Yeager: An Annotation-Based Framework for the Generation of Automated Long Sequence Regression Tests in Python

by

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"Yeager: An Annotation-Based Framework for the Generation of Automated
Long Sequence Regression Tests in Python",
a thesis by Casey Doran

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Abstract

TITLE:	Yeager: An Annotation-Based Framework for the Generation of Automated Long Sequence Regression Tests in Python
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This work presents a Python software package, Yeager, designed to enable the generation and execution of high-volume automated long-sequence regression tests. Users apply the package to existing suites of automated regression tests by annotating individual test methods as state changes for the Software Under Test. Given a sufficiently connected state model (as inferred from these annotations), it becomes possible to generate and execute configurable random walks through the SUT's various states instead of simple regression suites as originally written.

Divided into three sections, this thesis provides a concise overview of an exemplar regression test suite in Python for a web application, a guide to the usage of Yeager itself within the context of the aforementioned regression test suite, and an extensive discussion of the benefits and drawbacks of High Volume Automated Testing in general, and Long Sequence Regression Testing in particular, within the scope of a typical software development organization.

Contents

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Dedication

For Joseph Campo, Jr. and Alexander Yanes. Life is short. You'll be forever a lion.

Chapter 1

A Concise Overview of A Python Regression Test Suite For a Web Application

This thesis proposes a general-purpose python module for the implementation of high volume automated tests. To properly discuss the nuanced uses of the module, it is first critical to establish a "typical" industrial usage scenario.

To that end, this chapter describes the state of the art in the web test automation field, and walks through the construction of a web test suite for a popular open source relationship management site, Monica, available for use from the website `https://monicahq.org` as well for self-hosting from `https://github.com/monicahq/monica`. Later chapters will discuss implementation of the module for high volume long sequence regression testing as well as the industrial and academic context surrounding the practice of high volume automated testing.

The test suite discussed in this chapter is published in its entirety online at `https://github.com/elementc/monica-tests-traditional`. They are written against the 0.6.5 release of the Monica software, and may be run using Python 3.

1.1 Technologies

There are a considerable number of tools and libraries used in the development and execution of web application tests. Regardless of actual platform, there must be at least a browser driver, a test runner, and probably some set of inspection tools. As later chapters will use a Python library, the following Python-friendly libraries have been selected.

1.1.1 Selenium

The Selenium open source project is a library which permits the programatic control of a web browser. This library is ostensibly designed for automated testing purposes, but it may be used in any case where automated browser interaction is critical, including secretarial desktop automation, the development of testing tools, malicious purposes, and niche industrial purposes. It has a number of supported platforms, including Python and a purpose-built IDE. The general usage operational cycle is:

1. Instantiate a browser driver, selecting the type of web browser to be driven.
2. Load specific URLs using the driver's `get` method.
3. Query the loaded page using the driver's `find_element` methods.

4. Interact with page components using the element objects and associated methods returned from the above step.

[Holmes and Kellogg, 2006; Bruns et al., 2009; Razak and Fahrurazi, 2011; Wang and Xu, 2009; Kaur and Gupta, 2013; Kongsli, 2007; Artzi et al., 2011]

1.1.2 Python Test Runners

Test runners are executables that load test suites, execute selected subsets, and then report results. There are a number of different test runners in the Python ecosystem, varying in their usage, provided test libraries, and reporting capabilities. Common test runners like pytest and nose live in the Python package archive, and have many users. However, there is a test runner built into the Python standard library named unittest. In the interest of keeping the dependencies of this test suite down (and taking advantage of familiar, high quality documentation), we have selected the unittest library for the runner of this test suite. [Nielsen, 2014; Pajankar, 2017]

1.1.3 Developer Tools and Resources

Test authors need to be able to inspect the web application under test from the UI perspective in order to effectively use Selenium. Historically, a web debugger such as Firefox's Firebug tool has been used to fill this requirement. In modern web development, however, the debugger and inspector are built directly into the desktop web browser. These are all roughly equivalent in capability, but for the purposes of this document we'll use terminology consistent with Google Chrome's Inspector toolkit, which can be accessed with the F12 key.[Odell, 2014]

1.2 Architecture

A typical web application test suite is built from three components: a collection of page object models, a set of configuration parameters, and a set of test sequence scripts. In most cases, these will be stored in similarly named directories (/pages/, /config/, and /tests/).

