ANUBIS LMS

A PREPRINT

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ABSTRACT

The Anubis LMS is a tool to give students live feedback from their homework assignments while they are working on them and before the deadline. Instead of having students submit a patch file or individual files, each student will have their own private repo for every assignment. The way students then submit their work is simply by pushing to their repo before the deadline. Students submit as many times as they would like before the deadline.

When a student pushes to their assignment repo, a job is launched in the Anubis cluster. That job will build their code, and run tests on the results. Students can then use the live feedback to see which areas they need to improve on before they get their final grades.

Keywords LMS, Cloud IDEs, Autograding, Distributed Computing, Kubernetes

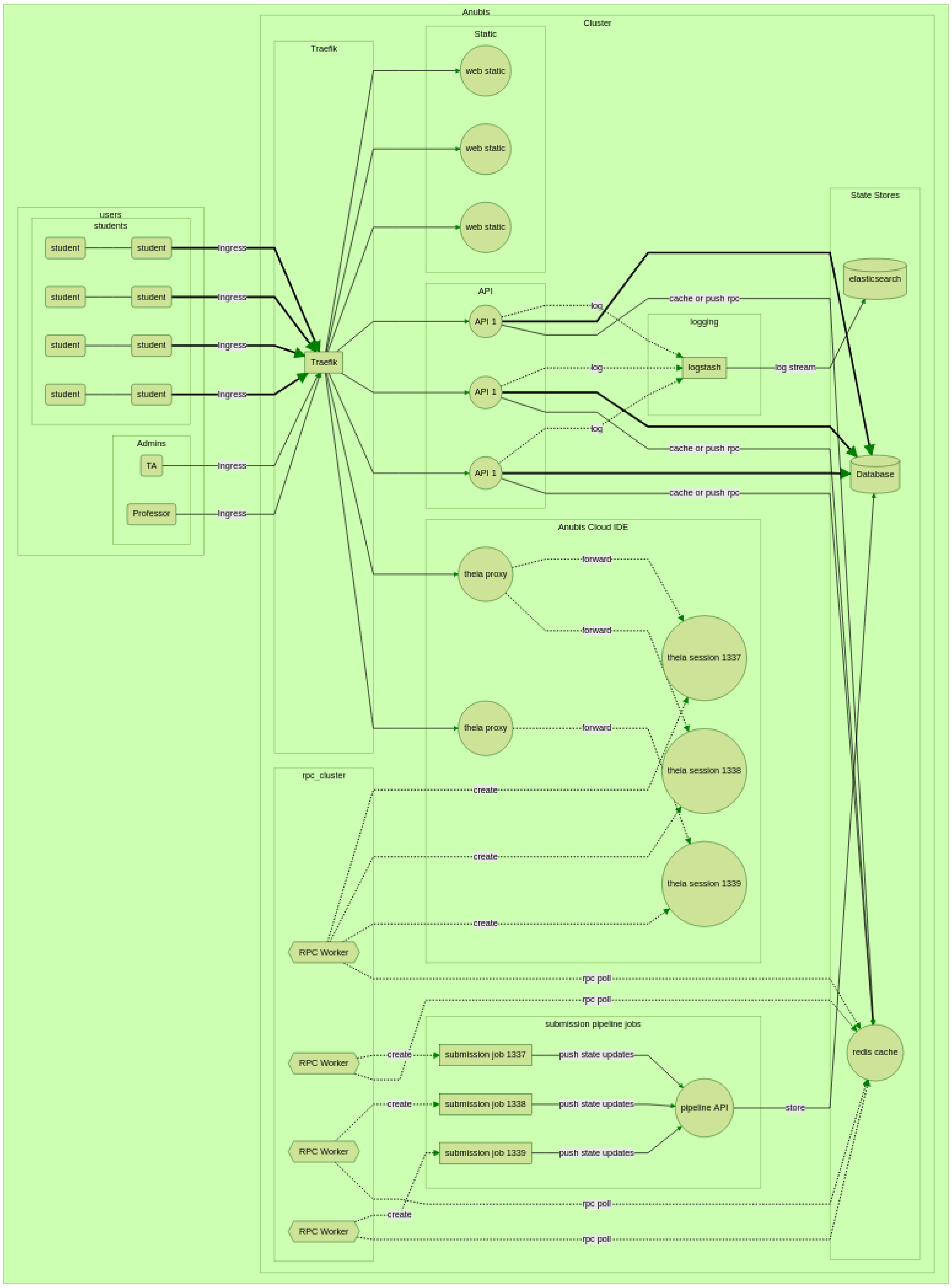

Figure 1: The Anubis Cluster

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Chapter 1

Project Overview

1.1 Autograding

When a student pushes to their assignment repo, a job is launched in the Anubis cluster. That job will build their code, and run tests on the results. Students can then use the live feedback to see which areas they need to improve on before they get their final grades.

