



COLLEGE OF ENGINEERING, DESIGN AND PHYSICAL SCIENCES,  
ELECTRONIC AND COMPUTER ENGINEERING

DISTRIBUTED COMPUTING SYSTEMS ENGINEERING

## INTERIM REPORT

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Conception and realization of a distributed and  
automated computer vision pipeline

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# Declaration of Independence

TODO: hehe

# Abstract

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	MEC-View . . . . .	2
<b>2</b>	<b>The Program</b>	<b>3</b>
2.1	Current Workflow . . . . .	3
2.2	Desired Workflow . . . . .	4
2.3	Deliverable Requirements . . . . .	5
<b>3</b>	<b>State of the art</b>	<b>6</b>
3.1	Similar solutions . . . . .	6
3.1.1	Hadoop MapReduce . . . . .	6
3.1.2	Build Pipelines . . . . .	8
3.1.3	Camunda . . . . .	8
3.1.4	Nomad . . . . .	9
3.1.5	dCache . . . . .	9
3.1.6	Further mentions . . . . .	10
3.2	Docker Integration . . . . .	12
<b>4</b>	<b>Outcome and further work</b>	<b>13</b>
4.1	Storage . . . . .	13
4.2	Coordination . . . . .	13
4.3	Binary distribution . . . . .	14
4.4	User Interface . . . . .	14
<b>5</b>	<b>Schedule</b>	<b>15</b>

<b>6</b>	<b>Introducing Winslow</b>	<b>16</b>
6.1	Domain Language(?) . . . . .	16
<b>7</b>	<b>Requirements</b>	<b>17</b>
7.1	Use Case Diagrams . . . . .	17
7.1.1	Managing Pipelines and Projects . . . . .	18
7.1.2	Managing Resources and Workspaces . . . . .	18
7.1.3	Managing and Monitoring Executions . . . . .	19
7.1.4	Monitoring Nodes . . . . .	19
7.1.5	System Administration . . . . .	20
7.2	Requirements . . . . .	20
7.2.1	Managing Pipelines and Projects . . . . .	20
7.2.2	Managing Resources and Workspaces . . . . .	21
7.2.3	Managing and Monitoring Executions . . . . .	21
7.2.4	Monitoring Nodes . . . . .	22
7.2.5	Derived Requirements . . . . .	22
7.3	Systemanalyses . . . . .	23
<b>8</b>	<b>The architecture</b>	<b>24</b>
8.1	Targeting capabilities . . . . .	24
8.1.1	General thoughts . . . . .	24
8.2	Planned . . . . .	24
8.3	Implementation details . . . . .	24
8.4	Synchronization, Locking, publishing events . . . . .	24
8.5	REST for UI . . . . .	24
8.6	Event Bus . . . . .	24
8.6.1	Atomicity of (Unix) Filesystems . . . . .	25
8.6.2	Atomicity and behavior of NFS in particular . . . . .	25
8.6.3	Using as lock backend . . . . .	25
8.6.4	Using as election backend . . . . .	25
8.7	Election System . . . . .	25
<b>9</b>	<b>Making decisions</b>	<b>26</b>
9.1	Execution environment . . . . .	26

9.2 Continuous Deployment . . . . .	26
<b>Bibliography</b>	<b>29</b>

# Chapter 1

## Introduction

Since the industrial revolution, humans strive for more automation in the industry as well as in the every day life. What was at first a cost saving measurement in factories, now also is a differentiation method for products. A new product must prove a higher level comfort to the customer than the previous generation as well as all the competitors. As such, the ambitions of the industry are focused on increasing the value of their products for the customer.

The automotive industry is one of the prime examples of this. Never was traveling from one place to another as comfortable as nowadays. Aspects like an elegant interior design, comfortable seats, air conditioning, entertainment systems and safety measurements need to be considered by car manufacturers to be competitive these days. The next luxury enhancement will be the autonomously driving vehicle. No longer shall the owner of a car steer it, but instead the car becomes his or hers personal chauffeur, driving the optimal route, the most comfortable way and being more reliable and safer than any human ever could.

The reason, autonomously driving cars are not common already, is their big complexity increase. Compared to already established technologies like parking assistants, entertainment systems or more efficient engine controllers, letting a computer reliably understand a certain traffic situation requires masses of input data and complex algorithms to process. As such, the problem itself becomes massive and cannot be solved that easily. To solve this, the industry has no choice than to divide this into many small pieces and work out solutions to it step by step.