1.2.1 Page Objects

To abstract out much of the low level work associated with interacting with the system under test, a typical usage case is to write a Python class for each "page" of the web application, and for each class to have a function related to each of the low level interactions, eg setting a field to a value or pulling a string from the page title. In the constructor of the page object, common sanity checks are often run to ensure the system is in a good state. [Liu et al., 2000; Kung et al., 2000; Leotta et al., 2013a; Marchetto et al., 2008]

1.2.2 Configuration

It is common for different environments to have different credentials and settings, for instance, a continuous integration server might deploy with one set of passwords while a developer workstation has another and a user acceptance test server has a third set. To that end, it is critical that such variances are captured corectly, often in a configuration file or by reading correct values from execution environment variables. This may also be sensitive to certain differences in environments, for instance the need to skip verification of emails by system or application of different sets of mock interfaces.

1.2.3 Test Sequences

With page interfaces well defined and a suite of configuration details available, actual test authorship becomes fairly simple, with files conformant to the selected test runner's interface being filled with sequences of fairly easy to understand, high-level steps. Most of the time, a test script will be authored for each user story in the requirements of the system under test. Scenario-based tests is usually the easiest for novice programmers to write, but advanced methods may include detailed tours of the system or even exhausive tests of certain featue sets in isolation: test scripts for each of a calendar, a mail client, a presentation tool, and a contacts manager in an office productivity suite.[Leotta et al., 2013b]

1.3 Building The Test Suite

While we submit anecdotally that many would-be test automators are NOT traditionally trained software engineers, resulting in many industrial practices that are somewhat backwards to a software engineering-conscious observer, the composition of a web test automation suite is thoroughly a software engineering exercise. Various documents and projects attempt to reconcile these skillsets with these testers, including many project templates and several useful boilerplates. [Sandström, 2015]

The following domain-specific considerations are relevant to software engineers who would study or experiment with automated tests of a web system. The reader is encouraged to study existing boilerplates or the refeence Monica test impementation to supplement these considerations.

1.3.1 Planning A Set Of Tests

Testers usually recieve two sets of testing goals: verify conformance to some set of design and acceptance criteria, whether through the performance of some set of user story scenarios, touring features from a requirements document, or some other list of "shoulds"; and discover and verify new bugs through careful torture-testing of the system under test. We'll cover how to do the discovery part later on in chapter 2, and the verification process is currently a manual process, but verifying conformance is a straightforward enough task to automate.

In fact, the most common way to start writing automated regression tests is to copy the step-by-step instructions for a given scenario into comments in the body of a python test script. Each step becomes a snippet of code during the authorship process, with steps and checks corresponding to actions and assertions in the code that gets written. Then, as a tester walks through the steps in the application under test, they write the code bit by bit until theyve completed walking through an entire scenario. In this way, an automated test is designed and built. [Nguyen, 2001] Later subsections will outline these smaller authorship steps in the context of a web application.

1.3.2 Determining DOM Object Identification Methods

In order to be able to construct a proper page action, it is critical that our test code is able to interact with the right specific parts of the page under test. In Selenium, we use the driver's `find_element_by_*` methods to do so. There are methods for finding page elements by many methods, including html ID, html name, link text and partial link text, css selectors, and several other more

unique methods like an xpath string or just the tag's name. All of these methods are convenience wrappers for a base method named find_element that takes a special constant from the `selenium.webdriver.common.by.By` class, such as `By.ID` or `By.CSS_SELECTOR`.

While it may be more immediately readable to write test code using the convenience methods, this does have an effect on maintainability in that if a particular field must change the method it is found by, many function calls will need to be replaced. To prevent such a replacement nightmare, we can use python tuples and the unzip (splat) operator to combine a method of selection with a string constant as a single "element selector" field which may universally be consumed by a `find_element` function call.