1.2 Anubis Cloud IDEs

New in version v2.2.0, there is now the Anubis Cloud IDE. Using some kubernetes magic, we are able to host theia servers for individual students. These are essentially VSCode instances that students can access in the browser. What makes these so powerful is that students can access a terminal and type commands right into a bash shell which will be run in the remote container. With this setup students have access to a fully insulated and prebuilt linux environment at a click of a button.

1.3 Insights

Anubis passively captures very interesting usage data from users. Most users elect to using the Cloud IDEs as they offer an easily accessable environment. When they do this, the autosave pushes their work to github every 5 minutes, and submission tests are run on the repo. With this feedback loop, Anubis captures near minute by minute progress on an assignment for most all users. With the usage data generated by Anubis, very interesting questions and answers can be

Chapter 2

Autograding

2.1 Assignment Structure

Under Anubis each student gets their own github repo for each assignment. When they push to their repos, Anubis sees the push and runs tests on their code. The results are then available to students on the Anubis website before the deadline. Under this model students can push as many times as they would like before the assignment deadline.

Assignment repositories are created from template repositories. TAs or professors can set up a repo with the necessary files or starter code for students to work on. Template repositories can be set up in such a way that constrains student code. With c or c++ assignments, starter files c or c++ with a Makefile constrains students to all start from the same point. Instead of getting N submissions all with different file names and run options, everyone's code will compile and run with the same commands. This structure makes automating tests possible.

2.2 Creating Autograde Tests

Using the anubis cli, you can initialize a new assignment using

```
anubis assignment init <name of assignment>
```

The first file you will want to edit is the *meta.yml* that gets created. This is where things like the assignment name, and due dates should be defined. There is also a generated unique code that anubis uses to identify this assignment. Hold on to this, as we will use it in the next step.

```yaml
assignment:
  name: "OS Final Exam"
  class: "CS-UY 3224"
  hidden: false

  # Optionally specify the github classroom link
  # for students to get their repo.
  #
  #  !! Remember to set the Custom repository
  #  !! prefix to {name}-{unique_code}
  #  !! when creating the assignment on
  #  !! Github Classroom
  github_classroom_url: "...."

  # Don't change these!
  unique_code: "839f70b2"
  pipeline_image: "registry.digitalocean.com/anubis/assignment/{unique_code}"

  # Specify the important dates here
  # * Remember! These are interpreted as America/New_York *
  date:
    release: "2021-05-17 06:00:00"
    due: "2021-05-19 06:00:00"
    grace: "2021-05-19 06:30:00"

  # This description will be shown to the user on the Anubis website.
  description: |
    Good luck.
```

Here is an example generated meta.yml from the OS final exam this semester. The only fields that you will need to fill in are the github classroom url. This is the URL that is given to you when you create a github classroom assignment. That link will then be provided as a button for students to click in the frontend.

2.3 Writing Autograde Tests

All the files to build and run a complete anubis pipeline image will be dropped into the new directory.

```
new-assignment
|- assignment.py
|- Dockerfile
|- meta.yml
|- pipeline.py
|- test.sh
`- utils.py
```

The only thing you will ever need to edit is assignment.py. This is where you define your build and test code. Just like all the other cool libraries out there, the anubis pipeline works through hooking functions. Here is a minimal example of an assignment.py that will build and run a single simple test.

```python
from utils import register_test, register_build, exec_as_student
from utils import (
    TestResult, BuildResult, Panic, DEBUG,
    xv6_run, did_xv6_crash,
    verify_expected, search_lines, test_lines
)

@register_build
def build(build_result: BuildResult):
    stdout, retcode = exec_as_student('make xv6.img fs.img')

    build_result.stdout = stdout.decode()
    build_result.passed = retcode == 0


@register_test('test echo')
def test_1(test_result: TestResult):
    test_result.stdout = "Testing echo 123\n"

    # Start xv6 and run command
    stdout_lines = xv6_run("echo 123", test_result)

    # Run echo 123 as student user and capture output lines
    expected_raw, _ = exec_as_student('echo 123')
    expected = expected_raw.decode().strip().split('\n')

    # Attempt to detect crash
    if did_xv6_crash(stdout_lines, test_result):
        return
    # Test to see if the expected result was found
    verify_expected(stdout_lines, expected, test_result)
```

