



Facilitating student understanding of Internetworking via e-learning



ANDREAS KOKKALIS

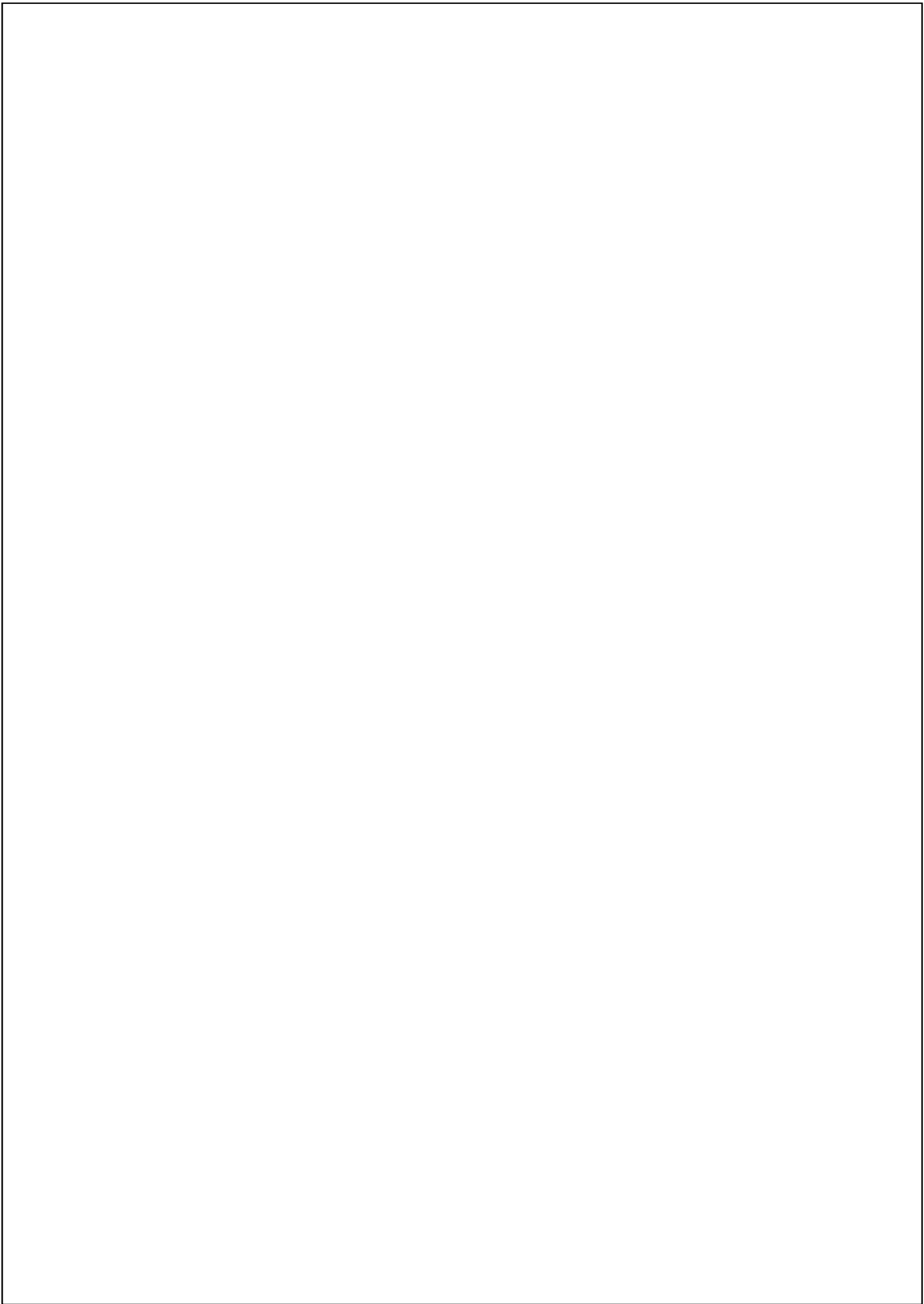
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Abstract

Learning Management Systems (LMSs) are widely used in higher education to improve the learning, teaching, and administrative tasks for both students and instructors. Such systems enrich the educational experience by integrating a wide range of services, such as on-demand course material and training, thus empowering students to achieve their learning outcomes at their own pace.

Courses in various sub-fields of Computer Science that seek to provide rich electronic learning (e-learning) experience depend on exercise material being offered in the forms of quizzes, programming exercises, laboratories, simulations, etc. Providing hands on experience in courses such as Internetworking could be facilitated by providing laboratory exercises based on virtual machine environments where the student studies the performance of different internet protocols under different conditions (such as different throughput bounds, error rates, and patterns of changes in these conditions). Unfortunately, the integration of such exercises and their tailored virtual environments is not yet very popular in LMSs.

This thesis project investigates the generation of on-demand virtual exercise environments using cloud infrastructures and integration with an LMS to provide a rich e-learning in an Internetworking course.



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Is this perhaps one of the main points of the thesis - that one can dynamically instantiate virtual exercise environments without having to have the CAPEX of running ones own infrastructure for this. This is especially important as the usage of such systems is very bursty (due both to the academic calendar and other factors).

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Acknowledgements

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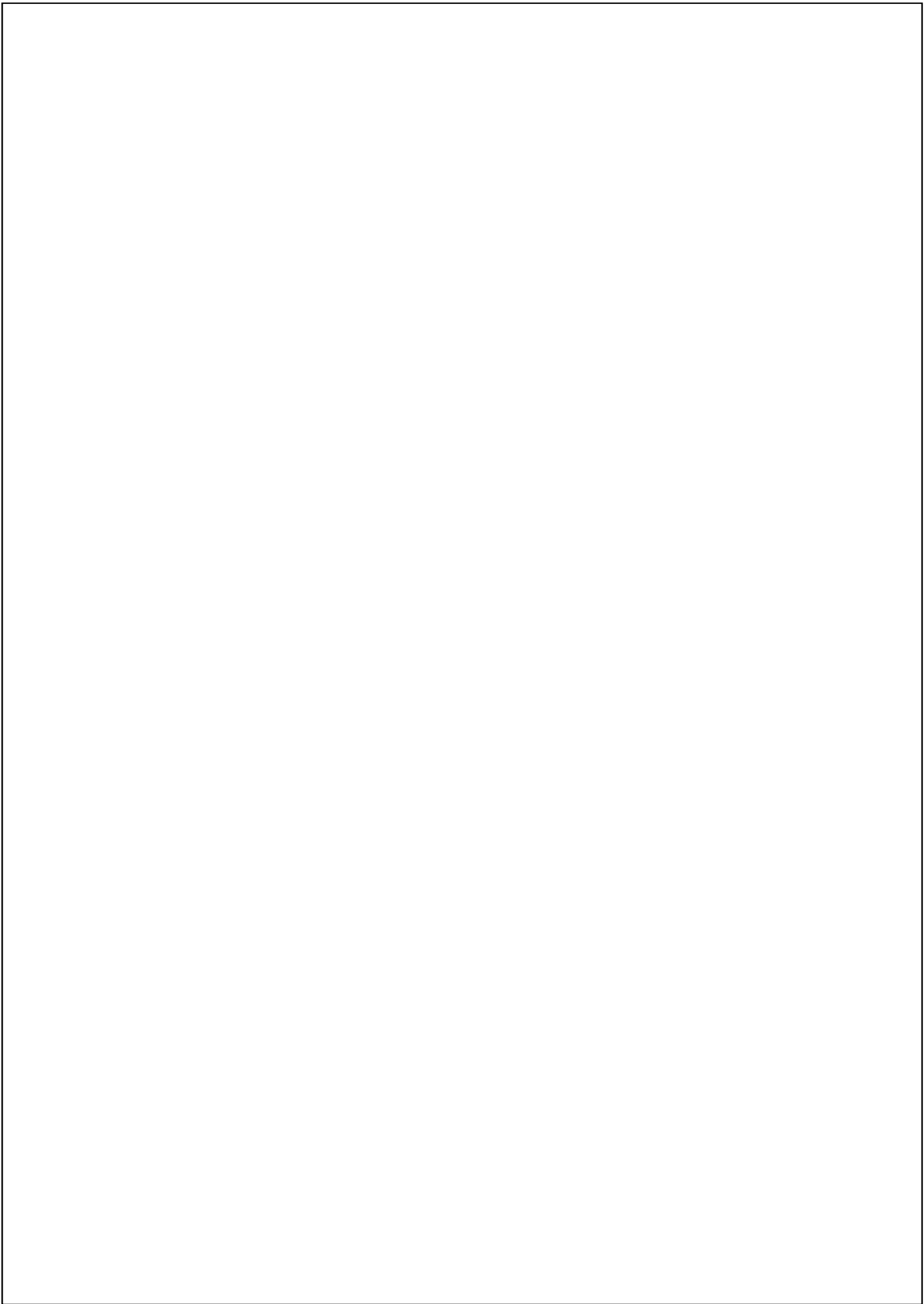
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List of Acronyms and Abbreviations

Keep alphabetical
order!

AJAX Asynchronous JavaScript and XML

AWS Amazon Web Services

CA Certificate Authority

CS Computer Science

CPU Central Processing Unit

DSL Domain Specific Language

e-learning electronic learning

EC2 Elastic Compute Cloud

ERB Embedded RuBy

GLUE! Group Learning Uniform Environment

GUI Graphical User Interface

HTML Hyper Text Markup Language

HTTP Hypertext Transfer Protocol

HTTPS Hypertext Transfer Protocol Secure

IT information technology

JSON JavaScript Object Notation

KTH Kungliga Tekniska Högskolan

LIS Learning Information Services

LMS Learning Management System

LTI Learning Tools Interoperability

LXC Linux Containers

MIME Multipurpose Internet Mail Extensions

MOOC Massive Open Online Course

OCI Open Container Initiative

SCROM Sharable Content Object Reference Model

SHA Secure Hash Algorithm

SSH Secure Shell

TC Tool Consumer

TCP Transmission Control Protocol

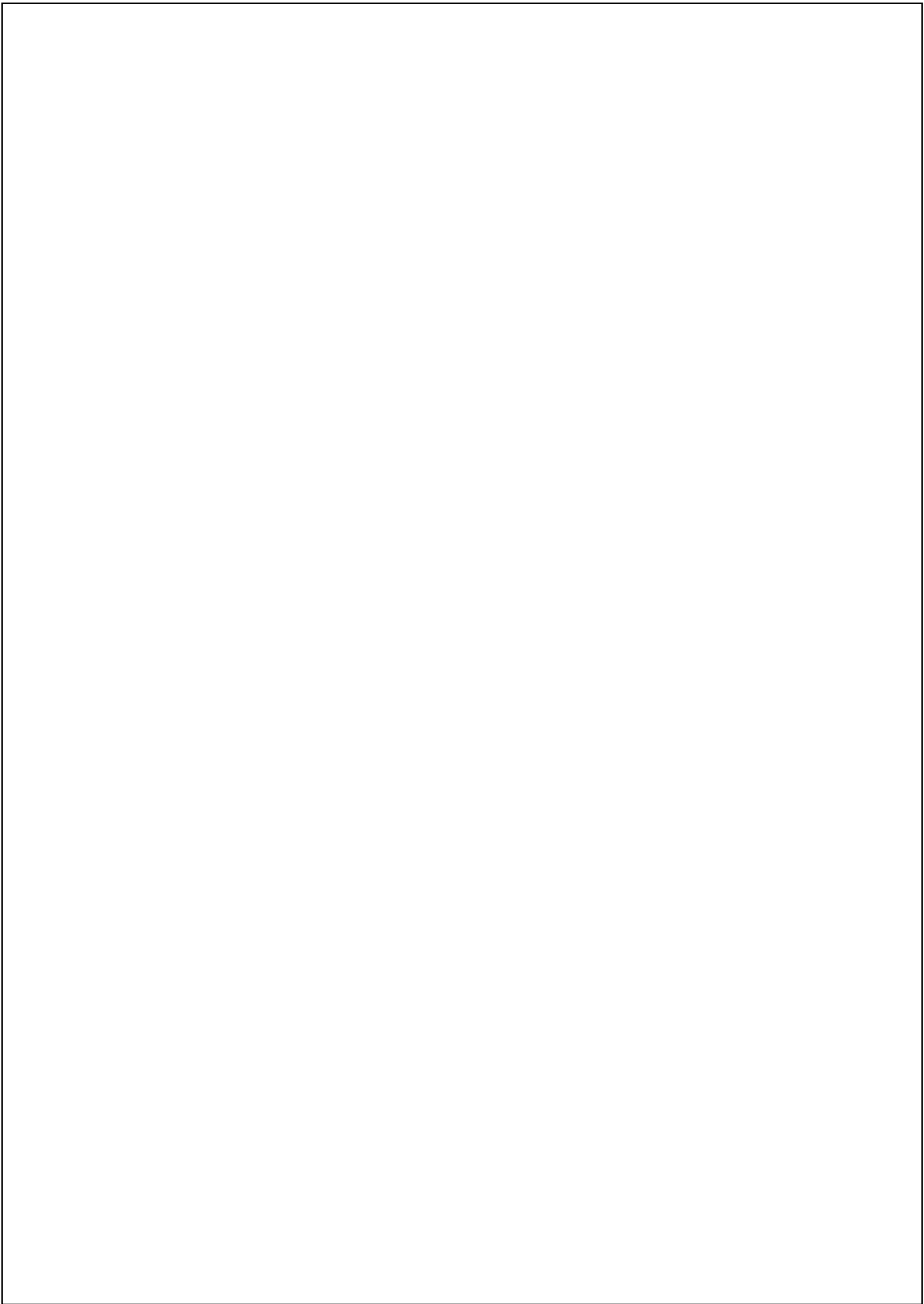
TLS Transport Layer Security

TP Tool Provider

UI User Interface

URL Uniform Resource Locator

XML Extensible Markup Language



Chapter 1

Introduction

The use of electronic learning (e-learning) technologies has been well established in modern education to assist both students and instructors in their learning, teaching, and administrative tasks. One of the e-learning technologies most widely adopted by the academic community is Learning Management Systems (LMSs). A LMS is a software application that handles all aspects of the learning process [1], enabling instructors to design rich e-learning courses and students to experience self-paced learning using a variety of features, such as on-demand course material, video lectures, automatic delivery and evaluation of assignments, collaboration tools, etc.