The MEC-View research project explores one such step: whether and how to include external, steady mounted sensors in the decision finding process for partially autonomous vehicles in situations where onboard sensors are insufficient. To not disrupt traffic flow with non-human behavior, one needs to study and thereby watch human traffic. Automatically analyzing traffic from video footage requires a lot of computation power and can be further optimized by specialized hardware such as GPUs.

This thesis will conceptualize and realize a distributed and automated computer vision pipeline which can be used to analyze traffic flow within video footage. Compared to an existing but highly manual workflow, the new system shall help to utilize the available hardware more efficiently by reducing idle times. Stage transitions and basic scheduling shall be automated to allow a user to plan and execute multiple projects ahead of time and in parallel.

## 1.1 MEC-View

The MEC-View research project [**mecview:main**] - funded by the German Federal Ministry for Economic Affairs and Energy - aims to supplement the field of view of automated driving cars with road-side sensor data using 5G mobile communication. The sensor information is merged into an environment model on the so-called Mobile Edge Computing (MEC) server. This server is directly attached to the radio station to ensure low latency environment model updates.

The project is tested at an intersection in Ulm, Germany. Currently, there are 15 lidar and video sensors installed. Those sensors send their detections to the (MEC) server. A fusion-algorithm merges those detections into one environment model and sends it back to the (MEC) server and to the automated cars.

Additionally, general traffic flow is analyzed to learn about movement patterns. To do so, 4k video data is captured by an air drone from real world cross roads. On each frame of such a recording, cars are detected with a neuronal network. Detected cars are tracked throughout the video to compute the movement speed and position in time of each car. In an analysis of all vehicles, hot-spots of high and low traffic flow can be determined.



# Chapter 2

## The Program

This chapter will discuss the program which shall be implemented. To do so, the problem to solve must be understood. To gather requirements and understand the technical hurdles to overcome, this chapter is split into two sections. First, a rough glance over the current workflow is given, which is followed by a more detailed description for the desired workflow.

### 2.1 Current Workflow

Currently, to analyze a video for the trajectories of the recorded vehicles, the following steps are executed manually:

1. Upload the input video to a new directory on the GPU server
2. Execute a shell script with the video as input file and let it run (hours to days) until completed. The shell script invokes a Java Program - called `TrackerApplication` - with parameters on what to do with the input file and additional parameters.
3. The intermediate result with raw detection results is downloaded to the local machine and opened for inspection. If the detection error is too high, the camera tracking has a drift or other disruptions are visible, the previous step is redone with adjusted parameters.
4. Upload the video and intermediate result to a generic computing server and run data cleanup and analysis. This is achieved with the same Java

Program as in step 2, but with different stage environment parameters.

5. Download the results, recheck for consistency or obvious abnormalities. Depending on the result, redo step 2 or 4 with adjusted parameters again.
6. Depending on the assignment, steps 4 and 5 are repeated to incrementally accumulate all output data (such as statistics, diagrams and so on).

Because all those steps are done manually, the user needs to check for errors by oneself. Also, if a execution is finished or failed early, there could be hours wasted if the regular check intervals are too far apart, such as during nights.

## 2.2 Desired Workflow

The desired workflow shall be supported through a rich user interface. This user interface shall provide an overview of all active projects and their current state, such as running computation, awaiting user input, failed or succeeded.

To create a new project, a predefined pipeline definition shall be selected as well as a name chosen. Because only a handful of different pipeline definitions are expected, the creation of such does not need to happen through the user interface. Instead, it is acceptable to have to manually edit a configuration file in such rare circumstances.

Once a project is created, the user wants to select the path to the input video. This file has to be been uploaded to a global resource pool at this point. The upload and download of files shall therefore also be possible through the user interface. Because a video is usually recorded in 4k (3840 x 2160 pixels), encoded with H.264 and up to 20 minutes long, the upload must be capable of handling files which are tens of gigabytes large.

Once a pipeline is started, it shall execute the stages on the most fitting server node until finished, failed or a user input is required. Throughout, the logs of the current and previous stage shall be accessible as well as uploading or downloading files from the current or previous stages workspace. In addition to the pipeline pausing itself for user input, the user shall be able to request the pipeline to pause after the current stage at any moment. When resuming the pipeline, the user

might want to overwrite the starting point to, for example, redo the latest stage.

Mechanisms for fault tolerance shall detect unexpected program errors or failures of server nodes. Server nodes shall be easily installed and added to the existing network of server nodes. Each server node might provide additional hardware (such as GPUs), which shall be detected and provided.

For the ease of installation and binary distribution, Docker Images shall be used for running the Java Program for analyzing the videos as well the to be implemented management software.