There are a couple functions to point out here. The *register_build* and *register_test* decorators are how you tell anubis about your build and test. The *exec_as_student* function is how you should call any and all student code. It lowers the privileges way down so that even if the student pushes something malicious, they are still low privileged enough where they can not do much. It also adds timeouts to their commands. Boxing student code in like this is absolutely essential. Do not underestimate the creative and surprising ways students will find to break things.

Each test is passed a *test_result* object. This object has 3 fields. All you need to do is set the fields on the *test_result* object. The results will then be reported to the anubis api, and then to the student.

```
class TestResult(object):
    def __init__(self):
        # The standard out for the students tests. You can
        # add extra text in this field as needed.
        self.stdout: str = None

        # The message is an optional parameter that will
        # insert a short message in bold above the standard
        # out on the website frontend.
        self.message: str = None

        # Passed should be a boolean value. True if the test
        # passed, and False if it did not.
        self.passed: bool = None
```

The functions *run_xv6* and *did_xv6_crash* are very specific to the Intro to OS needs. There are also some general functions that are just as helpful.

```
def exec_as_student(cmd, timeout=60) -> typing.Tuple[bytes, int]:
    """
    Run a command as the student. Any and all times that student
    code is run, it should be done through this function. Any other
    way would be incredibly insecure.

    :param cmd: Command to run
    :param timeout: Timeout for command
    :return: bytes output, int return code
    """


def verify_expected(
    stdout_lines: typing.List[str],
    expected_lines: typing.List[str],
    test_result: TestResult,
    case_sensitive: bool = True,
    search: bool = False
):
    """
    Check to lists of strings for quality. Will strip off whitespace from each line
    before checking for equality. The stdout_lines should be from the student code.
    The expected_lines should then be whichever lines are expected for this test.

    * The fields on the test_result object will be set automatically based on if the
    expected output was found. *

    :param stdout_lines: students lines as a list of strings
    :param expected_lines: expected lines as a list of strings
    :param test_result: TestResult object for this test
    :param case_sensitive: boolean to indicate if the comparison should be case sensitive
    :param search: boolean to indicate if the stdout should be searched instead of
                   directly compared for equality
    :return:
    """


def test_lines(
        stdout_lines: typing.List[str],
        expected_lines: typing.List[str],
        case_sensitive: bool = True
) -> bool:
    """
    Test lines for exact equality. Whitespace will be stripped off each line automatically.

    * Optionally specify if the equality comparison should be case sensitive *

    >>> test_lines(['a', 'b', 'c'], ['a', 'b', 'c']) -> True
    >>> test_lines(['a', 'debugging', 'b', 'c'], ['a', 'b', 'c']) -> False
    >>> test_lines(['a', 'b'],      ['a', 'b', 'c']) -> False

    :param stdout_lines: students standard out lines as a list of strings
    :param expected_lines: expected lines as a list of strings
    :param case_sensitive: optional boolean to indicate if comparison should be case sensitive
    :return: True if exact match was found, False otherwise
    """


def search_lines(
        stdout_lines: typing.List[str],
        expected_lines: typing.List[str],
        case_sensitive: bool = True
) -> bool:
    """
    Search lines for expected lines. This will return true if all expected lines are in the
    student standard out lines in order. There can be interruptions in the student standard out.
    This function has the advantage of allowing students to still print out debugging lines
    while their output is still accurately checked for  the expected result.

    >>> search_lines(['a', 'b', 'c'], ['a', 'b', 'c']) -> True
    >>> search_lines(['a', 'debugging', 'b', 'c'], ['a', 'b', 'c']) -> True
    >>> search_lines(['a', 'b'],      ['a', 'b', 'c']) -> False

    * Optionally specify if the equality comparison should be case sensitive *

    :param stdout_lines:
    :param expected_lines:
    :param case_sensitive:
    :return:
    """
```