Many courses, especially in various sub-fields of Computer Science depend on training events in the form of programming assignments, laboratory exercises, simulations, etc. These activities are crucial for students to gain hands-on experience with complex concepts and systems [2]. Although LMSs support on-line training events, such as interactive quizzes with automatic evaluation and analysis of results, providing training events that depend on using complex virtual environments and software are not yet very popular (and hence not widely supported or used).

One of the main advantages of using an LMS is that it supports the integration of external applications to provide personalized, domain specific e-learning, such as messaging and video streaming services, on-line office suites, collaboration tools, or even training environments with exercises tailored to the needs of a specific course.

1.1 Background

Hands-on experience is very important to achieve understanding of complex systems and concepts. For example, when studying computer networks, laboratory exercises are a common student activity. An Internetworking course often involves students studying the performance of different Internet protocols under different conditions (such as varying throughput bounds, error rates, and patterns of changes in network conditions).

These experiments depend on specific software, network topologies, and local or virtual hardware. Traditional approaches for realizing such environments depend upon the student's own hardware or on-site computer labs with pre-configured software[3]. More modern approaches involve remote access to virtual machines running on central servers or cloud infrastructures [4].

Currently LMSs do not have built-in support for such laboratory environments. However, one of the main advantages of designing an on-line course on top of an LMS that supports the integration of external applications is to provide tailored functionality for the course's and student's specific needs. Today, many LMSs, such as Instructure Inc.'s Canvas [5] LMS, implement the IMS Global Learning Consortium Tools Interoperability[®] (LTI[®]) specification. Learning Tools Interoperability (LTI) allows the exchange of information between the LMS and third party components, thus exposing internal functionality of the LMS to external applications in a controlled manner.

Supporting virtual laboratory environments in a LMS in order to meet the needs of an Internetworking course, requires the design of a software framework that implements the LTI interoperability specification in order to exchange relevant information between the laboratory environment and the LMS.

1.2 Problem definition

Hands on experience is very important aspect of the learning process in several fields of Computer Science, including computer networks. Understanding the domain specific concepts and problems of an Internetworking course, depends greatly on exercise material and laboratory practice. Today, such exercises, are not usually designed to extract suitable analytics for the instructor (as an instructor ideally wishes to evaluate each student's level of understanding of each of the different concepts covered in an exercise). Assessing the student's understanding is currently achieved by using additional training material, such as quizzes or assignments in forms of reports which are manually evaluated by instructors or by other students in the form of peer reviews. These alternative methods both introduce a delay in feedback to the student (hence reducing the student's rate of learning) and are not scalable (for example, preventing their use in Massive Open Online Courses (MOOCs)).

Supporting an on-line version of an Internetworking course through a LMS that enables students to achieve the course's learning outcomes at their own pace, depends greatly on designing interactive practice environments. Such environments should be easily modified by the instructor to fit the needs of different exercises. Moreover, the environment must provide feedback for both students and teachers. Although today LMSs support a variety of training events, such as quizzes and assignments through integration of external services, on-line virtual laboratory environments that fulfill the requirements of an Internetworking course are not yet well supported and hence not widely used.

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1.3. GOALS

However, similar practice environments are common in on-line courses that teach programming languages. Such environments are part of systems that provide tools for designing coding assignments, and support several assessment methods, including automatic evaluation and grading of code[6] and programming quizzes. These systems often provide standalone web applications or LTI integrations in LMSs that expose functionality for developing code, submitting assignments, and presenting feedback to users[7, 8].

This project aims to design a software framework that supports interactive training material for an Internetworking course that extracts suitable analytics of the learning process for both students and instructors , and integrates with a LMS to provide a rich e-learning experience.



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1.3 Goals

The design of such a laboratory environment for an Internetworking course has to meet several user requirements from the perspective of both students and instructors, and integrate with a LMS to offer a rich e-learning experience. The expected outcome of this project is a software framework that supports instantiation of on-demand laboratory environments using cloud based technologies to enrich the learning experience of students, allowing them to proceed at their own pace. Additionally, the framework should enable a teacher to customize the environment according to different exercises' requirements, and provide the instructor with constructive feedback about each student's progress and understanding.

The process of designing this framework can be realized by achieving the following goals:

- Devise a method to easily build virtual laboratory environments,
- The framework should support evaluation and analysis methods to be applied to the exercise in a way that is useful for both instructors and students.
- The framework should be integrated with the LMS to enable students to access the training environments via the LMS,
- The method of integration of such exercise environments should be usable by others - thus an important part of this thesis project is documenting the selected method to facilitate the integration of a diverse set of external environments (for example, an ns-3 simulator configured for a particular simulation),
- The framework should scale in such way that it enables students to do assignments at any given time, thus offering on-demand availability of the underlying services, and



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Similarly - move to future work.

- A student should be able to access a training environment within reasonable upper bounded time from the moment she requests from the LMS to start an assignment.

1.4 Research Methodology

Design science research addresses important unsolved problems in unique or innovative ways or solved problems in more effective or efficient ways. It focuses on the design and construction of information technology (IT) artifacts that have utility in real-world, application environments. The artifacts, as the outcome of the research process, aim to improve domain-specific systems and processes [9, 10]. The utility, quality, and adequacy of a design artifact, is thoroughly evaluated under varying experimental setups to verify that it successfully fulfills the stated requirements.

Design, in several research fields, including IT, is an iterative process of planning, generating alternatives, and selecting a satisfactory outcome. Design science research, although it is not performed using strictly defined processes, can be summarized by three closely related cycles of activities (these cycles are the relevance cycle, the rigor cycle, and the design cycle)[11], that act as guidelines for designing, constructing, and evaluating an artifact. The relevance cycle establishes the application context that not only provides the requirements for the research as inputs, but also defines acceptance criteria for the evaluation of the research results. The rigor cycle provides past knowledge to the research project to ensure its innovation. It is contingent on researchers to thoroughly research and reference this knowledge base in order to guarantee that the designs produced are research contributions and not routine designs based upon the application of well-known processes. The central Design Cycle iterates between the core activities of building and evaluating the design artifacts and processes of the research [9], until the acceptance criteria, as defined in the Relevance Cycle, are met.

This project is carried out using the design science research approach. The resulting software and documentation attempt to solve the problem of designing and realizing a framework for rich on-line laboratory environments for an elearning course on Internetworking, that is to be accessible via a specific learning management system (Canvas LMS). The two different domains that define the context of this problem are the Internetworking course domain, and the LMS along with the method(s) of integration of external applications into Canvas (in this case via LTI).

1.5 Delimitations

This project addresses the problem of designing and integrating virtual laboratory environments to support e-learning in an LMS for an Internetworking course. The laboratory framework, the expected outcome of this project, has to fulfill several

1.6. STRUCTURE OF THE THESIS

requirements: usability for different types of users (instructor, administrator, and student.), integration into the Canvas LMS via the LTI specification, and satisfy the laboratory and pedagogical challenges of this particular course. Although there are different specifications for integrating external applications and services into a LMS [12], this project addresses only the LTI specifications, as this method is supported by Canvas (along with many other LMSs, for example LTI can be used together with edX as either a consumer or producer[13]). The laboratory framework, is designed to suit the needs of a typical classroom (in this case approximately 30 students), thus its scalability is limited.

Testing the scalability of the designed system regarding the number of users is outside of the scope of this thesis project. However, a system might be scaled up ~~by Amazon Web Services (AWS)~~ by using larger instances (vertical scaling) or by creating multiple instances (horizontal scaling) . Additionally, scaling up and down of services in clouds has been investigated by others [14].

TODO: Internetworking assignments, and extraction of relevant analytics have also limitations. Make sure that they are reflected in this section.

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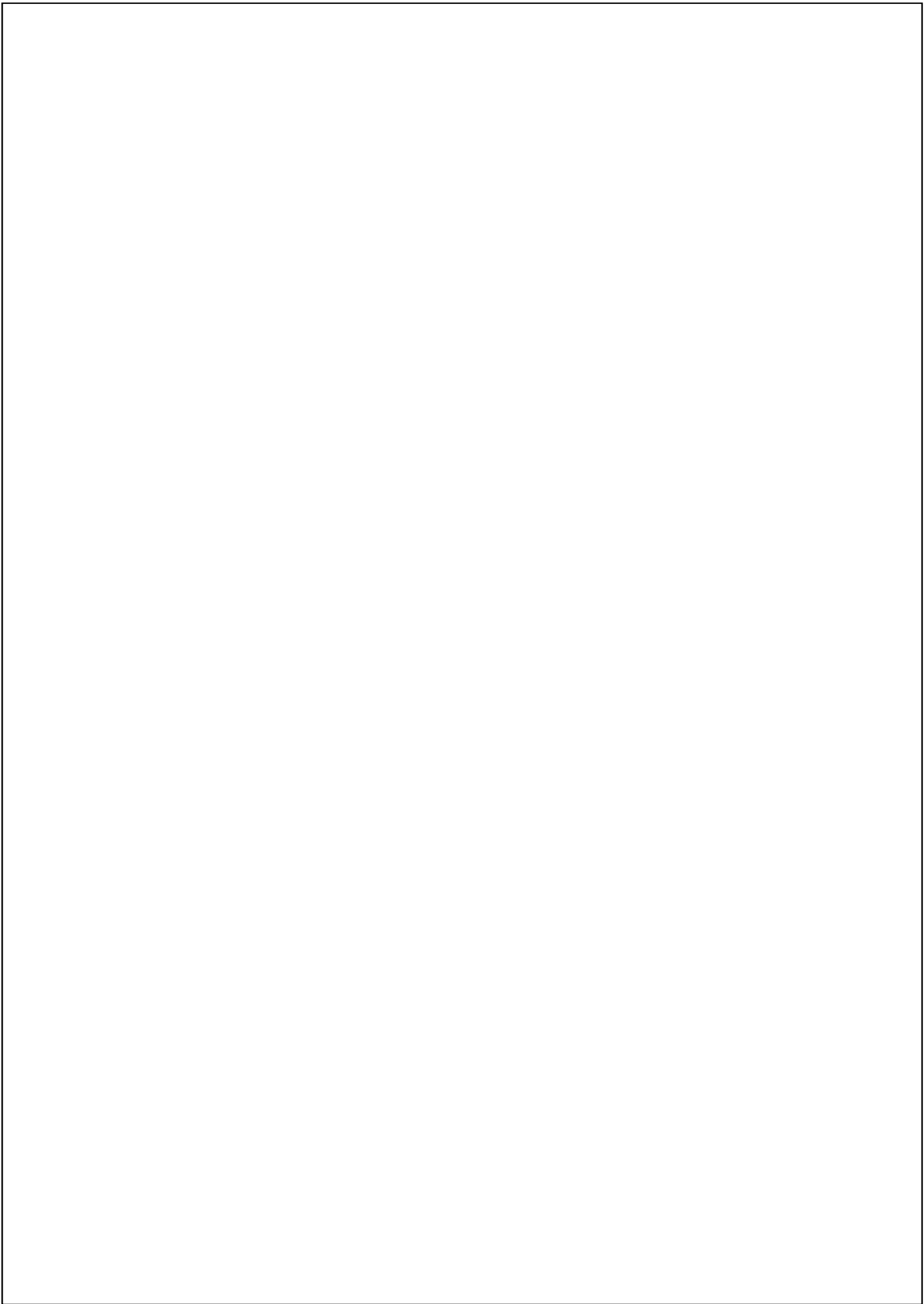
1.6 Structure of the thesis

Chapter 2 explains what an LMS is, introduces the LTI specification for integrating external learning applications into such systems, and presents an example of an external learning tool which is integrated with Canvas LMS. Furthermore, it presents the related technologies that was used to implement the software outcome of this project, along with projects that addressed problems related to the e-learning process in other fields of Computer Science (CS). Chapter 3 explains the methods used to evaluate the proposed artifact. Chapter 4 presents the software artifact that was designed to facilitate student understanding of Internetworking via e-learning, and finally, Chapter 5 presents the results and the future work required to prepare the software artifact for use in production with Canvas LMS.

