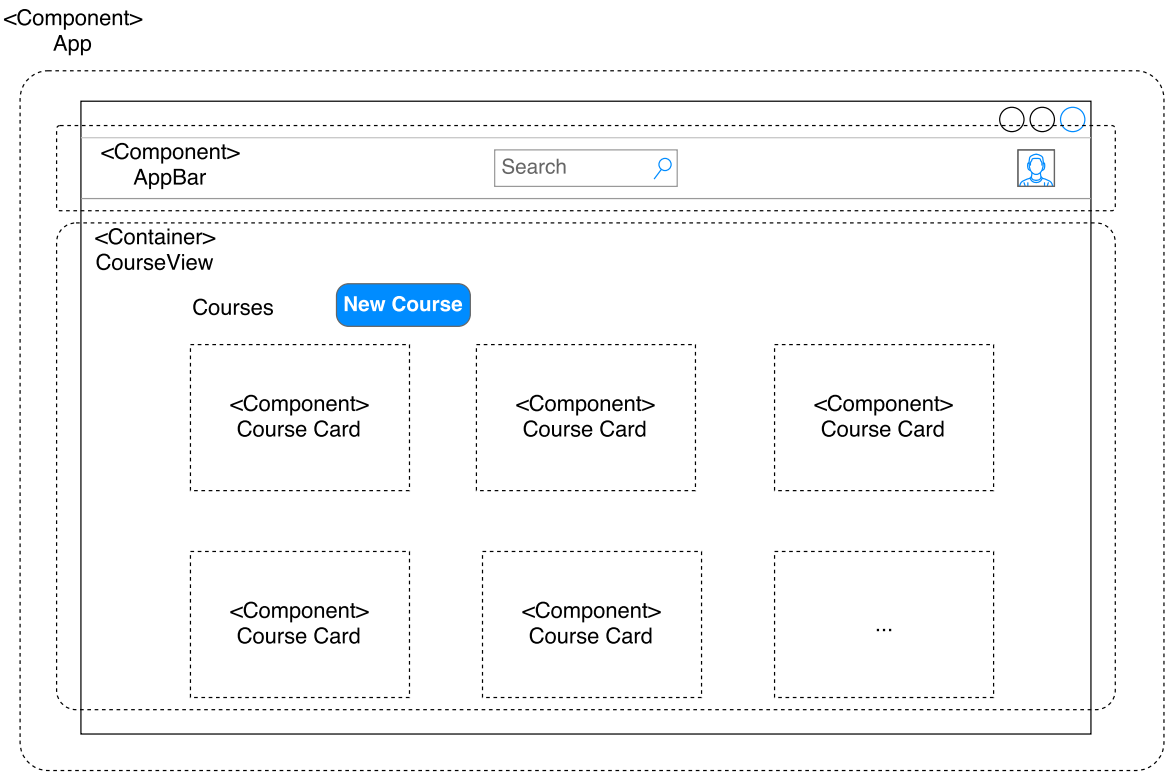

Figure 5.11.: Composition of components in courses' page

5.3.3. DATA FLOW

Since data is passed as properties of components from top to bottom in the React application, maintaining data models between components and the data flow through components is a problem. *Flux*[9] is a architecture which aims to solve this problem. Data flows in single direction, which keeps the process simple and ensures the correctness of view rendering.

There are four main concepts of Flux architecture:

- **View**: view layer which references the data model and renders the data model into template.
- **Action**: action made by view, trigger for processing data model, for example a mouse click event.
- **Dispatcher**: receives the actions and run callback functions to modify the data model.
- **Store**: stores the states of data, if the states of data are changed, store will notify the views to re-render with the new state of data.

The main process of data flow in Flux architecture is illustrated in figure 5.12. The key of Flux is unidirectional data flow. For example, user wants to submit a new answer to a certain question in Graphicuss system, as soon as the new answer is synchronized with server side, the new answer will be rendered into the answer list attached to the question. The process of data flow in this case is described as following:

1. User submits a new answer, *Action(NEW_ANSWER)* is triggered.
2. *Action* requests the API for submitting new answer.

[9] http://facebook.github.io/flux/

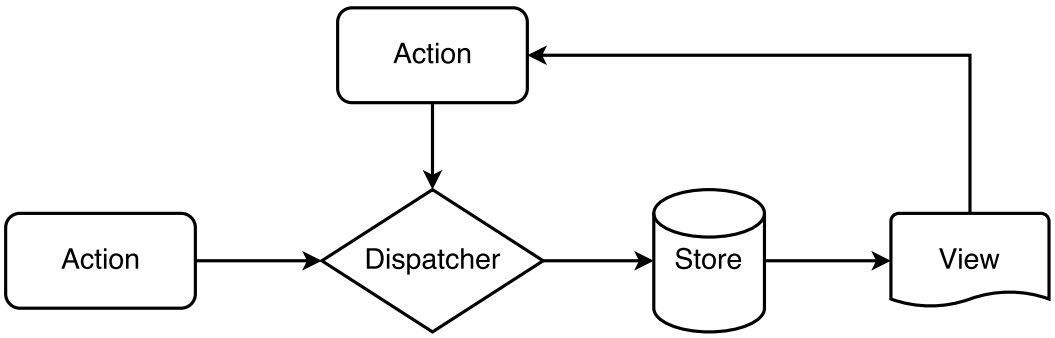

Figure 5.12.: Data flow in Flux architecture

3. *Dispatcher* receives the *Action(NEW_ANSWER)* and inserts an entry of this new answer into the *answers* state which is stored in *Store*.

4. Since the state of *answers* is changed, *Store* starts notifying the views to re-render.

5. Views re-render the templates with the new state of *answers* which contains the new submission of answer.

5.4. DRAWING TOOL FOR GRAPHICUSS

In this section, the implementation of converting Canvas to a storable data with JSON format is introduced. Afterwards, a drawing tool which provides user interfaces to draw various elements on Canvas is implemented.

5.4.1. OBJECTIFIED CANVAS

FABRIC.JS

Fabric.js[10] is a powerful and simple Javascript HTML5 canvas library, which provides interactive object models on top of canvas element. Since native Canvas only provides low-level APIs for creating elements, but not maintains the life cycle of elements on itself. Fabric.js solves this problem with objectifying native elements and encapsulating native methods for drawing elements.

Instead of dealing with low-level APIs natively provided by Canvas, Fabric.js provides objectified model for elements with different shapes on top of native methods. It takes charge of canvas state and rendering, make it possible to manipulate objects directly.

SERIALIZED CANVAS

Since all elements on the Canvas drawn by Fabric.js can are maintained as an object with properties like position, size and styles. So the Canvas within Fabric.js can be simply serialized to a JSON object or other formats.

Fabric.js provides a helper function called *toJSON()*, which will serialized the canvas with canvas properties as well as all object models on the canvas. Code list 5.9 is an example that shows how the serialized output looks like if an rectangle object is created by using Fabric.js.

[10] http://fabricjs.com/

```
var canvas = new fabric.Canvas();
canvas.backgroundColor = 'red';
canvas.add(new fabric.Rect({
  left: 50,
  top: 50,
  height: 20,
  width: 20,
  fill: 'green'
}));
console.log(JSON.stringify(canvas));
/* --- Output of serialized Canvas ---
{"objects":[{"type":"rect","left":50,"top":50,"width":20,"height":20,"fill":"
    green","overlayFill":null,"stroke":null,"strokeWidth":1,"strokeDashArray
    ":null,"scaleX":1,"scaleY":1,"angle":0,"flipX":false,"flipY":false,"
    opacity":1,"selectable":true,"hasControls":true,"hasBorders":true,"
    hasRotatingPoint":false,"transparentCorners":true,"perPixelTargetFind":
    false,"rx":0,"ry":0}],"background":"rgba(0, 0, 0, 0)"}
*/
```

Listing 5.9: Serialized Canvas by Fabric.js

Comparing with output generated by native Canvas mentioned in section 4.3, this serialized JSON object is not only efficient for storing, but also has the possibility for restoring all object models and re-rendering them on Canvas.

5.4.2. DRAWING TOOL

The drawing tool is developed on top of the library Fabric.js. It provides the functionalities such as drawing, styling, dragging and resizing of various element. Not only graphical elements, texts could also be rendered and styled on the Canvas while using drawing tool.

ARCHITECTURE

Figure 5.13 illustrates an overview of the drawing tool's architecture.

STYLE MANAGER

At the startup of drawing tool, *StyleManager* is instantiated. *StyleManager* receives the the config instance, in which the DOM elements with relevant styling functionalities are defined. And in the *init()* function of *StyleManager*, listeners for the DOM elements are created. If the DOM elements are triggered by user, *StyleManager* will apply the chosen style to the active objects on the Canvas.