## 2.3 Deliverable Requirements

From the desired workflow, the following requirements can be extracted (shortened and incomplete due to early project stage):

- Rich user interface
- Storage management for global resource files as well as stage based workspaces
- Pipeline definition through configuration files
- Handling of multiple projects with independent progress and environment
- Reflecting the correct project state (running, failed, succeeded, paused)
- Log accumulation and archiving
- Accepting user input to update environment variables, resuming and pausing projects as well as uploading and downloading files into or from the global resource pool or a stages workspace.
- Assigning starting stages to the most fitting server node
- Detecting program errors (in a stage execution)
- Cope with server node failures
- Docker Image creation for the Java Binary as well as the program implementation, preferred in an automated fashion.

# Chapter 3

## State of the art

In this chapter, programs solving similar problems, as described in the desired workflow, or dealing with a subset of the problem are looked into. The reason for this is to use well established or suitable programs as middle-ware to reduce implementation overhead. Where this is not possible, one might be able to gather ideas and learn about proven strategies to use or pitfalls to avoid while implementing custom solutions.

### 3.1 Similar solutions

This sections focuses on programs trying to provide somewhat similar workflows.

#### 3.1.1 Hadoop MapReduce

For big data transformation, Hadoop MapReduce[1] is well known. With MapReduce, the input data is split into blocks of data and distributed onto Mappers. Mappers then apply the business logic and output intermediate results in form of key/value pairs. After shuffling, the Reduce stage will combine values from key/-value pairs with the same key. In the final output, each key is unique accompanied with a value.

This strategy has proven to be very powerful to process large amount input data because Mappers and Reducers can work independently on their data-sets and therefore scale very well when adding further instances.

If the implementation were to be based on Hadoop MapReduce to achieve the desired workflow, it could be done like the following:

- Each video is split into many frames and each frame is applied to a Mapper
- A Mapper tries to detect all vehicles on a frame and outputs their position, orientation, size and so on
- The Reducer then tries to link the detections of a vehicle through multiple frames
- The final result would be a set of detections and therefore all positions for each vehicle in the video

But at the moment, this approach seems to be unfitting due to at least the following reasons:

1. It is not always trivial to reasonable link the detections of a vehicle. For example, a vehicle can be hidden behind a tree for a few frames until visible again. In addition, MapReduce requires the combination to be performed per common key. Until one is trying to link the detections of multiple frames, there is no common identifier that could easily be used as key. The position of a moving vehicle cannot be used as key, neither can the color or size, because of the noise of the camera, deviation in detection output and perspective distortions. The current implementation of the TrackerApplication is archiving this by finding similarities between detections, but for the Mapper it would be required to express this as a deterministic key.
2. MapReduce is great in combining many machines to solve a big computational problem. But at the moment, this is neither a desired nor given condition. At the moment, there are a handful of very powerful workstations with specialized hardware. Therefore it is perfectly acceptable and sometimes required, when each workstation works through a complete video at a given time instead.

### 3.1.2 Build Pipelines

Build pipelines such as GitLab[2] and Jenkins[3] can also distribute the execution of stages onto other server nodes. In a common use-case, such build pipelines are used to build binaries out of source code, after a new commit into a SCM<sup>1</sup> repository was made. At IT-Designers GmbH GitLab as well as Jenkins are commonly used for scenarios exactly like this. A pipeline definition in GitLab CI/CD [4] or in a Jenkinsfile [5] describe stages and commands to execute. Each stage can be hosted on another node and be executed sequential or in parallel to each other.

Although this seems to be quite fitting for the desired workflow, there are two issues. First of all, such a pipeline does not involve any user input besides an optional manual start invocation. The result is then determined based on the state of the input repository. Second, such a pipeline is designed to determine the output (usually by compiling) whereas each run is independent from the previous and a repeated run shall provide the same result as the previous did. Usually, a new run is only caused by a change of the input data. However, the desired workflow differs in this aspects. A redo of a stage can depend on the result of the previous stage, for example, if the results are poor or the the stage failed. Instead of having multiple complete pipeline runs per project, the desired workflow uses a pipeline definition as base for which the order can be changed. Also, intermediate results need to influence further stages, even if repeated.

### 3.1.3 Camunda

Camunda[6] calls itself a “Rich Business Process Management tool” and allows the user to easily create new pipelines by combining existing tasks with many triggers and custom transitions. Camunda is focused upon visualizing the flow and tracking the data through a pipeline. The Camundas Process Engine[7] also allows user intervention between tasks.

One of the main supporting reason for it Camunda is the out of the box rich graphical user interface for process definition and interaction. Through its API[8], Camunda also allows custom external workers to execute a task. But it misses the

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<sup>1</sup>Source Code Management

capability to control which task shall be processed on which worker node which is required by the desired workflow. It does also not provide any concept on how to allocate and distribute resources. The user interface - while being rich overall - is quite rudimentary when it is about configuring tasks and would therefore require custom plugins to be developed for more advanced user interactions.