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Chapter 2

Background

This chapter explains what is a LMS and how learning applications are integrated in such systems to support rich e-learning. Moreover, it introduces research artifacts that offer on-line training environments for various courses in the CS domain. Lastly, it introduces those technologies that were used to design the framework that supports training events for an Internetworking course.

2.1 LMS

LMSs are software applications that automate the training, teaching, and administrative tasks of the learning process [1]. They have been widely adopted by higher education institutions to automate their organizational functions and provide a rich e-learning experience for both instructors and students.

Such systems are designed to provide self-guided services; rapid delivery and composition of learning material; tracking and reporting of progress through training programs, classroom, or on-line events; personalized content; and centralization and automation of administration [15]. From a learner's perspective the most common use cases of a LMS are planning ones own learning experience and collaboration with colleagues; while from an instructor's perspective the most common use cases are the design and delivery of educational content along with tracking and analysis of students' learning evolution [16].

The main functionality of a LMS concerns content organization and delivery, communication and collaboration, and assessment* of student's learning process. Some of the most commonly used features of an LMS for e-learning are video streaming of lectures, on-line notes and presentations, quizzes and practice environments, automatic evaluation of assignments (usually exercises with

*According to Wynne Harlen and Mary James [17], formative assessment is performed by teachers during the learning process, to modify and improve the teaching and learning activities. It is based on observation of students' individual efforts and development; thus, having a qualitative and diagnostic nature. Summative assessment, performed by both instructors and students, is based on public criteria that aim to measure student's achieving of the course learning outcomes.

predefined input and output), wikis, and discussion forums [18]. These services are either offered directly by the LMS or by integrating external applications that are designed according to specific interoperability standards. Section 2.2 describes this interoperability and integration in detail.

Although LMSs provide built-in learning applications for designing e-learning courses, their functionality is often very limited and might not suit the needs of every course. Moreover, not all LMSs support the same learning tools, nor provide the same functionality for e-learning. On the contrary, external learning tools can be integrated with multiple different LMSs, and allow re-using existing material thus minimizing the effort for designing an e-learning course. Usually such tools are web services* that are discoverable by an LMS via the service's Uniform Resource Locator (URL) and authorization parameters (such as secret keys). The communication between the LMS and the tool is performed by exchanging messages whose format and content is defined by the interoperability specification. Section 2.3 shows several web frameworks that can be used to design external learning tools as web services.

There are several LMSs in the market (Blackboard, Moodle, Kanu, ...) that are used by multiple institutions. In the scope of this project the chosen learning management platform is Canvas [5]. This LMS was chosen because the system is open source, supports a well defined interoperability specification, and was selected in 2016 by KTH as their LMS.

2.2 LTI

Interoperability is the ability to communicate, execute programs, or transfer data among functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units [19]. An e-learning platform usually consists of several services such as course and user administration modules, and learning applications that exchange information in a formal and standardized way.

The IMS Global Learning Consortium Tools Interoperability (LTI) specification establishes a way of integrating rich learning applications (often remotely hosted and provided through third-party services) with platforms, such as LMSs, portals, learning object repositories, or other educational environments [20]. The main goal of LTI is to standardize the process of building links for sharing information and exposing functionality between external learning tools and the LMS [21]. There are two major pieces of software involved in LTI. The first is called a Tool Consumer (TC) and it refers to the software (such as an LMS) that consumes the output of

*In service oriented architectures, a web service is a piece of software that makes itself available over the Internet and allows third-party software to communicate with them by exchanging strictly defined messages formatted in Extensible Markup Language (XML), JavaScript Object Notation (JSON), etc.

2.2. LTI

external tools, and the second, is a Tool Provider (TP) which provides an external tool for use by the TC.

An example of a basic learning tool, is a service that accepts a request to perform a course assignment such as multiple choice question via a web form, evaluates the user's input, and returns a pass/fail grade. In this scenario, the service is the TP and Canvas LMS is the TC. A user of Canvas with administrative access (e.g., teacher), configures the integration of the external tool, a course assignment for which the tool will be launched, and finally, chooses whether the interface of the tool will be embedded in Canvas, or run in a new browser window. Figure 2.1 shows a basic flow for launching a TP from the TC. The user requests from the LMS that they want to do an assignment. This specific assignment has been configured to launch a specific LTI capable external tool together with arguments that are passed to the TP. The TP authenticates and accepts the LTI Launch request by the TC and starts a session for that particular user that allows this user to interact with the assignment.

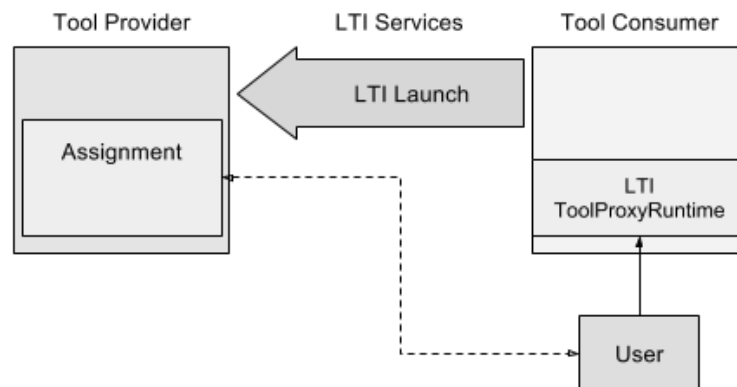


Figure 2.1: User launching an external tool

A TP often requires access to course related information, such as people, groups, memberships, courses, and outcomes. This information along with standardized ways of retrieving it are defined by the IMS Global Learning Consortium Learning Information Services (LIS) specification [22]. These services can be provided either by the TC or by a third party system. Canvas LMS implements the LTI version 1.1 which includes a subset of the LIS specification, called the LTI Basic Outcomes Service. In the example mentioned above, the information that Canvas provides to the TP when performing an LTI Launch are: how to access the LIS services, the resource identifier (assignment) for which a grade will be reported, and user information such as the unique identifier of the student. Figure 2.2 shows how a TP can communicate with LIS services to get user data and report the grade of the assignment back to the TC.

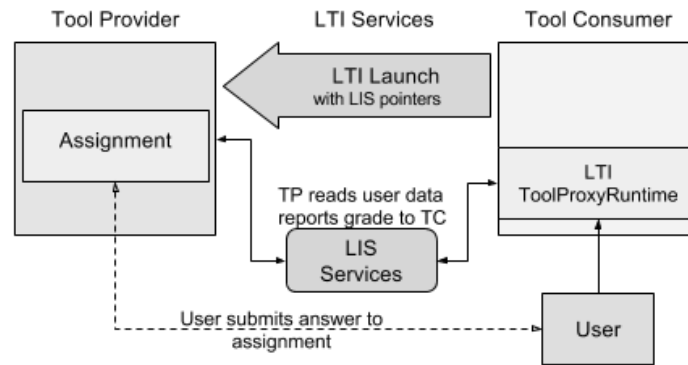


Figure 2.2: A TP using LIS services

2.3 Sinatra DSL

A simple web server is a piece of software designed to process Hypertext Transfer Protocol (HTTP) requests. Many web frameworks have been developed in several programming languages that allow to quickly develop web servers and applications. Sinatra[23, 24] amongst them, is a Domain Specific Language (DSL) for writing web applications in Ruby. A Sinatra web application is organized around routes which are HTTP methods paired with a URL-matching pattern. Listing 2.1 presents a minimal sinatra application. The route "/" is paired with a `get` HTTP method. Every time this route is invoked, it provides a "Hello World!" text response.

```
# hello_world.rb
require 'sinatra'

get '/' do
  'Hello world!'
end
```

Listing 2.1: Sinatra basic route

A file named `hello_world.rb` contains the code shown in Listing 2.1, which is called a route block. A route block starts with a keyword such as `get`, `post`, `put`, ... and corresponds to an HTTP method, and finishes with the keyword `end`. Executing the web application is as simple as running the command `ruby hello_world.rb`. This will start a sinatra web server on the default host (`localhost`) that listens for Transmission Control Protocol (TCP) connections on the default port (4567). By visiting the URL `http://localhost:4567/` with a browser, the route "/" is invoked and the response returned to the user.

A route can also utilize HTTP GET query parameters as shown in Listing 2.2. In this case, if a `course_id` is provided as a parameter of query string, then its value

2.3. SINATRA DSL

is loaded into the local variable `courseID`. The same concept could be applied if the route was an HTTP POST method and `course_id` was one of the post's parameters.

```
get '/assignments' do
  # matches "GET /assignments?course_id=IKXXX"
  courseID = params['course_id']
  # uses course_id variable; query is optional to the / route
end
```

Listing 2.2: Sinatra route with HTTP GET parameters

Sinatra also supports the use of wildcards to match all parameters of the query string. Such parameters are called `splat`, are symbolized with a `"*"` router pattern, and are accessible via the `params['splat']` array. In the Listing 2.3, the route `'/department/*/course/*'` represents the course catalog of a university. The `splat` parameters match the department (`informatics`) and course (`ID001`) identifiers respectively.

```
get '/department/*/course/*' do
  # matches /department/informatics/course/ID001
  params['splat'] # => ["informatics", "ID001"]
end
```

Listing 2.3: Wildcard route pattern

Templates are a text injection mechanism, that allows static text to be enriched using dynamic content (e.g., an Hyper Text Markup Language (HTML) template might contain some static text and variables, where the variables are replaced during runtime). In Sinatra a template by default is stored under the directory `./views`, and can be used in many different ways, including rendering HTML pages, constructing a JSON object as a response to an HTTP request, etc. Listing 2.4 shows the route `get '/assignments'` which stores the value of the `course_id` parameter into an instance variable `@courseID` which makes the value of this variable available for use in the template shown in Listing 2.5.

```
get '/assignments' do
  @courseID = params['course_id']
  erb :index
end
```

Listing 2.4: Sinatra route with template

Calling the `assignments` route by visiting the url `http://localhost:4567/assignments?course_id=IK1552` will parse the query parameter, invoke the `index.erb` template* stored under the directory `./views`, and substitute the text `<%= @courseID%>` with the value of the variable `@courseID`. The response that will be rendered by the browser will be an HTML page that contains the text "List of assignments for IK1552" in its body.

*Embedded RuBy (ERB) is part of the Ruby standard library, and serves as the mechanism for variable substitution within template files.

```

<!DOCTYPE html>
<html>
  <head>
    <title>Assignments</title>
  </head>
  <body>
    <p>List of assignments for <%= @courseID%></p>
  </body>
</html>

```

Listing 2.5: index.erb

A Sinatra route can be used to serve static files. By default, static files are served from the `./public` directory that is located under in the same directory as the application. A Sinatra application, though it is minimalistic, it is not limited to default options, thus one can configure different port numbers, root directories, custom template engines and locations, etc. Other web servers similar to Sinatra are: Flask in Python, Netty in Java, and goa in golang.

2.4 LTI tool producer

This section presents a TP written in Ruby Sinatra that implements the Basic Outcomes Service of the LTI specification, and is integrated into the Canvas LMS which will act as a TC. The TP has three routes (listed in Table 2.1).

Table 2.1: Routes of the TP

launch	route for launching the external tool
assignment	route for starting an assignment
report	route for reporting the result of the assignment to Canvas LMS

The **launch** route implements the LTI Launch functionality of the LTI specification, accepts requests for launching the external tool, and initiates a unique session per request. The **assignment** route checks for a valid session, and then returns an HTTP response with an HTML form. The form is the assignment and in this example contains a simple arithmetic question that the student has to reply to by submitting her answer in the form's input. Finally, the **report** route validates the student's input, and reports a pass/fail grade to the TC.

This example assumes that a Canvas instructor has created an assignment and configured it to launch the TP. The following code snippets present the code implementation of the TP (inspired by `lti_example` from this github repository[25] of Instructure Inc.), the functionality of each route, and the XML messages that are used to communicate with the TC.