2.4 Deploying Autograde Tests

Once you have tests written, then it is time to push them to Anubis. The next thing that needs to be done is push the image to the docker registry and upload the assignment data to anubis. This is as simple as running two commands:

```
# sends assignment metadata to anubis api
anubis assignment sync
```

```
# builds then pushes the assignment
# pipeline image to the registry
anubis assignment build --push
```

2.5 Submission Pipelines

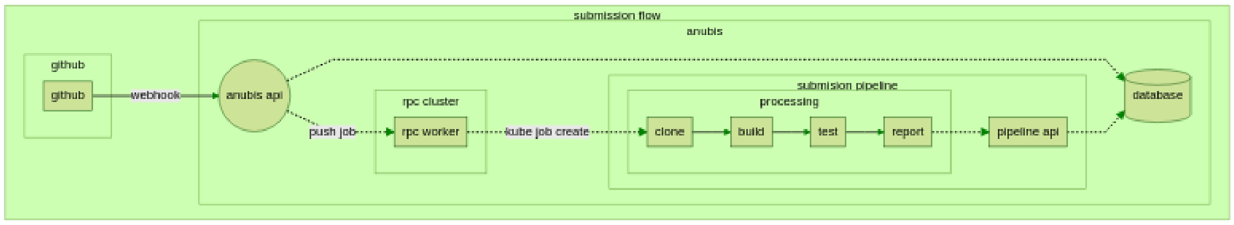


Figure 2.1: Submission Pipelines are a complex multi service data flow.

Submissions Pipelines 2.1 are where the autographing is really happening. When students push code to their github repositories, Anubis sees the new commits and creates a pipeline job. Each commit to student github repository gets a new Submission Pipeline.

2.5.1 Kubernetes Job

Each Submission Pipeline is a Kubernetes Job. There are certain assurances that can be made when using Kubernetes Jobs. If there is an issue on one node on the cluster that prevents a submission job from finishing, Kubernetes will reschedule and retry the Submission Pipeline elsewhere.

2.5.2 Pipeline State Reporting

Some assignment tests will also take a long time to process each submission. Due to this reality, live state updating was added to the Submission Pipelines.

There is an internal REST api that is only for submission pipelines to report state to. This pipeline is called the *pipeline-api*. The *pipeline-api* is specifically a subset of the main api. It has different view functions defined for it. The purpose of these special api servers is to take state updates from submission pipelines and update the database.

If a submission is processing the website will poll for updates. This complex multi service state reporting model is how results from isolated submission pipelines appear on the website for students as they happen.

2.5.3 Pipeline Stages

It is important to note that at each stage of the submission pipeline, we will be moving execution back and forth between two unix users. There will be the entrypoint program managing the container as user *anubis*. The *anubis* user will have much higher privileges than the *student* user. The *student* user will be used whenever executing student code. It will not have any level of access to anything from the *anubis* user.

Clone

n this initial stage, we will pull the current repo down from github. After checking out the commit for the current submission, we will also delete the *.git* directory as it is not needed. Lastly we will chown the entire repo as *student:student*. This will then be the only place in the container that the student user can read or write to (other than /tmp of course).

Build

At this stage we hand execution off to student code for the first time. Code must be built as the student user. The function that was marked with the *register_build* decorator handles this phase. The stdout and return code of the build will be captured by the *anubis* user. For most assignments, the success of the build is determined by the return code. No extra parsing of the stdout should be necessary.

Test

Tests are defined on a per-assignment basis. Again, student code will be executed for this step. That code must be executed as the *student* user.

Each test is defined as a python function that was decorated with the *register_test* decorator. The function should run the student code for whatever they are testing, then confirm that the standard out matches whatever was expected.

The state updating at this step is automatic. After each test hook is called, the results will automatically be sent off to the *pipeline-api*.

After the last test is called, the pipeline sends a special state update stating that the submission tests have completed. It is important that this step happens as it is where the submission is marked as processed.