Camunda is also not designed to reorder stages or insert user interactions at seemingly random fashion. The user itself is considered more as a worker that gets some request, “executes” this externally and finally marks the request as accepted or declined. Mapping this to the desired workflow does not feel intuitive. Finally, there is also no overview of task executors, no centralized log accumulation and no file up- or download for global project resources.

#### **3.1.4 Nomad**

Nomad[9] by HashiCorp is a tool to deploy, manage and monitor containers, whereas each job is executed in its own container. It provides a rich REST API and can consider hardware constraints on job submissions. Compared to Kubernetes[10], which is similar but more focused on scaling containers to an externally applied load, it is very lightweight. It is also available in many Linux software repositories - such as for Debian - which makes the installation very easy.

Because there were no grave disadvantages found (depending on a third party library can always be considered be a disadvantage for flexibility, error-pronous and limit functionality) Nomad is being considered as a middle-ware to manage and deploy stages. Others[11] seem to be using Nomad to manage and deploy containers for similar reasons. Nonetheless, further testing and prototyping will be required for a final decision.

#### **3.1.5 dCache**

“The goal of this project is to provide a system for storing and retrieving huge amounts of data, distributed among a large number of heterogenous server nodes, under a single virtual filesystem tree with a variety of standard access methods”[12]. dCache seems to be able to solve the storage access and distribution concern for the stages and sever nodes. When using dCache, one could store the

global resources distributed between the server nodes. Built-in replication would prevent access loss on a node or network failure and an export through NFS<sup>2</sup> allows easy access for Linux based systems[13].

But the installation is complex and requires many services to be setup correctly, such as postgresql and many internal services such as zookeeper, admin, poolmanager, spacemanager, pnfsmanager, cleaner, gplazma, pinmanager, topo, info and nfs. The documentation is also rather outdated and incomplete which meant, early tests with a prototype setup took days to setup and behaved rather unstable (probably due to a wrong configuration). It is to be seen, whether such an complex and heavy system is actually required or if there are feasible alternatives.

### 3.1.6 Further mentions

The following list shall acknowledge programs that behave similar to the previously mentioned strategies. Programs that are listed here, were looked into, but not in-depth because miss-fits were detected early on (listed in no specific order):

- **Quartz**[14] is a Java based program to schedule jobs. Instead of doing so by using input, Quartz executes programs through a timetable and in certain intervals.
- **Luigi**[15] also executes pipelines with stages and is written in python. The advertised advantage is to define the pipeline directly in python code. But, this is at the same time the only way to define pipelines which contradicts with the existing Java TrackerApplication implementation.
- **Calery**[16] is focused on task execution through message passing and is written in Python. Intermediate results are expected to be transmitted through messages. Because there is no storage strategy and python adapter-code would have been required, Calery was dismissed.
- **IBM InfoSphere**[17] provides similar to Camunda a rich graphical user interface but for data transfer. Dismissed due to commercial nature.

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<sup>2</sup>Network File System



- **qsub**[18][19] is a CLI<sup>3</sup> used in HPC to submit jobs onto a cluster or grid. Dismissed due to an expected high setup overhead, non-required multi-user nature and the fact, that it only provides a way to submit jobs.
- **CSCS**[20] High Throughput Scheduler (GREASY). Dismissed for similar reasons as qsub, although it is more light weight and hardware agnostic (it can consider CUDA/GPU requirements).
- **zsync**[21], similar to rsync, is a file transfer program. Zsync allows to only transfer new parts when a file that shall be copied already exists in an older version on the target. This tool might be useful when implementing a custom resource distribution strategy is required.
- **OpenIO**[22] provides a distributed file system, is already provided as Docker image and provides a simple to use CLI. Because the NFS export is only available through a paid subscription plan, it was dismissed from further investigation.
- **SeaweedFS**[23] provides a scalable and distributed file system. The most interesting aspects are that it is rack-aware as well as natively supports external storage such as Amazon S3. When adding server nodes from the cloud this could allow all nodes to access the same file system while using rack-aware replication to reduce bandwidth usage and latency. A local test also proved that it is easy to setup, but because it cannot hot-swap nodes and was not able to recover when the seaweed master node became unreachable it was dismissed.
- **Alluxio**[24] provides a distributed file system but was dismissed because it itself requires a centralized file system for the master and its fallback instances
- **GlusterFS**[25] is another tool to provide a distributed file system with replication. It was bought by IBM but is nonetheless available through the software repository of many Linux distributions such as Debian. A local test showed that the setup is very easy and no adjustments of configuration files

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<sup>3</sup>Command Line Interface

are required. However, the replication mechanism requires that an integer multiple of nodes of the replica value are assigned to the file system. This makes GlusterFS hard to use in a scenario, where adding and removing nodes are expected to happen frequently. It was therefore dismissed.