Listing 2.6 shows the code dependencies to implement the TP. First it requires the `sinatra` gem* and the `oauth` gem (used to implement the service provider,

*Ruby gems are versioned packages of ruby source code. In practice they are libraries that

2.4. LTI TOOL PRODUCER

according to the LTI specification for authorization between a a TP and a TC). The `$oauth_key` and `$oauth_secret` variables define the key and secret that is used by the TP to identify the TC. These variables are configured in a Canvas LMS when specifying the external tool. Finally the `disable :protection` statement allows for the HTML content produced by the Sinatra application to be embedded into an HTML frame of the TC, and the `enable :sessions` statement allows for session information to be used between subsequent HTTP requests to Sinatra routes.

```
# dependencies
require 'sinatra'
require 'oauth'
require 'oauth/request_proxy/rack_request'

# key and secret for authenticating requests from the TC
$oauth_key = "test"
$oauth_secret = "secret"

# disable x-frame to allow embedding the TP in the TC
disable :protection

# enable sessions for uniquely identifying students
enable :sessions
```

Listing 2.6: Code dependencies and some global variables of the TP

The `launch` route shown in Listing 2.7 is responsible for authorizing a request from the TC to launch the assignment. First it verifies the `request` against the `secret` variable. If the authorization fails, then a text message is returned to inform the Canvas user that the integration of the tool was not successful. After the authorization succeeds, the HTTP request parameters `lis_outcome_service_url` and `lis_result_sourcedid` (these correspond to the LTI LIS services) are read. The first corresponds to the TC URL that is used to report a grade for an assignment, while the latter is a unique identifier that is used to map an assignment grade for a particular student. If these parameters were not provided when Canvas invoked this route, then the request will fail. By default Canvas sets these parameters when a tool provider is correctly configured as graded assignment. After the successful verification of the afore mentioned parameters, their values are stored in corresponding session objects and the route redirects to the `get /assignment` route.

are hosted in public servers that make them available for download via ruby package management systems.


```

post "/launch" do
  # verify the request of the TC
  begin
    signature = OAuth::Signature.build(request, :
    consumer_secret => $oauth_secret)
    signature.verify() or raise OAuth::Unauthorized
  rescue OAuth::Signature::UnknownSignatureMethod,
    OAuth::Unauthorized
    return %{{Unauthorized attempt. Make sure you used the
    consumer secret "#{$oauth_secret}"}}
  end

  # Verify that this is a valid request to perform an
  assignment
  unless params['lis_outcome_service_url'] && params['
  lis_result_sourcedid']
    return %{{It looks like this LTI tool was not launched as
    an assignment, or you are trying to do the assignment as a
    teacher rather than as a student.}}
  end

  # store the relevant parameters from the launch into the
  user's session, for
  # access during subsequent HTTP requests.
  %w(lis_outcome_service_url lis_result_sourcedid).each { |v|
    session[v] = params[v] }

  # Go to the assignment
  redirect to("/assignment")
end

```

Listing 2.7: Launch route

The `/assignment` route, presented in Listing 2.8, starts by validating the session variable `lis_result_sourcedid`. If this parameter was not set, then the tool was not launched via the TC, hence an error text message is returned. This error message will be visible to the user's browser (either as a frame within Canvas LMS or as a new tab on the user's browser). If the session is valid, then the route replies with an HTML form that is rendered by the user's browser. This form includes a simple arithmetic addition question and an input field for the student to reply. The form action sends the form to the `report` route and using HTTP `post` method. When the student presses the submit button within the browser, the `report` route is invoked. Note that in this listing the form has been included directly in the route block, but it could have been placed in a ruby template such as the one of Listing 2.5.

2.4. LTI TOOL PRODUCER

```
get "/assignment" do
  # Verify the validity of the session
  unless session['lis_result_sourcedid']
    return %{{You need to take this assignment through Canvas.}}
  end

  # Render a form with the assignment question.
  <<-HTML
  <html>
    <head><title>Demo LTI Assignment</title></head>
    <body>
      <form action="/report" method="post">
        <p>What is the sum of 100 + 200 ?</p>
        <input name='sum' type='text' width='5' id='sum'
required />
        <input type='submit' value='Submit' />
      </form>
    </body>
  </html>
  HTML
end
```

Listing 2.8: Assignment route

The `report` route is displayed in Listing 2.9 and is invoked when the student submits the form. If the form parameter `sum` is not provided, then the user is redirected (again) to the assignment via the corresponding route. Upon successful validation of the form input, an XML response message is defined and sent to Canvas via the appropriate LIS services to report the student's grade for this assignment. The format of the XML message is based upon the `imsx_POXEnvelopeRequest` class defined in the XML schema of the IMS General Web Services documentation [26] and described in the LTI 1.0 implementation guide [27].

The body of the message contains the field `sourceID` that is assigned the value of the session variable `#session['lis_result_sourcedid']`, and the `resultScore` field that corresponds to the assignment's grade and gets the value 1 in the `textString` subfield if the provided sum was 300 or 0 otherwise. The corresponding assignment had been configured earlier in Canvas to accept a maximum of 1 point for the grade for this assignment.

The message is signed according to OAuth 1.0 protocol* using the same consumer key and secret that were provided during the LTI launch request (`launch` route). The message is posted synchronously to the Canvas LIS service defined by `session['lis_outcome_service_url']` using a Multipurpose Internet

*OAuth provides a method for clients to access server resources on behalf of a resource owner (such as a different client or an end-user). It also provides a process for end-users to authorize third-party access to their server resources without sharing their credentials (typically, a username and password pair), using user-agent redirections.[28]

Mail Extensions (MIME)[†] encoding, and the response is stored in the `response` variable. Because the post was done synchronously the code will wait until the response to this post is received. Thus the body of the response can be used to compute the message to be displayed to the user via their browser.

Listing 2.9: Report the assignment grade to Canvas

```
post "/report" do
  sum = params['sum']
  if !sum || sum.empty?
    redirect to("/assignment")
  end

  # now post the score to canvas. Make sure to sign the POST
  # correctly with
  # OAuth 1.0, including the digest of the XML body. Also make
  # sure to set the
  # content-type to application/xml.
  xml = %{
<?xml version = "1.0" encoding = "UTF-8"?>
<imsx_POXEnvelopeRequest xmlns = "http://www.imsglobal.org/lis
/omsip0/pox">
  <imsx_POXHeader>
    <imsx_POXRequestHeaderInfo>
      <imsx_version>V1.0</imsx_version>
      <imsx_messageIdentifier>12341234</imsx_messageIdentifier>
    </imsx_POXRequestHeaderInfo>
  </imsx_POXHeader>
  <imsx_POXBody>
    <replaceResultRequest>
      <resultRecord>
        <sourcedGUID>
          <sourcedId>#{session['lis_result_sourcedid']}</sourcedId>
        </sourcedGUID>
        <result>
          <resultScore>
            <language>en</language>
            <textString>#{sum == 300 ? 1 : 0}</textString>
          </resultScore>
        </result>
      </resultRecord>
    </replaceResultRequest>
  </imsx_POXBody>
</imsx_POXEnvelopeRequest>
}
```

[†]The MIME-type is a two-part identifier for file formats and format of contents transmitted on the Internet.

2.4. LTI TOOL PRODUCER

```
consumer = OAuth::Consumer.new($oauth_key, $oauth_secret)
token = OAuth::AccessToken.new(consumer)
response = token.post(session['lis_outcome_service_url'],
  xml, 'Content-Type' => 'application/xml')

headers 'Content-Type' => 'text'
%{
Your score has #{response.body.match(/\bsuccess\b/) ? "been
  posted" : "failed in posting"} to Canvas. The response was:
#{response.body}
}
end
```

Lastly the contents of `reponse` are evaluated and checked whether posting the grade was successful or not, and a text message is sent to the user to be rendered by her browser informing her about the status of posting the grade to Canvas. The response of a successful post is highlighted in Listing 2.10 in the `imsx_codeMajor` xml field.

```
<?xml version="1.0" encoding="UTF-8"?>
<imsx_POXEnvelopeResponse xmlns="http://www.imsglobal.org/
  services/ltiv1p1/xsd/imsoms_v1p0">
  <imsx_POXHeader>
    <imsx_POXResponseHeaderInfo>
      <imsx_version>V1.0</imsx_version>
      <imsx_messageIdentifier/>
      <imsx_statusInfo>
        <imsx_codeMajor>success</imsx_codeMajor>
        <imsx_severity>status</imsx_severity>
        <imsx_description/>
        <imsx_messageRefIdentifier>12341234</
imsx_messageRefIdentifier>
        <imsx_operationRefIdentifier>replaceResult</
imsx_operationRefIdentifier>
      </imsx_statusInfo>
    </imsx_POXResponseHeaderInfo>
  </imsx_POXHeader>
  <imsx_POXBody><replaceResultResponse/></imsx_POXBody>
</imsx_POXEnvelopeResponse>
```

Listing 2.10: XML response from Canvas

2.4.1 Integration of an external application into Canvas LMS

The text above presented how to develop a simple LTI producer that supports graded assignments. The Graphical User Interface (GUI) of Canvas LMS allows the integration of external applications via different options such as manual configuration forms, launch URLs, and pasting XML entries. This section will present how to configure the external tool of the previous section using a manual

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configuration form via the **Settings->Apps->External Apps->Add App** menu for a course. Here we assume that an instructor wishes to add an external app for a particular course. The input form shown in Figure 2.3 is loaded. The instructor inputs a name for the application, the LTI Launch URL, and the consumer key and secret.

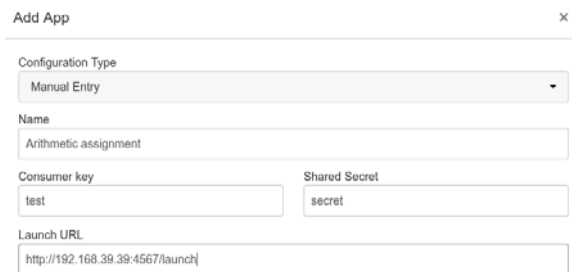


Figure 2.3: Adding an external application to Canvas

After adding this external tool, the instructor creates a new assignment, configures it to launch the application within Canvas, or using an external window as shown in Figure 2.4, and specifies a grading scheme. Once the assignment is configured and published in Canvas, a student can do this assignment via the course page. Section 2.5 explains how to integrate external applications using URLs and XML configuration.

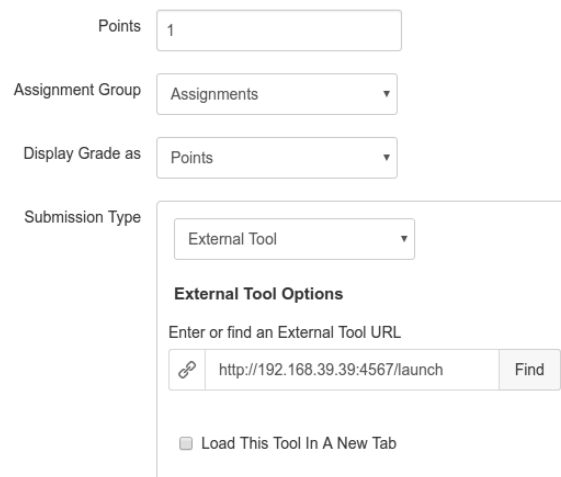


Figure 2.4: Configuring an assignment to use an external tool

2.4. LTI TOOL PRODUCER

2.4.2 Securing the connection between a TP and a TC

The communication between Canvas LMS and external application tools is by default expected to be performed using the Hypertext Transfer Protocol Secure (HTTPS)* protocol. In the example presented in previous section, the communication between the TP and the TC was over HTTP, hence Canvas generated a corresponding error while launching the TP. The Sinatra web-server can be easily configured to listen for HTTPS connections on some port. Listing 2.11 shows such a configuration of the Sinatra web server (named Webrick). HTTPS requires a TLS certificate which for the purposes of this example was issued and signed using the OpenSSL[29] cryptography and TLS toolkit, rather than a trusted third party Certificate Authority (CA).

*HTTPS is a protocol for communication over HTTP within a connection encrypted by Transport Layer Security (TLS). TLS uses a public and a private encryption key to generate a session key which is used to encrypt the data flow between client and server. An HTTP message is encrypted prior to transmission and decrypted upon arrival.

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```
require 'sinatra/base'
require 'webrick'
require 'webrick/https'
require 'openssl'

CERT_PATH = '/opt/CA/'

webrick_options = {
  :Port          => 8443,
  :Logger        => WEBrick::Log::new($stderr, WEBrick::
    Log::DEBUG),
  :DocumentRoot  => "/ruby/htdocs",
  :SSLEnable     => true,
  :SSLVerifyClient => OpenSSL::SSL::VERIFY_NONE,
  :SSLCertificate => OpenSSL::X509::Certificate.new(File.
    open(File.join(CERT_PATH, "cert.pem")).read),
  :SSLPrivateKey => OpenSSL::PKey::RSA.new(File.open(File.
    .join(CERT_PATH, "key.pem")).read),
  :SSLCertName   => [ [ "CN", '127.0.0.1' ] ]
}

class MyServer < Sinatra::Base
  post '/' do
    "Hello, world!"
  end
end

Rack::Handler::WEBrick.run MyServer, webrick_options
```

Listing 2.11: TLS configuration of a Sinatra application

Listing 2.12 shows how to generate a TLS certificate using the OpenSSL command line tool. The command is `openssl req` and it takes several arguments such as `-new` (request new certificate), `-x509` (format of the public key), `-extensions v3_ca` (the extensions to add for a self signed certificate, shown in the corresponding block of Listing 2.13, `-keyout key.pem` (the output file for storing the key), `-out cert.pem` (the output file for storing the self-signed certificate), `-days 365` (the number of days until the certificate expires), and finally the sample configuration file `openssl.conf` for reading the default values.