Code list 5.10 takes the listener for DOM element of color picker, which is used for changing the color of a object on Canvas. It acquires the reference of color picker DOM from the config instance, and starts listening for the *onchange* event. If the *onchange* event is fired, the listener will set the object's *fill* property to the color value. Afterwards, the canvas is re-rendered and the active object with new color is shown up.

```
class StyleManager {
  constructor(canvas, config){
    this._canvas = canvas;
    this._config = config;
  }
  init(){
    el = this._config['color-picker-dom']
    this._listenColor(el)
    // ... more styling listeners
  }
  _listenColor(el){
```

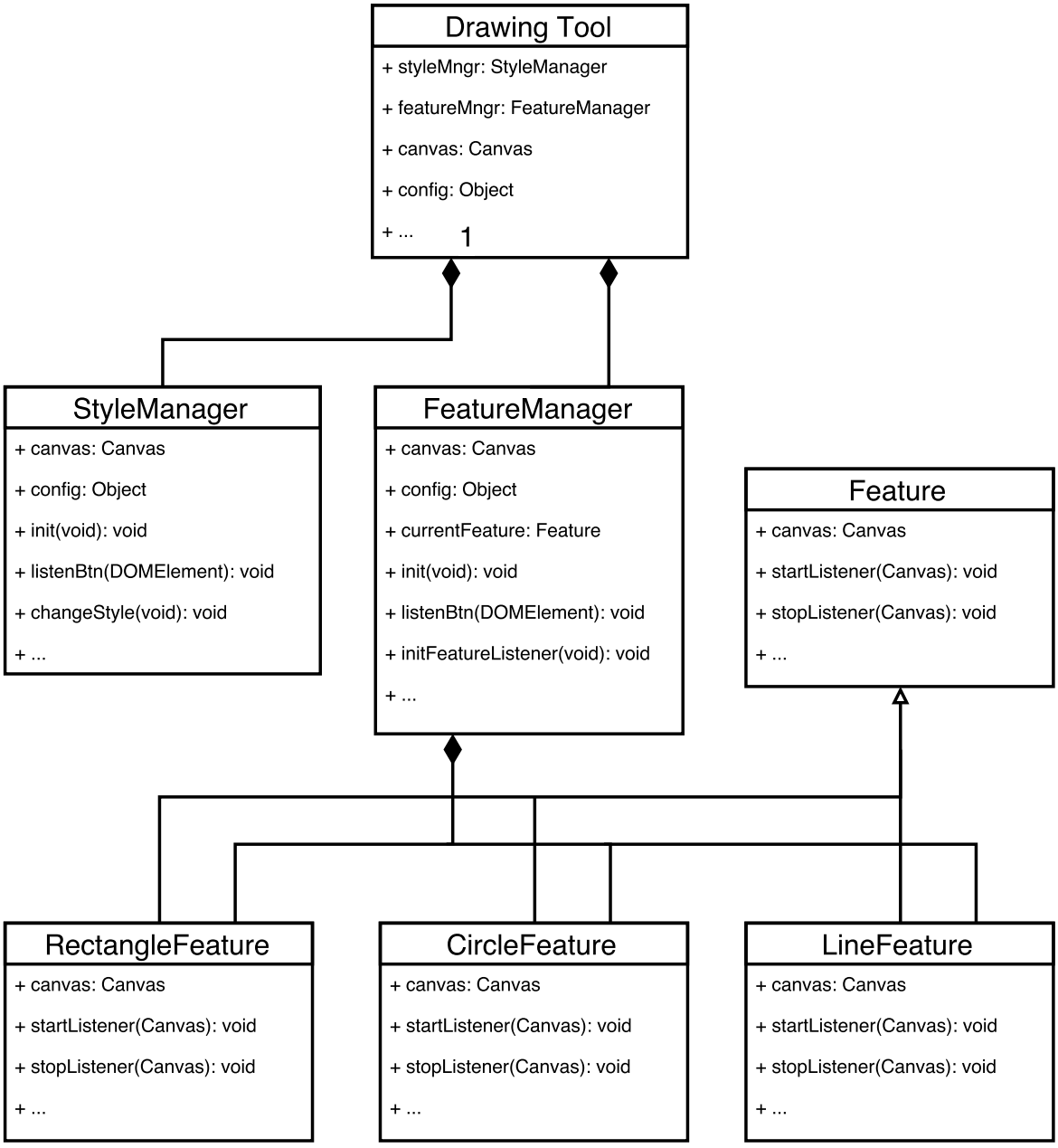

Figure 5.13.: Architecture of drawing tool

```
    let self = this;
    el.onchange = function(){
      var obj = self.canvas.getActiveObject();
      self._setObjStyle(obj, 'fill', el.value);
      canvas.renderAll();
    }
  }
  // ...
}
```

Listing 5.10: Main process of StyleManager

FEATURE MANAGER & EXTENSIBLE FEATURES

In addition, a *FeatureManager* is also created for managing different drawing functionalities. The basic idea of *FeatureManager* is quite similar as *StyleManager* mentioned above. It also listens for the DOM elements to toggle different drawing behaviours.