## 3.2 Docker Integration

As describe before (see section 2.2), for easy deployment, the implementation as well as the stages shall be executed inside Docker[26] containers. This allows easier isolation of the stages and workspaces from each other and other host programs. Because one needs to communicate with the Docker daemon, this increases the complexity for the implementation. But by using third party libraries, the increase in complexity can be limited.

# Chapter 4

## Outcome and further work

In this chapter the main concerns are listed. For each concern the current progress is described as well as further work that needs to be done.

### 4.1 Storage

One of the central concerns is the storage management. The program needs to make input files available on each execution node and collect the results once the computation is complete. There are a few main architectural strategies to approach this. Simplified, either at a centralized location which is accessed by all execution nodes, a copy of the input files to the execution nodes or decentralized and distributed between all execution nodes and replication. The advantages and disadvantages can depend on the specific implementation and is therefore discussed in combination of such (see chapter 3).

Further testing is required to decide whether a more complex storage system is required, or the simplicity of a centralized solution outweighs the setup and maintenance overhead.

### 4.2 Coordination

Another important concern is the coordination of the nodes. A central coordinator with external server nodes, such as GitLab and Jenkins have, might not be sufficient for more complex and longer lasting pipelines. The probability that the

master would need to be offline while there is a stage executed, is in the scenario of the desired workflow higher than for GitLab or Jenkins, because the stage is being execution for hours or days. Coupling stage execution plans on node availability ahead of time, as well as recovering from a sudden master failure implies additional implementation complexity. A decentralized coordination needs to be able to do this as well, but also allows the usage of the system while a node failed or is unreachable due to maintenance. With further prototyping and research a reasonable solution shall be found.

### 4.3 Binary distribution

In a time where containers are common and have proven to be usable, the installation of the binaries directly on the operating system they are executed on shall be avoided. There shall be no manual, nor automatic but custom file copies of the binaries or images from one server to the other. Experience shows, that without a proper management, this can easily become a mess, in which it is no longer clear, which files or images belong to which version. At the same time, making all binaries publicly available through the Docker Hub[27] is no option either. Whether a self hosted Docker Registry[28] could be the solution to this will be determined in further testing.

### 4.4 User Interface

Providing a useful user interface might not be important to the functionality of the system itself but for the user experience. A bad user experience will cause a system not to be used. It became common practice for a rich user experience to be web based and interactive with JavaScript. For a potentially decentralized system, it is also advantageous to be able to access a disconnected node in the same manner as the remaining system, which further encourages a web based solution. Web based solutions such as React and Angular shall therefore be investigated for being used as user interface.

# Chapter 5

## Schedule

The following figure shows schedule for further and past work:

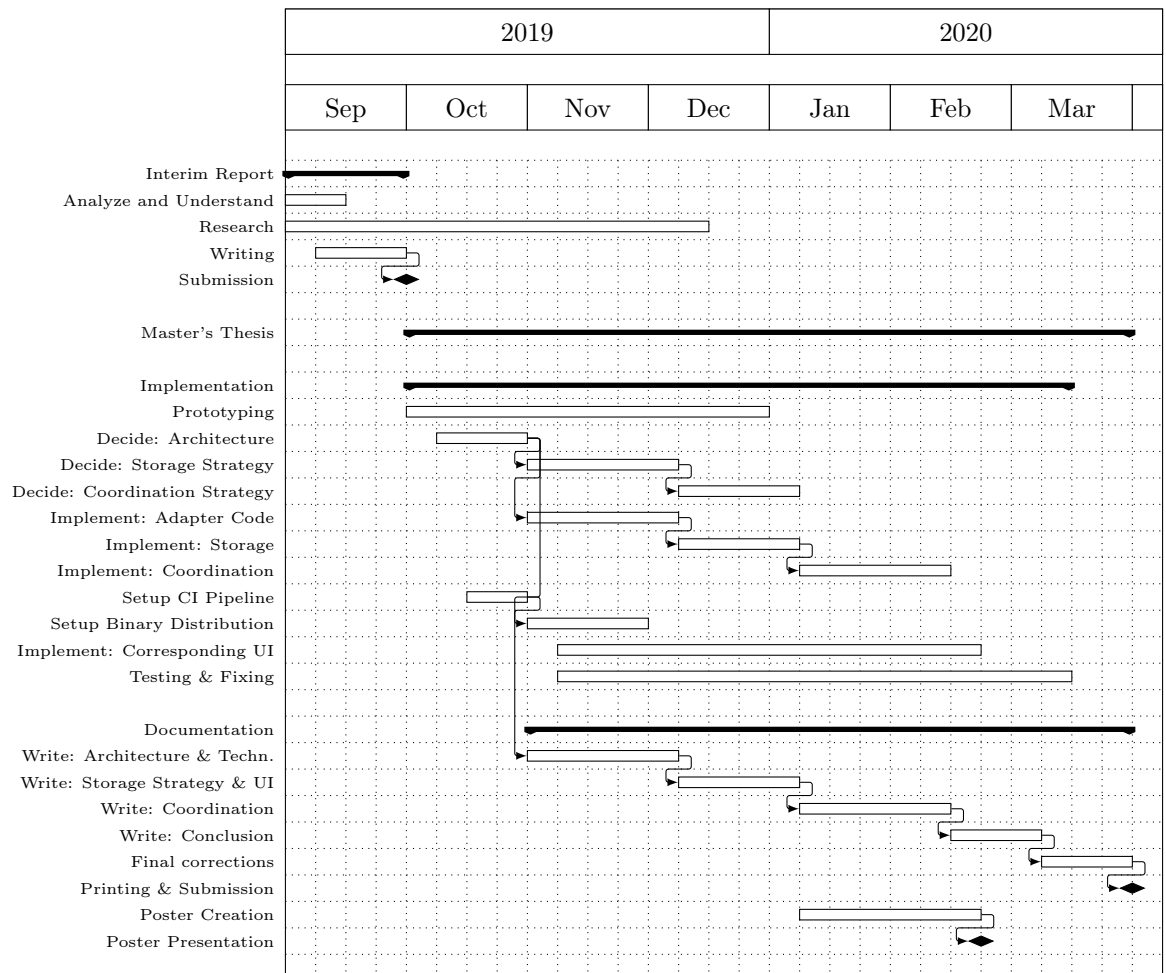


Figure 5.1: Time schedule

# Chapter 6

## Introducing Winslow

Giving it a name helps to refer to it.

### 6.1 Domain Language(?)

what is a pipeline

what is a project

what is a stage

..

# Chapter 7

## Requirements

This chapter works out the desired capabilities of the software and then lists the resulting requirements. Requirements help to keep track of whether the software covers all customer needs and wishes. They also help during development to keep track of the progress and estimate the time required to implement the remaining requirements.

### 7.1 Use Case Diagrams

Finding all requirements can be challenging. Drawing Use Case Diagrams can help to discover requirements while being very easy to understand. This helps in understanding the customers needs [29] while the customer receives an impression on what will be reflected in the final product.

Listing all use cases in a single diagram negates the desired effect of it being easily understandable because of the number of interaction possibilities. Instead, the interactions are grouped in categories and displayed in separate diagrams. Figure 7.1 shows high-level use cases of all categories that are relevant to a user of the system.

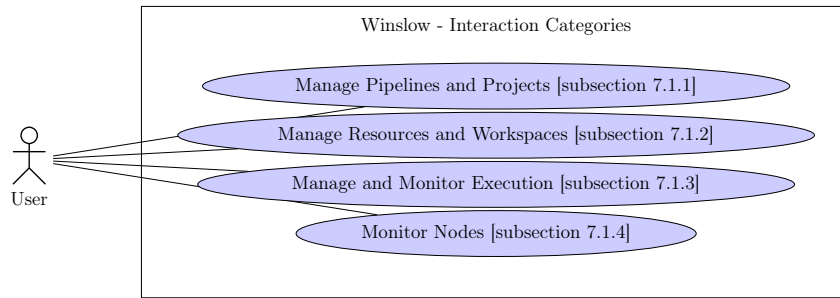


Figure 7.1: Use Case Diagram showing the top level interaction categories

### 7.1.1 Managing Pipelines and Projects

TODO: .