```
openssl req -new -x509 -extensions v3_ca -keyout key.pem -out
cert.pem -days 365 -config ./openssl.conf
```

Listing 2.12: Generating a self signed TLS certificate and encryption key

2.4. LTI TOOL PRODUCER

The OpenSSL configuration shown in Listing 2.13, is a sample file containing default values for generating a TLS certificate and a public key file, and is available for download in Markus Redivo's page "Creating and Using SSL Certificates" [30]. More details regarding the use of the `req` command of the OpenSSL toolkit can be found in the corresponding man page[31], and information about the configuration file can be found in Phil Dibowitz's blog page "Openssl.conf walkthru" [32].

Listing 2.13: Sample OpenSSL configuration for issuing SSL/TLS certificates

```
---Begin---
# OpenSSL configuration file.

# Establish working directory.
dir = .

[ ca ]
default_ca = CA_default

[ CA_default ]
serial      = $dir/serial
database    = $dir/index.txt
new_certs_dir = $dir/newcerts
certificate = $dir/cacert.pem
private_key = $dir/private/cakey.pem
default_days = 365
default_md   = md5
preserve     = no
email_in_dn  = no
nameopt      = default_ca
certopt      = default_ca
policy       = policy_match

[ policy_match ]
countryName      = match
stateOrProvinceName = match
organizationName = match
organizationalUnitName = optional
commonName       = supplied
emailAddress      = optional

[ req ]
default_bits      = 1024      # Size of keys
default_keyfile    = key.pem  # name of generated keys
default_md         = md5      # message digest algorithm
string_mask       = nombstr   # permitted characters
distinguished_name = req_distinguished_name
req_extensions     = v3_req

[ req_distinguished_name ]
# Variable name      Prompt string
```



```

#-----
0.organizationName      = Organization Name (company)
organizationalUnitName  = Organizational Unit Name (department, division)
emailAddress            = Email Address
emailAddress_max        = 40
localityName            = Locality Name (city, district)
stateOrProvinceName     = State or Province Name (full name)
countryName             = Country Name (2 letter code)
countryName_min         = 2
countryName_max         = 2
commonName              = Common Name (hostname, IP, or your name)
commonName_max          = 64

# Default values for the above, for consistency and less typing.
# Variable name          Value
#-----
0.organizationName_default = The Sample Company
localityName_default      = Metropolis
stateOrProvinceName_default = New York
countryName_default       = US

[ v3_ca ]
basicConstraints          = CA:TRUE
subjectKeyIdentifier      = hash
authorityKeyIdentifier    = keyid:always,issuer:always

[ v3_req ]
basicConstraints          = CA:FALSE
subjectKeyIdentifier      = hash

----End----

```

2.5 LTI applications

Edu App Center[33] is an open database for learning tools maintained by Instructure [34] and among its several services, it offers a collection of open learning applications that implement the LTI specification. These applications can be integrated with different LMSs. The user can apply filters to locate an appropriate tool and can browse tutorials about integrating a tool with the LMS of their choice. Often these tools are hosted by third party services (e.g GitHub, Youtube, Turnitin). The goal of Edu App Center is to enable instructors to easily configure these external applications to their courses, thus providing and fostering a market place for LTI applications.

Section 2.4.1 presented how an instructor can integrate a Ruby Sinatra external application into Canvas LMS using a web form. This approach is limited to the functionality of Canvas LMS. An alternative method for integrating

2.5. LTI APPLICATIONS

external applications via XML configuration can be used across different LMSs. Edu App Center offers such configurations for every LTI tool listed in the marketplace. Additionally, it provides the XML Config Builder service, that allows instructors to generate XML for integrating custom built external LTI applications into different LMSs. Listing 2.14 shows an example of such XML entry (generated by the Edu App Center's XML Config Builder) that was used to integrate the Ruby Sinatra application (presented in the previous section) into Canvas.

First, the XML version and the charset encoding are defined. Then the `cartridge.basiclti.link` xmlns specifies that this is an LTI link that can be used for integrating an external application. This block contains the whole XML configuration. It starts by defining the IMS Global XML schema that is used to describe this entity. Then the LTI Launch URL is specified (`blti:launch_url`), and it is followed by metadata, regarding the title (`blti:title`) and description (`blti:description`) of the external application. Finally, it defines a block for lti extensions (`blti:extensions platform`) that specifies the LMS platform to act as a TC for this TP. This block of XML code can contain information that is specific to each LMS that is supported by the TP.

```

<?xml version="1.0" encoding="UTF-8"?>
<cartridge_basiclti_link xmlns="http://www.imsglobal.org/xsd/
  imslticc_v1p0"
  <!-- Definition of the XML Schema -->
  xmlns:blti = "http://www.imsglobal.org/xsd/imsbasiclti_v1p0"
  xmlns:lticm = "http://www.imsglobal.org/xsd/imslticm_v1p0"
  xmlns:lticp = "http://www.imsglobal.org/xsd/imslticp_v1p0"
  xmlns:xsi = "http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation = "http://www.imsglobal.org/xsd/
    imslticc_v1p0 http://www.imsglobal.org/xsd/lti/ltiv1p0/
    imslticc_v1p0.xsd
    http://www.imsglobal.org/xsd/imsbasiclti_v1p0 http://www.
    imsglobal.org/xsd/lti/ltiv1p0/imsbasiclti_v1p0.xsd
    http://www.imsglobal.org/xsd/imslticm_v1p0 http://www.
    imsglobal.org/xsd/lti/ltiv1p0/imslticm_v1p0.xsd
    http://www.imsglobal.org/xsd/imslticp_v1p0 http://www.
    imsglobal.org/xsd/lti/ltiv1p0/imslticp_v1p0.xsd">

  <!-- The LTI Launch url -->
  <blti:launch_url>http://192.168.39.39:4567/launch</
    blti:launch_url>
  <!-- Title of the External Application -->
  <blti:title>Arithmetic Assignment</blti:title>
  <!-- Description for the external application -->
  <blti:description>Sample arithmetic assignment tool</
    blti:description>
  <-- Configuration specific to the TC -->
  <blti:extensions platform="canvas.instructure.com">
    <lticm:property name="privacy_level">public</
      lticm:property>
  </blti:extensions>
</cartridge_basiclti_link>

```

Listing 2.14: I am a comment

2.6 Previous efforts to provide on-line exercise material

Traditional practice events in Computer Science involve laboratory environments and exercises based on physical or virtual hardware and domain specific software. One of the problems is creating and managing these environments. Previously such material was packaged in virtual machines or run in an isolated environment (such as a sandbox or linux container as will be described in Section 2.7).

With the rapid growth of e-learning courses, the need for on-line exercise material has grown. Efforts in fields of cybersecurity include "A Comparison of Virtual Lab Solutions for Online Cyber Security Education"[35], and "Top 10 Hands-on Cybersecurity Exercises"[36]. In addition to the environment, there is a

2.7. LINUX CONTAINERS

need for domain specific source material. Some useful references and sources for exercise material regarding networking include "Hands-On Experience to a Massive Open Online Course on openHPI"[4], "Some Experiences in Using Virtual Machines for Teaching Computer Networks"[3], and "V-Lab: A Mobile Virtual Lab for Network Security Studies"[37].

6.1 IK1552

More info

- What are the requirements for successfully completing an exercise?
- What information about a student's progress in or success with the exercise should (or could) be communicated back to the LMS?

I would expect to get back:

1. a score (either scalar or vector)
2. time spent in exercise and the date & time when the exercise was completed
3. potentially file containing the results of the exercise (this could be text, pcap file, etc.)

- How are these requirements met by the chosen technologies?

2.7 Linux Containers

A container is a light weight operating system running inside the host system, executing instructions native to the Central Processing Unit (CPU), eliminating the need for instruction level emulation or just in time compilation [38]. Linux Containers (LXC)[39] is an operating-system-level virtualization method for running multiple isolated Linux systems (containers) on a host using a single Linux kernel. Its purpose is to virtualize a single application rather than a whole operating system inside a virtual machine. LXC uses cgroups* to isolate resources (such as CPU, memory, network, etc.) and namespaces[†] to isolate the application from the operating system [41].

Docker [42] is a Linux container engine, that provides the ability to manage containers as self contained images. Docker utilizes LXC for the container implementation, has image management capabilities, and implements a Union File System (UnionFS). It features resource isolation via cgroups and namespaces, network and file system isolation through LXC functionality, and allows managing

*Control groups (cgroups) is a Linux kernel feature that is responsible for managing resources such as CPU, memory, disk I/O, network, etc.

[†]A namespace wraps a global system resource (process IDs, mount points, network devices, network stacks, ports, etc.) in an abstraction that makes it accessible to the processes. Within a namespace each process has its own isolated instance of the global resource. Changes to the global resource are visible to other processes that are members of the namespace, but are invisible to other processes [40].



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Author: Gerald

Subject: Sticky Note

Date: 2016-12-19 10:44:37

Eliminate this section and move the relevant material to Section 1.3.

the lifecycle of a container [38]. Although docker initially utilized LXC as the only execution driver for resource isolation, lately it introduced libcontainer [43], which includes its own implementation for resource isolation, but also has bindings to leverage other technologies (such as LXC, libvirt-lxc[44] and systemd-nspawn[45]), thus libcontainer realizes a cross-system abstraction layer for packaging, delivering, and running applications in isolated environments. The implementation and functionality of libcontainer is defined by the Open Container Initiative (OCI)[46] specification which defines the image formats, the image management interface, and the container runtime life-cycle.

Docker leverages a client-server architecture. The server is called a docker daemon, and it is responsible for the container's runtime environment. It also has capabilities for building, running, and distributing docker containers. The Docker client is a user interface for communicating with the docker daemon. The client has several implementations, including a command line tool [47] and the Docker Remote API [48]. The Docker ecosystem includes different technologies and tools for managing images, container and application runtime, infrastructure deployment and orchestration, etc. The Docker Hub is an image registry that stores container images in a similar way as traditional package management stores software artifacts. An image is part of a repository and has an author and a version, thus making the image and its configuration easy to distribute and discover.

Listing 2.15 illustrates how a container image can be downloaded from the Docker Hub using the command line interface of the docker daemon. The command `docker pull ubuntu:14.04` requests a download of the image of Ubuntu from the repository that is tagged with version 14.04. To realize this pull, the Docker daemon connects to the Hub and then requests this particular image of that repository, and starts downloading the image together with its configuration and dependencies. Finally, after the downloading is complete, the Docker daemon creates a hash string of the image using the Secure Hash Algorithm (SHA) algorithm. Subsequently this hash is used uniquely identify the image in the local registry of this docker daemon.

```
$: docker pull ubuntu:14.04
14.04: Pulling from library/ubuntu

ba76e97bb96c: Pull complete
4d6181e6b423: Pull complete
4854897be9ac: Pull complete
4458f3097eef: Pull complete
9989a8de1a9e: Pull complete
Digest: sha256:062bba17f92e749bd3092e7569aa0\
6c6773ade7df603958026f2f5397431754c
Status: Downloaded newer image for ubuntu:14.04
```

Listing 2.15: Docker pull command

2.7. LINUX CONTAINERS

Using the command line client, docker can list all downloaded images along with a set of metadata for these images. Listing 2.16 shows the output of the command **docker images**, which contains the name of the repository, the repository tag, a unique identifier of the image, and additional information (such as when the image was created and stored in the Docker Hub), and its size.

```
$: docker images
REPOSITORY    TAG       IMAGE ID      CREATED        SIZE
ubuntu        14.04     4d44acee901c  3 days ago    187.9 MB
```

Listing 2.16: Docker images command

The container runtime, defines the different states of a container: created, started, paused, stopped, and deleted. In order to run an application inside an isolated environment, first a container has to be created from an existing image and then started. Listing 2.17 shows the command **docker run** which specifies the execution of a container from a particular image and causes it to execute a particular application (in this case `/bin/bash`).

```
$: docker run -t -i ubuntu:14.04 /bin/bash
```

Listing 2.17: Docker run command

In more detail, the command causes the runtime to create a container from the image `ubuntu:14.04`, and configures it according to the specified arguments. The command argument `-t` requires allocates a pseudoterminal (pty) [49], and the argument `-i` attaches the standard input to this pseudoterminal. Finally, the container starts and executes the command `/bin/bash`.

Listing 2.18 illustrates to **docker ps** command which lists the containers that are in the running state. The output of the command includes information such as the unique identifier of the container, the container image, the command that is running, and other information such as when the container was created it, when it started running, what port bindings the container has with the host operating system, and a unique name.