After that a specific drawing mode is triggered by user, *FeatureManager* will assign listeners for specific mouse events on the Canvas and track the drawing behaviours. According to the mouse events triggered by user on the Canvas, the correlate objects will be rendered into the Canvas context.

```
class FeatureManager {
  constructor(canvas, config){
    this._canvas = canvas;
    this._config = config;
  }
  init(){
    el = this._config['text-feature-dom']
    this._listenText(el)
    // ... more features' listeners
  }
  _listenText(el){
    let textFeature = new TextFeature(this._canvas);
    el.onclick = (e) => {
      this._clickHandler(text)
    }
  }
  // ...
}
class TextFeature{
  constructor(canvas){
    this._canvas = canvas;
  }
  startListen(){
    // tracking mouse event
  }
  stopListen(){
    // remove listeners
  }
}
```

Listing 5.11: Main process of FeatureManager

Features, namely drawing modes are highly extensible on the drawing tool. *TextFeature* in code list 5.11 is an example. All feature classes need to implement two interfaces *startListen()* and *stopListen()* basically. In *startListen()*, listeners for tracking mouse events are defined. And in *stopListen()*, all listeners should be removed. Both function will called by *FeatureManager* when this drawing mode is toggled.

5.5. CONCLUSION

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6. EVALUATION

After the development approach has been motivated, designed and implemented in the previous chapters, an evaluation for both usability and data model will take place in this part.

6.1. USABILITY

Usability testing refers to evaluating a product or service by testing it with representative users. In principle, during a usability test, participants will evaluate the system with quantitive metrics.

The goal of usability testing is to collect the quantitive data, analyse the result and issue the usability problems with tested system.

6.1.1. SYSTEM USABILITY SCALE

The System Usability Scale (SUS) offers a "quick and dirty", but relative reliable approach for measuring the usability[2]. It contains a 10 item questionnaire with five rating options for participants; from *strongly agree* to *strongly disagree*.

In order to calculate the SUS score, score contributions from each item should be calculated once separately at first. Score contribution will range from 0 to 4. For items with odd number, the score contribution should minus 1. For item with even number, the contribution is 5 minus the score. The sum of all scores is multiplied by 2.5 to obtain the overall value of SUS, which has a range of 0 to 100.

$$SUS_{sum} = 2.5 \times \left(\sum_{i=1}^{5} (a_{2i-1} - 1) + \sum_{i=1}^{5} (5 - a_{2i}) \right) \tag{6.1}$$

For the SUS testing of Graphicuss system, 5 participants are involved in the interview with SUS questionnaire, which is listed in appendix A. Each participant gives his own score contribution for each item, and the average score of each item is calculated. Table 6.1 shows the result.

According to the formula 6.1, the final sum SUS score of the system is **73.5**.

[3] [4][5][6][7][8][9][10][11][12]

Item(No.)	A	B	C	D	E	Average Score
1	3	4	3	4	4	3.6
2	2	1	1	1	2	1.4
3	5	4	4	5	4	4.4
4	1	2	1	2	2	1.6
5	4	4	3	4	5	4
6	4	5	4	3	4	4
7	5	4	4	5	5	4.6
8	3	3	2	1	3	2.4
9	5	4	3	4	5	4.2
10	2	3	2	1	2	2

Table 6.1.: Score of SUS table

6.2. RENDERING PERFORMANCE

6.3. DATA MODEL EVALUATION

6.4. CONCLUSION

Conclusion!

7. CONCLUSION AND FUTURE WORK

7.1. CONCLUSION

7.2. FUTURE WORK

LIST OF FIGURES

LIST OF TABLES

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GLOSSARY

Ajax (also AJAX; short for asynchronous JavaScript and XML) is a set of web development techniques using many web technologies on the client-side to create asynchronous Web applications.. 14

API (Application programming interface) is a set of routines, protocols, and tools for building software and applications.. 17

CRUD (Create, read, update and delete) are the four basic functions of persistent storage in computer programming. . 31

MVC (Uniform Resource Identifier) is a string of characters used to identify a resource. . 45

ORM (Uniform Resource Identifier) is a string of characters used to identify a resource. . 45

SEO (Search engine optimization) is the process of affecting the visibility of a website or a web page in a web search engine's unpaid results.. 17

SPA (Single-page application) is a web application or web site that fits on a single web page with the goal of providing a more fluid user experience similar to a desktop application.. 15

URI (Uniform Resource Identifier) is a string of characters used to identify a resource. . 31

A. SYSTEM USABILITY SCALE TABLE

		Strongly disagree				Strongly agree
1.	I think that I would like to use this system frequently	1	2	3	4	5
2.	I found the system unnecessarily complex	1	2	3	4	5
3.	I thought the system was easy to use	1	2	3	4	5
4.	I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5.	I found the various functions in this system were well integrated	1	2	3	4	5
6.	I thought there was too much inconsistency in this system	1	2	3	4	5
7.	I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8.	I found the system very cumbersome to use	1	2	3	4	5
9.	I felt very confident using the system	1	2	3	4	5
10.	I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

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