Consider this HTML tag:

```
<input
  type="email"
  class="form-control"
  id="email"
  name="email"
  value=""
>
```

This has a number of useful atributes we could use as a selector, but the best of all is the id field. HTML ids must be unique in an html document [Web Hypertext Application Technologies Working Group, 2017b] so selection by ID is extremely resillient. Here's a selector and a call to `find_element` for the id "email":

```
email_sel = (By.ID, "email")
email_field = driver.find_element(*email_sel)
```

While selecting by the id field is comparatively simple (application authors may wish to give constant ids to parts of their applications they know will be involved in testing), selection by other methods is more complex. Consider this HTML tag:

```
<button
  type="submit"
  class="btn btn-primary"
>
  Login
</button>
```

This button is critical, it must be clicked in order to complete a login! However, it lacks a unique ID. It is tempting to use the `By.LINK_TEXT` selection method since it has a fairly concise body text ("Login"), but this won't work since it's a `<button>` tag and not an `<a>` (anchor, a hyperlink base) tag. The next logical option is to select by class, the class attribute of html being whitespace-separated tags which are not guaranteed to be unique. If the software is designed to use classes in a way that relevant tags will be unique, this is an option, but it is not typical. In this case, the button has the btn and btn-primary classes, an identically styled button would have the same set of classes. This, then, is a candidate for improvement in the system under test, to at least provide a cleaner testing interface in the form of a unique id or class

on this button, but in the interim we can fall back to HTML's built-in selection system, the CSS selector.

A CSS selector is a string confomrant to the CSS selection grammar [World Wide Web Consortium CSS Working Group, 2017] which enables detailed selection of DOM element or elements. It can combine an element's tag, id, class, parents, children, or even position. For the purposes of this login button's selection, we require the following features of candidate elements:

- Tag named button
- Classes btn and btn-primary
- First on the page

The following CSS selector satisfies these requirements:

`button.btn.btn-primary:nth-of-type(1)`.

Here's a python example:

```
login_sel = (By.CSS_SELECTOR, "button.btn.btn-primary:nth-of-type(1)")
login_button = driver.find_element(*login_sel)
```

[Gupta et al., 2003; Web Hypertext Application Technologies Working Group, 2017a; Nicholus, 2016]

1.3.3 Scripting Actions

Now that each relevant element of the web page under test has a unique identifier for our use, the next step is to write the code that actually triggers the interactions with them. This is fairly straightforward, we use the Page Object's

driver field to retrieve elements using these identifiers, then take actions on those elements.

The following snippet from our login page test retrieves an email text field and a password text field by their html IDs, as well as a login button by a css selector. These elements are then interacted with via the `send_keys()` and `click()` methods. Note that `self.username` and `self.password` are defined in the object constructor from some secure source of testing account credentials.

```
email_sel = (By.ID, "email")
password_sel = (By.ID, "password")
login_btn_sel = (By.CSS_SELECTOR, "button.btn.btn-primary")
def log_in_correctly(self):
  email_field = self.driver.find_element(*self.email_sel)
  password_field = self.driver.find_element(*self.password_sel)
  login_button = self.driver.find_element(*self.login_btn_sel)
  email_field.send_keys(self.username)
  password_field.send_keys(self.password)
  login_button.click()
```

1.3.4 Asserting Validity

Consider what an assertion (the `assert` statement in python) does: it takes one mandatory argument, a statement that boils down to true or false, and if the statement evaluates to anything but true, the system halts immediately with a message (an optional second argument or a default one) as to what assertion failed and in what way. They explicate and then enforce contracts in programming systems and are a staple of high quality programming.

Since contracts are a core part of a test, much of the actual important work of a test suite consists of well-placed assertions about the state of the system under test. While the assert statement is the most obvious and common way to designate an assertion, any snippet of code which does not change the state of the running test and raises an exception if some assumption is not true can fulfill the same purpose- I call these "assert-alikes". For instance, if a Selenium webdriver find_element fails to find the element described, it simply raises an exception. There's no need to do something complex like

```
dash = self.driver.find_element(*self.dashboard_sel) or False
assert dash, "Couldn't find the dashboard."
```

when, for the purposes of asserting some page element is present, the element finding call itself (`self.driver.find_element(*self.dashboard_sel)`) can stand alone.

Within the page object model, two key places for the insertion of assertions becomes apparent: first, at the initialization of the page object model itself, and second, as necessary during action execution. In the `monicatests-traditional` repository, page object models are derived from a PageBase class in the page_base.py file. This includes an overridable function, `self.initial_status`, which is called in the lowest inherited class definition- and can be selectively chained upwards- after object construction is complete. This method is filled with a number of assertions and assertion-alikes for the given page object model at the expected starting state in that page. Methods on the page object mdoel also include assertions as necessary to verify successful operation, including constructing and returning a page model for a new page when a method causes a transition for that new page- therefore triggering the new page's initial_status

method all over again.