```
$: docker ps
CONTAINER ID   IMAGE          COMMAND                  CREATED        STATUS        PORTS   NAMES
91af84830636   ubuntu:14.04   "/bin/bash"             3 seconds ago  Up 2 seconds  lonely_lichterman
```

Listing 2.18: Docker ps command

The commands presented previously are just a subset of those available via the command line interface of the docker client. The complete set of commands can be found by running `docker` without any arguments or with the argument `"help"`. Figure 2.5, from the documentation about the Docker Remote API, shows a state diagram of a container, along with the various commands and events that are responsible for containers transitioning between different states.

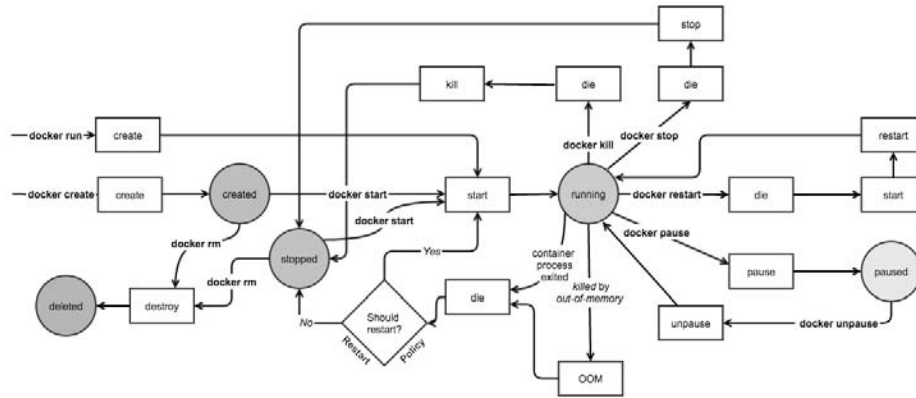


Figure 2.5: States of the container lifecycle

Listing 2.17 showed how to run the bash shell process inside a linux container. The code snippets of Listings 2.19 and 2.20 illustrate how one can install a package in the operating system of the container and then create a new image of the resulting container.

```
root@91af84830636:/# apt-get install traceroute
```

Listing 2.19: Installing a package in the container Operating System

Using the apt package manager of Ubuntu, the root user installs the traceroute package. Then this running container is used to create a new image, that will contain the current state of this container.

```
$: docker commit -m "traceroute-package" -a "KTH" 91af84830636
my-ubuntu:traceroute
```

Listing 2.20: Create a new docker image out of a running container

The command `docker commit` accepts a `-m` parameter containing a commit message, a `-a` parameter specifying the author of this commit, the id of the container that will be used to create a new image (in this case 91af84830636), the name of the repository (my-ubuntu), and the reference tag for this repository (:traceroute). Executing the command `docker images` as shown in Listing 2.21, will verify that the image was created.

```
$: docker images
REPOSITORY    TAG       IMAGE ID       CREATED        SIZE
ubuntu        14.04     4d44acee901c   3 days ago    187.9 MB
my-ubuntu     traceroute 1261c79eb3da   4 seconds ago 166.9 MB
```

Listing 2.21: List the docker images, shows the newly created image

2.8. WEB BASED SHELL EMULATORS

Linux containers can be used to create pre-configured machines for laboratory assignments of an Internetworking course. By creating container images tailored to the needs of each assignment, a student can focus on the exercise, while avoiding details that are not relevant to the learning process. A software solution that supports creating images and running containers on demand, can be very useful for e-learning, as it takes a student just a few seconds to access a unique laboratory environment via her web browser.

2.8 Web based shell emulators

When it comes to e-learning assisted by LMSs, students are used to performing most of their learning tasks via their web browser. Using pre-configured laboratory environments based on docker images entails the same risks as traditional labs, as the student has to install docker and manually execute a series of commands before she will be able to focus on the learning process. An alternative solution would be to support such environments in a remote server, and then simply provide the student access to the remote environment via a web browser. The software that provides access to a linux shell via a web browser is often called a web based terminal emulator. The technology that provides communication between the server (the terminal emulator) and the client (the web browser) is called Web-based Secure Shell (SSH). The server side of the implementation involves a web application that accepts requests for keyboard events and forwards these keyboard events to a secure shell client communicating with the connected SSH server. The terminal output is either passed to the client where it is converted into HTML via JavaScript or it is translated into HTML by the server before it is transmitted to the client [50].

There are several implementations of web based shell emulators, such as GateOne[51] and Shell In A Box[52]. The latter, implements a web server that can export arbitrary command line tools to a web based terminal emulator. This emulator is accessible to any JavaScript and CSS enabled web browser. The server listens on a specified port and publishes services that are displayed by a VT100[53] emulator implemented as an Asynchronous JavaScript and XML (AJAX)[54] web application.

2.9 Related work

The support for interoperability specifications by several LMSs has allowed rapid experimentation and implementation of external application frameworks that offer a variety of on-line training events for various Computer Science courses. This section presents some of these frameworks and describes how they are relevant to this project.

2.9.1 EDURange

Designing on-line training environments for the field of cyber security requires overcoming some technical constraints, such as high availability and scalability, and pedagogical limitations, such as teaching analysis skills to understand complex systems and concepts via practicing [2]. EDURange addresses these issues by designing an open source framework that provides interactive security exercises in an elastic cloud environment [55].

EDURange is a software framework, designed to work on Amazon Elastic Compute Cloud (EC2) [56]. It allows teachers to easily build and scale dynamic virtual environments to host cybersecurity training [57]. This framework provides ease of use for instructors, by offering the flexibility to specify exercises at a high level and allowing the instructor to configure different aspects of the training scenarios in order to provide a tailored learning experience that focuses on analysis skills.

2.9.2 GLUE!

Group Learning Uniform Environment (GLUE!) is a middle-ware integration architecture that aims to standardize the integration of existing external learning tools into several LMSs [58]. It facilitates the instantiation and enactment of collaborative learning situations within LMSs, by using the distinctive administrative features of these systems to manage users and groups. LTI and the Sharable Content Object Reference Model (SCROM) are two specifications for the integration of external learning tools into an LMS. However, each LMS usually supports only a single interoperability specification; thus, developing a universal external tool requires a substantial development effort to support the different interoperability standards. In contrast, GLUE! proposes a software architecture that takes advantage of the common integration features of LMSs to integrate multiple existing learning tools into multiple LMSs.

2.9.3 INGIInious

Programming exercises are the most common form of practice for students learning CS. Traditionally, the evaluation of these exercises, requires grading of reports, reading source code, and testing source code, thus making it time consuming, especially for large classes (i.e., large numbers of students). INGIInious [7, 59, 60, 61] is a software framework that empowers instructors to easily construct coding tasks and it supports automatic evaluation and grading of the code, thus providing both students and teachers with constructive feedback.

The framework consists of two main components: the frontend and the backend. The frontend provides a web interface where students perform programming tasks and an administration module that allows instructors to design these tasks. The backend is responsible for running and grading the code inside remote isolated Linux containers. Each container is specifically built for a particular programming

2.9. RELATED WORK

language, according to configuration provided by the instructor or the administrator of the system, thus supporting the evaluation of tasks written in any programming language that runs in a Linux environment.

One of the main features of INGINious is that the frontend component can be used either as a stand-alone web application or as an external learning tool that is integrated into an LMS using the LTI specification. Additionally, the backend component scales horizontally very easily, since it utilizes a docker container for every task request, therefore it is suitable for MOOC platforms.

A programming task in INGINious is designed using a configuration file (`task.yaml`) that identifies the problem to be solved by the student, and the evaluation process, a template file (`template.py`) that presents the task to the student, and defines the input field for the code, and finally, a file (`run`) that executes the student code, and validates the output. The following code samples show the minimum configuration required by the instructor, to design a simple "Hello World" task in Python. Listing 2.22 is the `task` file. It starts with key-value pairs that are used to describe the `name` and `context` of the task.

CHAPTER 2. BACKGROUND

```
name: "Hello World!"
context: "In this task, you will have to write a python script
        that displays 'Hello World!'."
problems:
  question1:
    name: "Let's print it"
    header: "def func():"
    type: "code"
    language: "python"
limits:
  time: 10
  memory: 50
  output: 1000
environment: "default"
```

Listing 2.22: Definition of a task in task.yaml

Then it defines the **problems** that have to be solved to complete this task. Each problem has a unique name within the task (**question1**) and a series of metadata such as the programming language to be used for solving the problem, and the text input to print in the input form. Finally it contains other metadata that defines the resources of the virtual environment that will be used to evaluate the code.

```
def func():
    @ @question1@@

    func()
```

Listing 2.23: Code input of question1 in template.py

Listing 2.23 defined the input into field in which the student will input their code. Finally, the **run** file defined in Listing 2.24, is a shell script, that parses the input code using the INGINIOUS commands **parsetemplate**, then evaluates the expected output against the results of the input function using the command **run_student**. Finally it prepares the result of the task using the **feedback** command.

Listing 2.24: Evaluation of student code by the run file