2.5.4 A Word on Isolation

Chapter 3

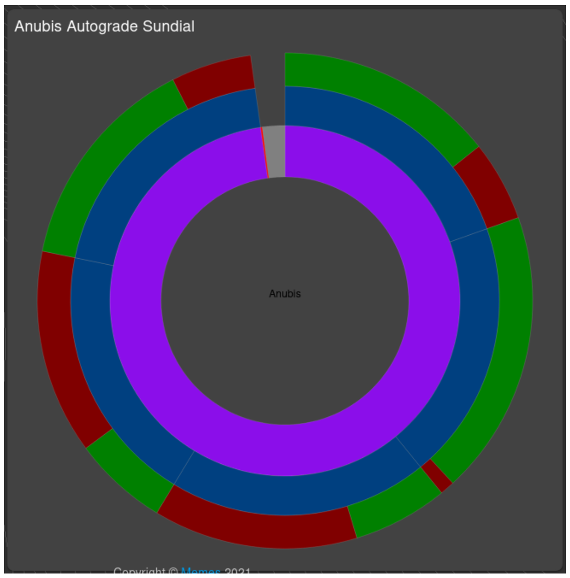
Anubis Cloud IDEs

Chapter 4

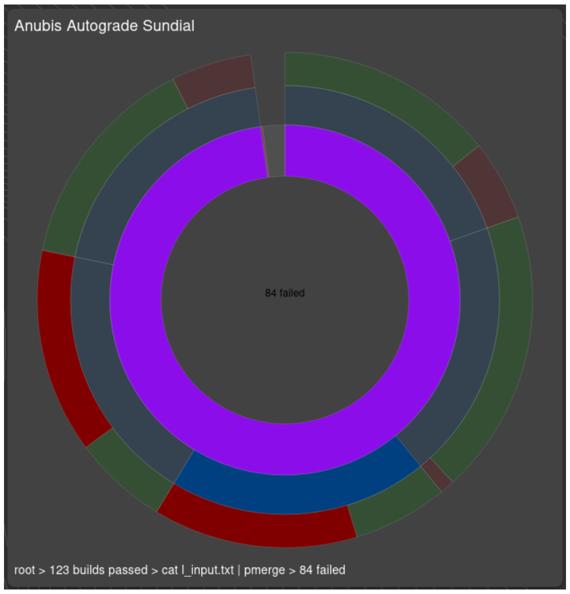
Insights

4.1 Class Level Autograde Results

A special visual is generated specifically for visualizing the success of an assignment at a glance. This visual is called the Anubis Sundial 2.2a. It is a radial graph that shows the proportion of students that are passing/failing tests for a specific assignment.



(a) The Anubis Sundial.



(b) Many students failed the long file lines test.

With this simple visualization professors can see which tests students are struggling with. Sundials are generated live. At any time, even before the due date, they will be available. For course administrators, this means that they can see which tests students are struggling with.

Take the simple example in 2.2b. By mousing over the sundial, we can see that the tests with long file lines are failing. This information can then lead to long line buffering being covered again in lecture or recitation.

4.2 Student Level Autograde Results

Given the structure of Anubis assignments, coupled with the Anubis Cloud IDEs we can track and measure each student's progress through an assignment. We can track and measure when students start and finish their assignments, and how long it takes them to pass specific tests. In the autograde results panel, a "visual history" is generated for each student. It shows when students started their assignment, then for each submission if their build passed or failed and how many tests passed. If they used the Anubis Cloud IDEs as most students do choose to, then the graph generated shows a near minute by minute representation of which challenges they faced and how long it took for them to overcome them.

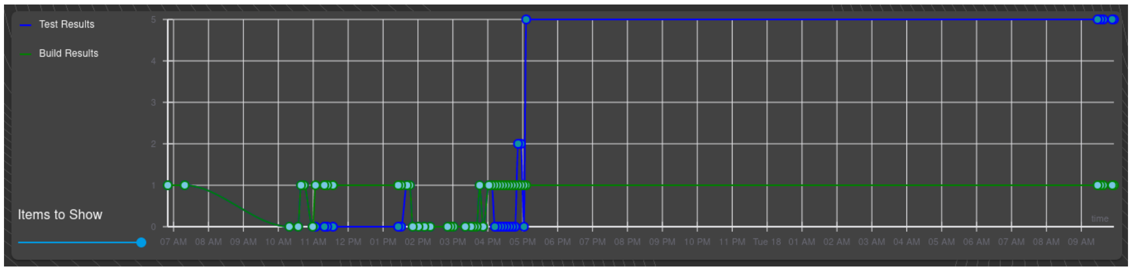


Figure 4.2: A Student Visual History

The example in 2.3 shows the build as the green line, and the assignment tests as the blue line. We can see that this student spent a good deal of time on the first day just getting their tests to pass, only to revisit their work the next day probably to clean up their submission.

Chapter 5

Services

Chapter 6

Deployment