Chapter 2

Using Yeager To Generate Long Sequence Regression Tests

The test suite assembled in the previous chapter is a great way for a software development team to verify that the core functionality of the system under test is fundamentally operational. When executed, it will test the few well-understood scenarios we have outlined consistently and, assuming enough assertions are present, thoroughly. In fact, the suite requires the entire process from the previous chapter in order to accomodate the additon of new scenarios.

It's a boring, tedious, and repetitious task that can be the entire career of a test engineer. However, as any test automator will know, tasks which are boring, tedious, and repetitious are ripe targets for computer automation, and the task of scenario authorship is no different.

This chapter will outline a method for adapting the existing test suite explored in the previous chapter, using a tool of our own authorship named yeager, to enable the computer to generate scenarios automatically. Yeager

is an MIT-open sourced python version 3 module, with source available at `https://github.com/elementc/yeager`. It provides a python annotation and a set of utility functions. Usage of yeager's state transition annotation allows testers to quickly and easily map an existing suite of test code onto a state machine, in the form of a graph. This graph can then be traversed using the utility functions, thereby generating new test scenarios from the existing code.

The resultant adapted test suite is published online at `https://github.com/elementc/monica-tests-yeagerized` for your convenience.

2.1 Software As A State Machine

Consider the system under test, Monica. As a relationship management web site, it has a few obvious states it can be in: logged out and on the landing page, logged in and on the dashboard, viewing a list of contacts, viewing a list of journal entries, or viewing the settings page. This maps nicely to the page objects we defined in the previous chapter. Actions on those page objects assume a current state (eg, we're logged in and on the dashboard) and after execution are in a new state which may or may not be the same state (eg, the `Dashboard.click_contacts_button()` method transitions from the dashboard to the contacts list, while the `LoginPage.log_in_incorrectly()` method should result in the system being in the same login page it was before the method was run).

In fact, most modern programs can be looked at as systems composed of a finite set of states (pages, in this case) with some state transitions (links) and a data context (the stuff you've already typed into the system in those states).

Yeager uses this fact to enable automated test sequence generation.

2.1.1 States in Our Example System

Let's consider Monica's pages, which are already built into our test suite, to be states.

We have: the login page (`Login`) and logging in takes us to the `Dashboard` which has tabs for the `Contacts` list and the `Journal` log. There's also a `Settings` page which has subpages for `Import`, `Export`, `Users`, and `Tags`.

The Dashboard and Contacts list both let us `AddAContact`, while the Journal tab lets us `AddAJournalEntry`. From a given `Contact`, one can `AddASignificantOther`, `AddAChild`, `UpdateJobInformation`, `AddANote`, `AddAnActivity`, `AddAReminder`, `AddAGift`, and `AddADebt`.

For the purpose of our discussions, these pages will constitute the entire set of states in the system under test. Conveniently, each of them is a python class.

2.1.2 State Transitions As Actions In Our Example System

A graph consists of a set of nodes and a set of edges. If our nodes are the states the system under test may be in, the edges are the actions that may be taken from those states, possibly resulting in a state transition. It is certainly possible for an edge to be a loop connecting the starting state to itself. In the particular case of testing web applications, note that though it's reasonable to author a page object model with each method corresponding to an edge, this is not an assumption that is necessary to make, and would-be yeager adopters

may choose to lump lower-level page object methods into clusters of function calls in new functions and treat those higher-level functions as edges instead. In fact, the example yeagerized monica tests does just this, creating a suite of yeager-friendly functions as snipets of existing test sequences, built from page object function calls.

2.1.3 Capturing Contextual State

Before embarking on the journey of high volume test automation that follows, it is important to consider for a moment the entirety of the software system. More than just software, a system includes the entire context of the software's execution, from the software itself, to the contents of the database, to the number of active system threads, to the ambient temperature of the room the system is running in. Some of these are impossible to control for in a testing environment: it's unreasonable to unseat your CPU cooler to attempt to replicate a bug related to your cousin's dust-clogged Pentium II for instance. Others are possible to configure with initialization scripts and virtualization to a degree, for instance always having the same base OS image and environment variables, or always having the same amount of RAM and number of CPU cores. Still more can be controlled for using database snapshots and well-documented test data. Regardless, remembering these variables, which are external to the code but internal to the system under test, is critical to the development exercises in this chapter.