```
#!/bin/bash


# Parse the template and put the result in studentcode.py
parsetemplate --output studentcode.py template.py

# Verify the output of the code...
output=$(run_student python studentcode.py)
if [ "$output" = "Hello World!" ]; then
    # The student succeeded
    feedback --result success --feedback "Success!"
else
    # The student failed
    feedback --result failed --feedback "Your output is $output"
fi
```






2.10. SUMMARY

Detailed information for specifying a task in INGINious platform can be found in the official teacher documentation [62]. As part of the research in this thesis project, the LTI component of INGINious was configured with Canvas LMS, to perform sample programming tasks like the "Hello World!" code that was explained earlier.

2.10 Summary

Canvas LMS is an open source system that aims to assist in every aspect of the learning process. It offers functionality for e-learning activities such as rich media, interactive quizzes, methods for automatically evaluating assignments, and finally allows developers to design and integrate their own learning tools via the LTI specification. The LTI specification standardizes the method of integrating external learning applications in LMSs via XML configurations, and allows the LMS to exchange structured messages with a TP to share information such as user sessions^[1] and learning outcomes. ^[2] is only one of the several specifications for integrating learning applications into LMSs. GLUE! is a middleware implementation that supports the integration of external learning tools into different LMS that implement different specifications.

This is new

Designing assignments for an Internetworking course relies heavily on laboratory environments. Creating and managing such environments can easily be performed by using Linux Containers. Docker offers a high level ^[3] that allows to create container images with provisioned software, tailored to the requirements of different assignments. The Docker runtime, ^[4] allows to ^[5] instantly create and execute software of ^[6] particular laboratory environment. With the use of ^[7] web based shell emulators, students can access the environment and focus on the learning process, rather than configuring the environment themselves.

Similar approaches that address the problem of virtual laboratory environments^[8] and automatic assignment evaluation have been proposed by researchers in other fields of Computer Science. These approaches were evaluated, and provided useful guidelines for designing the software artifact of this project. The Edurange project focuses on devising a set of exercises that train students in the Cybersecurity domain. Moreover, it offers a method for deploying the framework in cloud infrastructures, to increase availability of the system for students and instructors, and also reduce the cost of hosting the framework for Education Institutions.^[9] The INginious framework focuses on providing an environment for evaluating coding assignments in all programming languages whose runtime is supported by the linux kernel. The system offers high availability for evaluating code using unit tests, and the actual evaluation is performed within a docker container.

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	Number: 1	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 11:21:10
	Number: 2	Author: Gerald	Subject: Sticky Note	Date: 2016-12-19 11:43:59
	I would suggest starting a new paragraph here.			
	Number: 3	Author: Gerald	Subject: Highlight	Date: 2016-12-19 11:44:45
	Set in all upper case.			
	Number: 4	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:46:12
	can nearly			
	Number: 5	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:45:48
	Number: 6	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:46:48
	realizing			
	Number: 7	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:47:14
	Using			
	Number: 8	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 11:47:17
	Number: 9	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:49:06
	educational institutions			

CHAPTER 2. BACKGROUND

It is nice to bring this chapter to a close with a summary. For example, you might include a table that summarizes the ideas of others and the advantages and disadvantages of each ? so that later you can compare your solution to each of these. This will also help guide you in defining the metrics that you will use for your evaluation.

Chapter 3

Methodology

This thesis project is carried out using the Design Science research method. This type of research focuses on the design and construction of IT artifacts that have utility in the real world, in this case as an application environment, and aim to improve domain-specific systems and processes. In the context of this research, the real world problem is the lack of interactive virtual laboratory environments in the form of e-learning tools.

3.1 Research Process

Vijay Vaishnavi and Bill Kuechler in *Design Science Research in Information Systems* [63] describe the process for performing Design Science Research in the following five steps: Awareness of the Problem, Suggestion, Development, Evaluation, and Conclusion. In the scope of this project, the first two steps are reflected by the Introduction and Background Chapters. The literature study that was performed, provided understanding of the problem, of how other researchers have addressed similar problems, and how existing technologies can be combined to devise a solution for the problem of this thesis work. The Development step is reflected by Chapter Implementation, which describes the designed software artifact. The Evaluation step, reflected by the corresponding Chapter, evaluates the functionality of the artifact against a set of criteria (listed in the section). Finally, the Conclusion step, summarizes the results, and proposes a series of actions to be taken as part of the future work of this project.

3.2 Evaluation Process

The literature study that was carried out within the scope of this project revealed two important software solutions (EduRange and INGenious) that address similar problems in different domains of CS. Further analysis on the functionality and implementation of those projects inspired the work of this project and concluded a few high level requirements that are listed below:


CHAPTER 3. METHODOLOGY

- The laboratory environments can be designed using Docker containers, in a similar way that INGINious is using them to perform the evaluation of student assignments. Generating a laboratory environment can be realized by creating a container image which includes all software requirements of an Internetworking assignment.
- High availability of these environments can be achieved by creating and running a docker container for each student session. This approach was both supported by INGINious for the evaluation of each coding assignment, and Edurange which relies on preconfigured virtual machines that are used to facilitate Cybersecurity training.
- The instructor should be able to dynamically update the underlying software and the assignments, similarly to the way INGINious creates a new assignment.
- Design a system that is not specific to a cloud infrastructure provider. The Docker runtime is supported by most linux operating system distributions which can run on dedicated or virtual hardware.

Furthermore, a series of goals were decided to be used as guidelines for the system design. These guidelines focus on the interaction for the main two user roles of the system, the instructor and the student, and are described below:

- The instructor should have complete control over the software used for a particular assignment (for example install the software and create a container image that will be used for a particular assignment).
- The instructor should always know which container images exist in the system, and should have sufficient privileges to delete and create these images.
- The system should provide a way for the instructor to access a laboratory environment, in similar to the way a student is expected to access it.
- The system should provide sufficient configuration for the instructor to create an assignment in Canvas LMS and connect it with a particular container image.
- The student should be able to launch a laboratory environment from Canvas LMS, by simply pressing the assignment button. The resulting container should be available to the user instantly.

The evaluation of the software artifact was performed in two steps. First, the system was evaluated against the requirements mentioned earlier to validate whether the solution is aligning with the goals of this project, and then, additional evaluation methodologies such as unit testing were used to test that the implemented code was performing as intended.



if unit testing is implemented



Number: 1

Author: Gerald

Subject: Sticky Note

Date: 2016-12-19 11:49:50

You will want to have some systematic functional testing.

Chapter 4

Implementation

The artifact that was designed within the scope of this thesis work can be described by two different modules, the TP that enables students to access a laboratory environment via LTI integrations with Canvas LMS, and the Tool Client, an administrative tool which exposes functionality to the instructor, to preconfigure such environments and provide sufficient configuration for integration with the [11]. Figure 4.1 presents a high level overview of the system architecture, which is explained in more detail in Section 4.1. Section 4.2 describes details of the software implementation.

finalize this once the sections are complete.

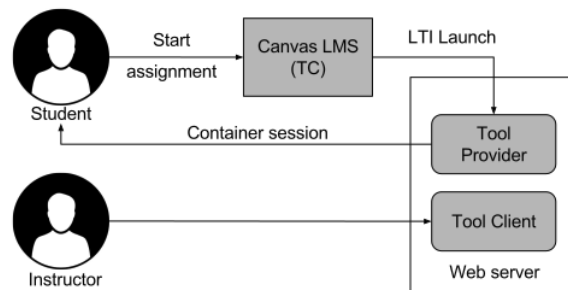


Figure 4.1: High Level Overview of the System Architecture

4.1 Software architecture

Section 2.3 introduced an example of a web server which had the role of a TP [12] that accepted and authenticated requests from Canvas LMS to launch assignments. Similarly to that approach, an HTTP web server was used to support the functionality of the LTI Tool Client and the LTI Tool Provider. The Docker daemon provided the required functionality to manage the container runtime [13] and container image manipulation. Such [14] functionality was exposed to the web server via a Docker Remote API client library. HTTP route endpoints were

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✚	Number: 1	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 11:51:01
✚	Number: 2 consists of	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:50:17
✚	Number: 3 : a TP and a TC. The	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:50:59
✚	Number: 4 while	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:51:15
✚	Number: 5 provides	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:51:37
✚	Number: 6 enabling the instructor	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:51:48
✚	Number: 7	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 11:52:04
✚	Number: 8	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 11:52:12
✚	Number: 9 the laboratory	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:52:02
✚	Number: 10 e the	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:52:32
T	Number: 11 Should this say "with the LMS acting as a TC"?	Author: Gerald	Subject: Highlight	Date: 2016-12-19 11:53:23
✚	Number: 12	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 11:55:48
✚	Number: 13	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 11:56:34
✚	Number: 14 This	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:57:14

developed as part of the web server functionality that consumed the Docker client library to support the various used cases of the Tool Client and the Tool Provider. The web server was communicating with two different data stores, the session and persistent storage for storing and retrieving user session information and storing and retrieving assignment configurations respectively. Figure 4.2 presents these components.

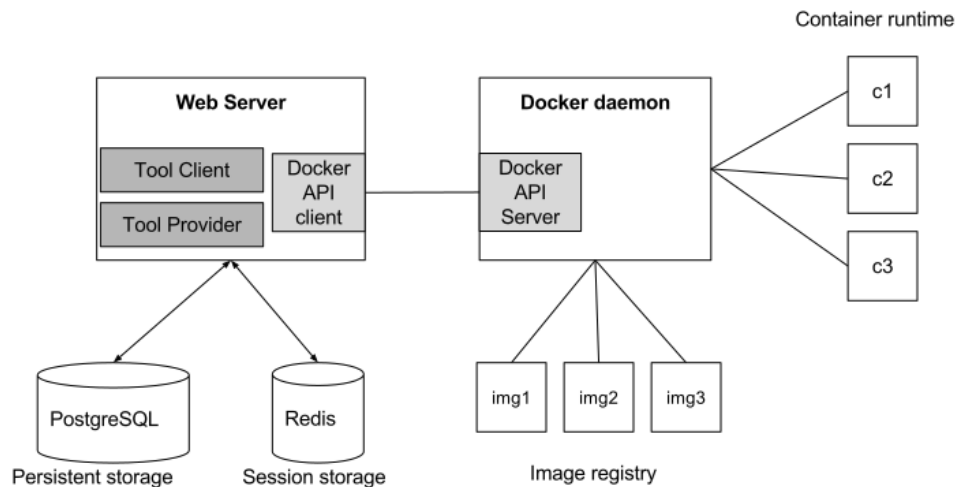


Figure 4.2: Architecture of the system components


Canvas LMS

Canvas LMS was used during the development phase of this project to understand and test the functionality of the LTI integration with the TP. Canvas is based on the Ruby on Rails framework [64] and has several software dependencies. For the installation of Canvas, a virtual machine was configured to run the Ubuntu 14.04 operating system. The software dependencies of Canvas were installed in the operating system as explained in the "Quick Start" wiki page of the official Canvas LMS GitHub repository[65]*.

After the installation was complete and the system was running successfully, the system was configured to have an administrator account. This account was used to register two additional user roles, the *instructor* and the *student*. The institution, the department, and a course were configured. The instructor user was configured to have the Canvas role *teacher* of this course, and the student user was configured to participate in this course. Figure 4.3 shows the configuration performed in the Canvas User Interface (UI).

*A simplified method for installing Canvas LMS in a virtual machine using Vagrant[66] and VirtualBox[67] was used in this project, and it is documented in a public GitHub repository[68].

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 Number: 1	Author: Gerald	Subject: Highlight	Date: 2016-12-19 11:58:23
You should use the acronyms consistently once you have introduced them.			
 Number: 2	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:58:39
: (1)			
 Number: 3	Author: Gerald	Subject: Sticky Note	Date: 2016-12-19 12:00:00
Is this the second data store?			
 Number: 4	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 11:59:20
(2)			
 Number: 5	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:01:00
To facilitate			
 Number: 6	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 12:01:32
 Number: 7	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:02:05
(
 Number: 8	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:02:13
)			
 Number: 9	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:02:19
(
 Number: 10	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:02:28
)			
 Number: 11	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:02:38
(
 Number: 12	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:02:46
),			
 Number: 13	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:02:54
(
 Number: 14	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:03:06
)			
 Number: 15	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:03:13
for			
 Number: 16	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:03:26
while			
 Number: 17	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:03:33
via			
 Number: 18	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:01:30
. This method			

4.1. SOFTWARE ARCHITECTURE

Course Details

Name: Internetworking

Course Code: TC12

Time Zone: Stockholm (+01:00)

SIS ID:

Root Account: KTH

Subaccount: ICT

(a) Structure of a course in Canvas

TC12 > People

Home
Announcements
Assignments
Discussions
Grades
People
Pages
Files
Syllabus
Outcomes
Quizzes
Modules
Settings

Everyone Groups

Search people All Roles

Name	Login ID	SIS ID	Section	Role
Instructor	instructor@kth.se		TestCourse	Teacher
Student	student@kth.se		TestCourse	Student



(b) People participating in a Canvas Course

Figure 4.3: Sample configuration of a course and its participants in Canvas LMS

The configuration of course assignments was explained in Figures 2.3 and 2.4 of Section 2.4.1, thus ¹not included in the current Section. ²

Web server

The functionality of the HTTP web server was implemented using the Go programming language (Go) [69, 70]. The web server itself, is implemented in Go and is part of the standard `net/http` [71] package. Listing 4.1 shows an example of an HTTP web server that is configured to listen for TLS connections on port 443.

 Number: 1 this material	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:04:28
 Number: 2 this section	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:05:04



Listing 4.1: Golang simple HTTPS web server

```

import (
    "net/http"
    "github.com/julienschmidt/httprouter"
)

func handler(w http.ResponseWriter, req *http.Request, _
    httprouter.Params) {
    w.Header().Set("Content-Type", "text/plain")
    w.Write([]byte("This is an example server.\n"))
}

func main() {
    router := httprouter.New()
    router.GET("/", handler)
    http.ListenAndServeTLS(":443", "cert.pem", "key.pem", router
    )
}

```

The line `import "net/http"` includes the package which implements the HTTP web server. The line `import "github.com/julienschmidt/httprouter"` includes a Go package developed by Julien Schmidt ¹¹ which maps URL paths like ¹² the root path `"/"` to HTTP Request methods (such as GET, POST, DELETE, PUT, etc.), and Go functions like ¹³ `handler(w http.ResponseWriter, req *http.Request, _ httprouter.Params)` that processes the corresponding HTTP request.

In the example above, ¹⁴ function `handler` has three parameters, ¹⁵ `w` ¹⁶ `http.ResponseWriter`, ¹⁷ `req` ¹⁸ `*http.Request`, and ¹⁹ `_` ²⁰ `httprouter.Params`. The ²¹ `http.ResponseWriter` is an interface that exposes functionality such as setting an HTTP response header ²² and writing an HTTP response. The ²³ `*http.Request` interface exposes functionality for reading request parameters, form data, etc., and ²⁴ `httprouter.Params` is a keyvalue data structure that maps http request parameters names to their values. ²⁵

The server starts using ²⁶ the command ²⁷ `listenAndServeTLS(":443", "cert.pem", "key.pem", router)`. This first paramter is the port number that the server will be listening ²⁸ incoming TLS connections, `cert.pem` and `key.pem` are the TLS certificate and key respectively, and `router` is the URL router. ²⁹

The implementation of this project, contains a series of functions like ³⁰ `handler` function mentioned earlier, that implement functionality, ³¹ such as creating a docker image, launching an assignment, etc. Each function is mapped with ³² specific URL path and an HTTP Method. Table 4.1 shows the URL Paths, the HTTP Method, and explains the functionality ³³ each route.

Page: 54

Number: 1	Author: Gerald	Subject: Sticky Note	Date: 2016-12-19 12:06:05
Be consistent about whether you put the caption above or below the listing.			
Number: 2	Author: Gerald	Subject: Sticky Note	Date: 2016-12-19 12:29:24
fix the citation			
You make file for running LaTeX should run bibtex and latex enough times to produced an up to date consistent version.			
Number: 3	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:29:48
such as			
Number: 4	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:30:34
such as			
Number: 5	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:30:41
the			
Number: 6	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:31:11
.			
Number: 7	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 12:38:49
Number: 8	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 12:38:55
Number: 9	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 12:39:00
Number: 10	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:39:55
type			
Number: 11	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 12:31:15
Number: 12	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:40:04
type			
Number: 13	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:40:49
the type			
Number: 14	Author: Gerald	Subject: Sticky Note	Date: 2016-12-19 12:38:44
You should explain that the first parameter is w and it is of type http.ResponseWriter, As Golang put the types after the variable name rather than before.			
Number: 15	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:41:08
executing following			
Number: 16	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:41:27
call to			
Number: 17	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:42:01
on			
Number: 18	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:42:31
created above			
Number: 19	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:42:45
such as			
Number: 20	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:42:58
,			
Number: 21	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:43:19
to			
Number: 22	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 12:43:35

Comments from page 54 continued on next page



Listing 4.1: Golang simple HTTPS web server