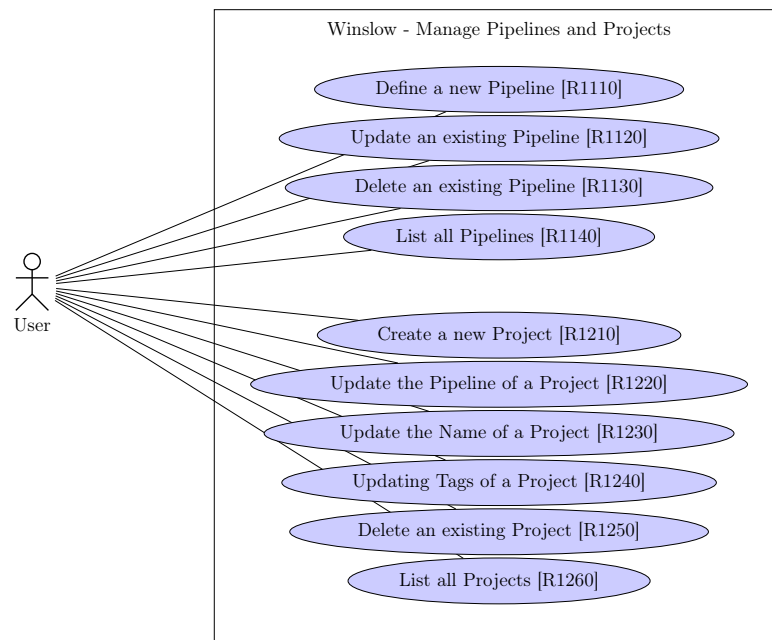


Figure 7.2: Use Case Diagram showing the general management interactions

### 7.1.2 Managing Resources and Workspaces

TODO: .



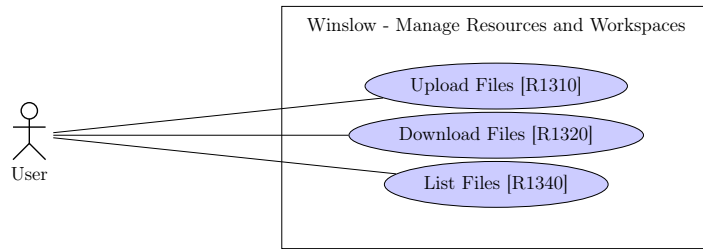


Figure 7.3: Use Case Diagram showing the general management interactions

### 7.1.3 Managing and Monitoring Executions

TODO: .

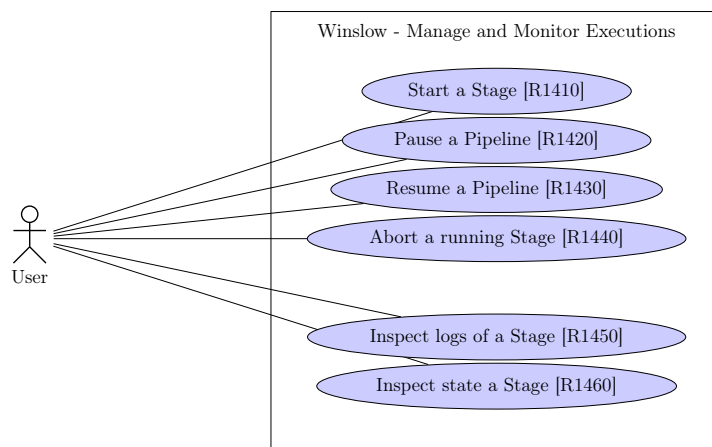


Figure 7.4: Use Case Diagram showing the general management interactions

### 7.1.4 Monitoring Nodes

TODO: .

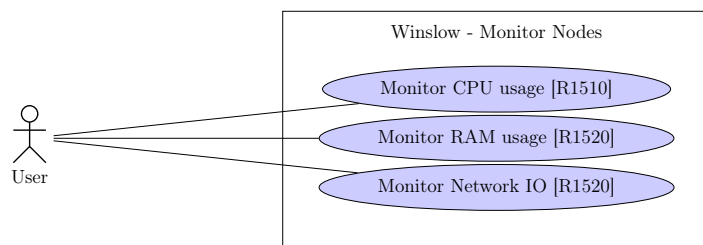


Figure 7.5: Use Case Diagram showing the general management interactions

### 7.1.5 System Administration

Furthermore to the interactions with a user, the system must provide further capabilities that are **TODO: of** concern to the administrator.

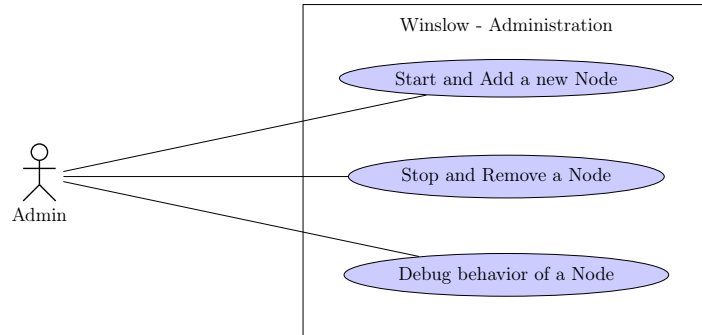


Figure 7.6: Use Case Diagram showing administrative interactions

## 7.2 Requirements

### 7.2.1 Managing Pipelines and Projects

- **Requirement 1110: Define a new Pipeline**

The user must be able to create a new pipeline definition. Only valid definitions must be accepted. A valid pipeline definition has a name and must contain at least one stage definition.