2.1.4 Taking A Walk On The Graph

Imagine standing on a giant picture of the program under test's state graph, at the starting point. You are able to walk along the lines in the directions they are drawn to new points but you can't walk backwards against their direction of travel. It's a strange looking environment for sure, many of the nodes you might stand on have leaving edges that just loop back to where they started. Existing test scripts are like following directions along this map, "from A, go to B, turn right at C, stop at D" and so on. These pre-planned scripts are a great way to make sure you visit the whole map at least once.

But, imagine that you had a lot of time to kill and had already done all of your maps for the day. An interesting way to spend your time might be to go wandering: wherever you are, pick one of the paths before you at random and walk that way. Keep flipping coins or rolling n-sided dice and walking and you might eventually trigger a secret passage in the labyrinth you've been wandering. Well, that or crash the program under test. How exciting!

Contrived thought experiments aside, the notion of wandering around a program is a useful one for testing. First, it simulates human usage a little more realistically than many test scenarios (how many users actually start from a freshly booted computer, load up and login to the dashboard, create one record, search for that record, delete that record, then log out?). Second, such a process can be of any arbitrary length which, while also contributing to a more realistic usage simulation (consider that the author's instance of the Atom text editor and the GNOME desktop environment has been open on their laptop since August, while the typical Atom CI instance takes 30 minutes to build the software and run all tests[Atom Open Source Project, 2017]), permits test

managers to use as much of the technique as they want to- wandering the program under test for a few hours on their laptop during a conference call or over a month on a virtual machine hosted in a cloud somewhere.

2.2 Yeager State Transition Annotations

The meat of yeager testing is accomplished through the annotation of python test methods. An *annotation*, also known as a *decorator* or a *function decorator* is a special python function which is executed at the time of another function's definition, recieves the function being defined as well as any other required items as parameters, and can optionally wrap the function being defined in a special modifier. Yeager is implemented as a special python annotation and a set of utility functions which register after definition and can then call plain old python functions.

The annotation, `yeager.annotations.state_transition` and some utility functions (`yeager.add_state_to_blacklist` and `yeager.walk`) are described in this section.

A note on python convention: there are two kinds of parameters a function may take. The first, *positional arguments*, are passed like this: `print("some argument")` or `math.pow(3,2)`. The second, *keyword arguments*, sometimes shortened to *kwargs*, are passed like this: `timedelta(hours=3, minutes=7, seconds=20)`. Order does not matter with kwargs. Positional arguments and kwargs that aren't explicitly defined in a function's signature can both be captured for use by a function. Positional arguments are captured into a python list by defining a (potentially semi-) final argument prefixed with a single aster-

isk, keyword arguments into a python dictionary with a final argument prefixed with two asterisks, like this: `def function(named_arg1="Default value", *args_var_name, **kwargs_var_name)`.

2.2.1 State Identifiers

Anything that can be a Python dictionary key can serve as a state identifier. For simplicity's sake we use strings in this document, but as long as Python will allow it, so will Yeager. Enterprising Yeager hackers may use the actual Python page object model class, for instance.

The example implementation of a yeager test uses unique strings for state identifiers. There's no strong reason for this, it's just illustrative.

2.2.2 Basic State Transition Annotations

The fastest way to get started with using Yeager is to define a function for each of the state transitions you wish to use in the test. These will probably be short snippets from the traditional-style test sequences. Then, for each of these functions, you should use the `yeager.annotations.state_transition` annotation to mark the transition of that function. Here's an example using some of our Monica test code from the previous chapter:

```
from pages.login import LoginPage
from pages.dashboard import DashboardPage
from yeager.annotations import state_transition


@state_transition(None, "login-page")
```

```
def open(driver, **kwargs):
    driver = webdriver.Chrome()
    driver.get("https://app.monicahq.com/")

@state_transition("login-page", "dashboard-page")
def log_in(driver, **kwargs):
    login = LoginPage(driver)
    login.log_in_correctly()

@state_transition("dashboard-page", "login-page")
def log_out(driver, **kwargs):
    dashboard = DashboardPage(driver)
    dashboard.log_out()
```

Note that we use the Python `None` constant as a reference to the uninitialized system. Yeager treats `None` as a special node in the implied state model our annotations provide: it's assumed to be the entry point.