```


import (
    "net/http"
    "github.com/julienschmidt/httprouter"
)

func handler(w http.ResponseWriter, req *http.Request, _
    httprouter.Params) {
    w.Header().Set("Content-Type", "text/plain")
    w.Write([]byte("This is an example server.\n"))
}


func main() {
    router := httprouter.New()
    router.GET("/", handler)
    http.ListenAndServeTLS(":443", "cert.pem", "key.pem", router)
}

```

The line `import "net/http"` includes the package which implements the HTTP web server. The line `import "github.com/julienschmidt/httprouter"` includes a Go package developed by Julien Schmidt  which maps URL paths like the root path `"/"` to HTTP Request methods (such as GET, POST, DELETE, PUT, etc.), and Go functions like `handler(w http.ResponseWriter, req *http.Request, _ httprouter.Params)` that processes the corresponding HTTP request.

In the example above, function `handler` has three parameters, `w http.ResponseWriter`, `req *http.Request`, and `_ httprouter.Params`. The `http.ResponseWriter` is an interface that exposes functionality such as setting an HTTP response header, and writing an HTTP response. The `http.Request` interface exposes functionality for reading request parameters, form data, etc., and `httprouter.Params` is a keyvalue data structure that maps http request parameters names to their values. 




The server starts using the command `ListenAndServeTLS(":443", "cert.pem", "key.pem", router)`. This first paramter is the port number that the server will be listening for incoming TLS connections, `cert.pem` and `key.pem` are the TLS certificate and key respectively, and `router` is the URL router.

The implementation of this project, contains a series of functions like the handler function mentioned earlier, that implement functionality such as creating a docker image, launching an assignment, etc. Each function is mapped with a specific URL path and an HTTP Method. Table 4.1 shows the URL Paths, the HTTP Method, and explains the functionality  each route.

4.1. SOFTWARE ARCHITECTURE

Table 4.1: Routes of the HTTP Web Server

URL Path	HTTP Method	Functionality
/admin/login	POST	Implements the login functionality for the admin user of the LTI Tool Client
/admin/logout	GET	Implements the logout functionality for the admin user of the LTI Tool Client
/admin/containers/run/:id	POST	Handles the container run functionality for the admin user of the LTI Tool Client. Parameter :id is the identifier of the image to be used for creating and starting a container.
/admin/containers/kill/:id	POST	Handles the container kill and remove functionality for the admin user of the LTI Tool Client. Parameter :id is the identifier of the running container.
/admin/images	GET	Lists all ¹ available container images ² for the admin user of the LTI Tool Client.
/admin/images/history/:id	GET	Returns the information of ³ a particular image to the admin user of the LTI Tool Client. Parameter :id is the identifier of the image.
/admin/images/delete/:id	DELETE	Deletes a particular image. Parameter :id is the identifier of the image.
/lti/launch/:id	POST	The LTI Tool Provider. Handles the LTI Launch request. Parameter :id is the identifier of the image that should be used to create and start a container for this particular request.
/ui/*filepath	GET	Handles requests for all static files that are located in a custom directory.

 Number: 1	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 12:56:48
 Number: 2 available	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:57:08
 Number: 3 about	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 12:57:53

Docker

The web server communicates with the Docker daemon via the Docker Remote API [48]. The web server is using the Go implementation of the Remote API Client library[72] to perform requests to the Docker server. This library has functionality similar to the docker command line client that was introduced in Section 2.7. Listing 4.2 shows how a request is performed by the client `Cli` to start a container using the `ContainerStart` function of the `Cli`. It is assumed that the container was previously created, using the `ContainerCreate` function.

Listing 4.2: Start container request

```
Cli.ContainerStart(context.Background(), containerID, types.
    ContainerStartOptions{})
```

The first parameter expects a variable of type `Context*`, the second parameter is the unique identifier of the container to start. The last parameter is an empty variable of type `types.ContainerStartOptions`.

The version of the Docker Server that was used in this implementation is 1.12.4, and the version of the server API was 1.24. The version of the API is very important when initializing the client library from the Go code. A matching version ensures the client will communicate using the same version. API calls that the server is responding to.

The source code of this implementation includes a Go package named `dc` for docker containers. This package contains code that initializes the client and implementations of functions that consume the Docker API Client library, and are used by several HTTP route handlers of the Tool Client and the Tool Provider.

LTI Tool Client

The LTI Tool Client has the role of administration panel for the system. It allows a user with admin privileges to create and delete docker images. These images can be used to configure an LTI integration for a course assignment in Canvas. This section explains the intended functionality of the Tool Client, presents the web pages of the Tool Client UI, and describes the key concepts the implementation.

Authentication

The API endpoints consumed by the Tool Client UI have access restrictions to prevent unauthorized requests from non-administrator users. The process for authenticating an administrator and creating a user session is performed by

*Package `context` defines the `Context` type, which carries deadlines, cancellation signals, and other request-scoped values across API boundaries and between processes[73]. `Background` function returns a non-nil, empty `Context`. It is never canceled, has no values, and has no deadline. It is typically used by the main function, initialization, and tests, and as the top-level `Context` for incoming requests.

Page: 56

	Number: 1 Does it have to be empty?	Author: Gerald	Subject: Sticky Note	Date: 2016-12-19 13:03:17
	Number: 2	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:03:20
	Number: 3 , as a	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:04:18
	Number: 4 of the	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:04:37
	Number: 5 (named	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:04:51
	Number: 6	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:05:06
	Number: 7)	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:05:03
	Number: 8 the	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:05:27
	Number: 9 . These functions	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:06:04
	Number: 10 in	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:06:19
	Number: 11 acts as	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:07:03
	Number: 12	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:07:05
	Number: 13	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:07:33
	Number: 14	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:07:41
	Number: 15 , i.e., requests not from	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:07:30
	Number: 16	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:01:09
	Number: 17 The package	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:01:39
	Number: 18 The	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:01:54
	Number: 19 This context	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:02:09
	Number: 20 The context	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:03:00

4.1. SOFTWARE ARCHITECTURE

submitting a web form with username and password parameters. The form is presented in Figure 4.4.



The image shows a web form titled "Please sign in". It contains two input fields: "Username" and "Password". Below these fields is a dark grey button labeled "Sign in".

Figure 4.4: Signin form - LTI Tool Client Interface

When the *Sign in* button is clicked by the user, a Javascript function executes, and performs the following steps. First it [1] accesses [2] the form [3] parameters, then it sets the HTTP request url [4] `/admin/login`, the header Content-Type to `application/json`, then it sets the request body to contain the following JSON object [5]

```
{
  "username": "admin",
  "password": "password"
}
```

























The request is performed asynchronously using the `ajax` function of the jQuery [74] Javascript framework. The server will reply with an HTTP status code that [6] will indicate a [8] success or an error. If an error occurs [7], a corresponding [9] message is presented to the user, and [10] the request was successful, the user is redirected to the home page of the Tool Client interface.

The server validates the form data and compares the given parameters with the corresponding values of the user entry in the persistence [11] page. If the credentials match, a user session is created and stored in the session storage, and [12] HTTP cookie is created [13] with unique information [14] [15] administrator [16] user. Afterwards, every subsequent request to other endpoints of the Tool Client, verify that a cookie exists [17] and that its value matches an existing entry in the session storage.

Home Page - Image List

The home page of the application is titled "List of Images" [18] and is presented in figure [19] 4.5. [20] It contains a table with two columns, [21] the image identifier and the name of the [22] image [23]. The user can click on each row of the table to go to the next page named "Image History" which provides more detailed information about the [24] page.

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	Number: 1	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:08:25
	Number: 2	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:08:30
	Number: 3 s	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:08:52
	Number: 4 URL	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:09:12
	Number: 5 :	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:09:35
	Number: 6	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:09:38
	Number: 7	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:09:54
	Number: 8 s	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:09:52
	Number: 9 error	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:10:12
	Number: 10 while	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:10:22
	Number: 11 persistent	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:11:00
	Number: 12 then	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:11:12
	Number: 13	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:11:15
	Number: 14 about this	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:11:35
	Number: 15	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:11:39
	Number: 16	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:11:46
	Number: 17	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:12:13
	Number: 18 Use double left quote - you can generate with ``	Author: Gerald	Subject: Sticky Note	Date: 2016-12-19 13:12:48
	Number: 19 (see Figure	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:13:04
	Number: 20)	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:13:21
	Number: 21 This page	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:13:31
	Number: 22 :	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:13:43
	Number: 23 Why capitalize this?	Author: Gerald	Subject: Sticky Note	Date: 2016-12-19 13:14:07
	Number: 24	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:14:17

Comments from page 57 continued on next page

4.1. SOFTWARE ARCHITECTURE

submitting a web form with username and password parameters. The form is presented in Figure 4.4.



The image shows a web form titled "Please sign in". It contains two input fields: "Username" and "Password". Below these fields is a dark grey button labeled "Sign in".

Figure 4.4: Signin form - LTI Tool Client Interface

When the *Sign in* button is clicked by the user, a Javascript function executes, and performs the following steps. First it gets accesses to the form parameters, then it sets the HTTP request url to `/admin/login`, the header Content-Type to `application/json`, then it sets the request body to contain the following JSON object₁

```
{
  "username": "admin",
  "password": "password"
}
```

The request is performed asynchronously using the `ajax` function of the jQuery [74] Javascript framework. The server will reply with an HTTP status code that will indicate a success or an error. If an error occurs, a corresponding message is presented to the user, and if the request was successful, the user is redirected to the home page of the Tool Client interface.

The server validates the form data and compares the given parameters with the corresponding values of the user entry in the persistence storage. If the credentials match, a user session is created and stored in the session storage, and an HTTP cookie is created, with unique information for the administrator user. Afterwards, every subsequent request to other endpoints of the Tool Client, verify that a cookie exists, and that its value matches an existing entry in the session storage.

Home Page - Image List

The home page of the application is titled "List of Images" and is presented in figure 4.5. It contains a table with two columns, the image identifier and the name of the image. The user can click on each row of the table to go to the next page named "Image History" which provides more detailed information about the image.

this specific

Admin Panel		Logout
List of Images		
ImageID	Name	
5653baa9445e	sspreitzer/shellinabox:test_commit	
e979af10a887	sspreitzer/shellinabox:latest	

Figure 4.5: List of Docker Images

When the browser renders the HTML elements of this web page, it performs an HTTP GET request to the `/admin/images` endpoint. The server upon successful authentication of the request, requests from the Docker Remote API to return the list of images in the system, and prepares a JSON array with image information as a response.

```
{
  "data": [{
    "Id": "5653baa9445e",
    "RepoTags": ["sspreitzer/shellinabox:test_commit"]
  }, {
    "Id": "e979af10a887",
    "RepoTags": ["sspreitzer/shellinabox:latest"]
  }]
}
```







The Javascript function will parse the response, and fill in the table with the data in the corresponding columns. Here `Id` is the image identifier and `RepoTags` is presented in the interface as the image name.

LTI Tool Provider

4.2 Implementation details

- risks
- limitations
- non reasoned choices

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	Number: 1	Author: Gerald	Subject: Highlight	Date: 2016-12-19 13:15:31
IN chapter two you should introduce the concept of endpoints so that your reader will know what you are talking about.				
	Number: 2	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:15:38
	Number: 3	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:15:41
	Number: 4	Author: Gerald	Subject: Inserted Text	Date: 2016-12-19 13:16:24
, for example:				
	Number: 5	Author: Gerald	Subject: Highlight	Date: 2016-12-19 13:19:41
What Javascript function? Perhaps you can show what the content of the page is (or at least some part of it) so that this statement makes sense.				
	Number: 6	Author: Gerald	Subject: Cross-Out	Date: 2016-12-19 13:19:46

Chapter 5

Conclusions and Future Work

5.1 Conclusions

5.2 Limitations

5.3 Future work

Scalability

The architectural design of the implementation presented in chapter 4 has limitation in terms of scalability. The docker daemon and the Tool Provider are running in the same virtual of physical environment, resulting to bounding the cpu and memory resources that the containers consume.

In addition this setup has limitations on the number of ports the docker daemon can use to bridge network connections between the containers and the host system.

A lot of work has been done in deploying scalable clusters of container runtime environments. Kubernetes being one of them ...

Web SSH

Shell In A Box was the chosen web terminal emulator, but there are alternatives implementations that have not being investigated within the scope of this project. I addition, the base container image used by the backend system was not evaluated. The configuration of shellinabox package has more capabilities than supported in the docker image. An alternative would be to manually create a base image...

User Experience

This system is intended to be user by instructors and students. Evaluation of the front-end performance and usability of the system should be performed, using UX prototypes ...

CHAPTER 5. CONCLUSIONS AND FUTURE WORK

Desired Features

- The system should evaluate if an image is functional, and if it can be used to integrate with Canvas via LTI. It should give feedback to the instructor if something went wrong, and what the errors were.

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Andreas_Kokkalis_report_20161120-commented-a.pdf contains important feedback for the Citations

Appendix A

Appendix Name X

content X