- **Requirement 1120: Update an existing Pipeline**

The user must be able to see and modify an existing pipeline definition.

- **Requirement 1130: Delete an existing Pipeline**

The user must be able to remove an existing pipeline definition. Deleting a pipeline definition must not break and therefore must not prevent associated projects from further execution.

- **Requirement 1210: Create a new Project**

The user must be able to create a new project. Only valid projects must be accepted. A valid project has a name and must be using an existing pipeline definition.

- **Requirement 1220: Update the Pipeline of a Project**

The user must be able to change the pipeline definition an existing project is based on.

- **Requirement 1230: Update the Name of a Project**

The user must be able to update the name of a project.

- **Requirement 1240: Updating Tags of a Project**

The user must be able to add and remove tags to and from an existing project.

- **Requirement 1250: Delete an existing Project**

The user must be able to delete a Project. Deleting a project must delete all associated files, directories and configuration files.

## 7.2.2 Managing Resources and Workspaces

TODO: what about res/workspace/init directories

- **Requirement 1310: Upload Files**

The user must be able to upload files into the scope of a project, so that further stage execution is able to retrieve said file.

- **Requirement 1320: Download Files**

The user must be able to download files that are within the scope of a project. Said files can be files that were previously uploaded by the user or are results of executed stages.

- **Requirement 1340: List Files**

The user must be able to retrieve a list of files associated with a project.

## 7.2.3 Managing and Monitoring Executions

- **Requirement 1410: Start a Stage**

The user must be able to start a new Stage for a project. Any Stage defined in the associated Pipeline Definition is considered a valid choice. The user shall be able to choose whether the following Stages shall be executed automatically or the pipeline shall be paused upon completion.

- **Requirement 1420: Pause a Pipeline**

The user must be able to mark a running Pipeline of a Project to be paused before executing the next Stage.

- **Requirement 1430: Resume a Pipeline**

The user must be able to resume paused Pipelines.

- **Requirement 1440: Abort a running Stage**

The user must be able to commit an abort request for a running Stage. An aborted Stage shall be considered failed and further Stage execution shall be paused.

- **Requirement 1450: Inspect logs of a Stage**

The user must be able to see log messages produced by a selected Stage as well as to that stage associated system events.

- **Requirement 1460: Inspect state a Stage**

The user must be able to retrieve the state ('RUNNING', 'PAUSED', 'SUCCEEDED', 'FAILED') for all stages of a project.

## 7.2.4 Monitoring Nodes

- **Requirement 1510: Monitor CPU usage**

The user must be able to retrieve the CPU utilization of all known nodes.

- **Requirement 1520: Monitor RAM usage**

The user must be able to retrieve the RAM utilization of all known nodes.

- **Requirement 1520: Monitor Network IO**

The user must be able to retrieve the Network IO utilization of all known nodes.

## 7.2.5 Derived Requirements

Requirements that are derived by looking at other requirements.

## 7.3 Systemanalyses

System Umwelt Diagram

System Interacts with the User and other instances of itself

# Chapter 8

## The architecture

event based

- common file system for communication because minimum requirements
- stick to unix principles(list): simple, human readable intermediate format
- voting/election by capabilities and 'will' of a node to run a stage

### 8.1 Targeting capabilities

#### 8.1.1 General thoughts

### 8.2 Planned

### 8.3 Implementation details

### 8.4 Synchronization, Locking, publishing events

### 8.5 REST for UI

### 8.6 Event Bus

requires common a way to exchange messages

- all messages - called events - are published to all nodes
- using file system as bus

clear and globally same order of events

events consist of a action, subject, timestamp, optional duration and **TODO:**

.

events might have a duration

unspoken requirement: all nodes share the same clock - or one with very little drift

### 8.6.1 Atomicity of (Unix) Filesystems

### 8.6.2 Atomicity and behavior of NFS in particular

### 8.6.3 Using as lock backend

### 8.6.4 Using as election backend

## 8.7 Election System

Utilizing Event Bus for timely limited elections and to ensure that there are no concurrent election for a single project.

**TODO: what about concurrent elections on multiple projects**

# Chapter 9

## Making decisions

### 9.1 Execution environment

### 9.2 Continuous Deployment



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