2.2.3 Verifying Connectedness

Yeager provides a utility function to check for states which cannot be reached from a given state, probably due to misconfigured annotations. The function, `yeager.orphaned_states`, takes one optional argument (the starting state, it defaults to `None`), and returns a list of all states that yeager knows about but doesn't know how to get to. The inverse, the known states, is also provided as a utility function with the same optional argument, as `yeager.reachable_states`. Though the orphaned states function is useful for debugging, it can be used in

other automated ways, for instance as a test coverage check or a way to automate `walk()` calls with each of the "orphaned" states actually being new entry points. They're useful in a number of different contexts for enterprising testers.

2.3 Yeager Test Harnesses

A suite of yeager-annotated python functions, while neat, is neither immediately useful (it's still just a chunk of naked functions), nor particularly intrusive (annotating a function with a yeager state transition only adds a print statement before the function executes). Analysis of the state transition graph can be done manually for sure (`from yeager.annotations import nodes, edges`), but yeager also provides a set of utility functions to actually exercise the system under test.

2.3.1 Test Setup and Entry Point

It's up to testers to generate python scripts that start up and execute a yeager test, but the process is very easy.

The first step is to cause the python interpreter to parse all of the relevant yeager annotations. In simple test scripts, it's enough to simply write the test code and annotations at the top of the file, but in large test suites, it may be necessary to simply import those python files at the top of the yeager test script instead. Critically, yeager annotation metadata exists as long as the python interpreter instance does, so it doesn't matter what modules or other structure applies to the code the yeager annotations are spread around in. If it has been parsed, yeager knows about it.

To actually start taking a walk on the state model, simply call yeager's `walk` function.

2.3.2 Walk Options and Execution

The function `yeager.walk` takes some special arguments that determine how a test will eventually come to an end. If a tester just wants to go walking until they tell it to stop, they can call it with no args and it will run until the test is killed. If a tester wants to just take a fixed number of steps, they can pass that as a naked integer or kwarg named count to `walk` and it will run for that many steps and then return. If a tester doesn't care about how long a test runs, and only wants to run until the program gets to some particular state, using the kwarg `exit_state` with the desired end state will cause the walk call to return as soon as yeager wanders to that state. And, finally, if a tester wishes to start the walking from a state other than the default starting state of `None`, they may do so by supplying the kwarg `start_state` with the desired starting state.

All of these different preferences are just plans- the intendedway to wander the graph. If an exception is raised in the underlying code, the exception is thrown all the way to the caller, yeager doesn't try to continue walking since the system under test may be in a corrupt state. It's not possible to resume the existing walk, but it is possible to call `walk` again from scratch.

2.3.3 Application Context

All other kwargs that are passed to the `yeager.walk` call will be passed to the transition functions by yeager, so a driver kwarg could be used to provide a webdriver to a web application's test suite, or a dict named context could store

contextual information about the system under test. Mutable All unrecognized kwargs by the walk call are passed to all of the transition functions that yeager steps throug, so it is in the yeager test style to have all test functions use the `**kwargs` catch-all argument in case a new context argument is added in the future of the test suite's development.

2.3.4 Logging in Yeager

Yeager doesn't make any particular assumptions about the logging toolkit that you use. It uses standard output to print its own data, though future revisions might use the standard python logging interface. For Long Sequence Regression Testing, it is very important to log with vigor, as a failure is often the result of many consecutive steps instead of one instant.

2.3.5 Controlling The Path: Blacklists

While it may seem counterintuitive after going to the effort to define them, it is possible to mark a state as one to not visit during a walk. This is useful, say, in cases where testers might want a run configuration that avoids certain known-buggy regions of the system under test, or try a yeager test but know parts of their yeager-specific code is still incomplete. It's accomplished by using the `yeager.add_state_to_blacklist` function. Any state identifier, when passed as an argument, will not be visited by a yeager walk.

2.3.6 Controlling The Path: Weights

Humans using software don't truly do actions equally randomly. A user of the the Atom text editor, for instance, probably spends more time typing and saving than they do moving tabs around, opening consoles, running compile/lint commands, changing themes or settings, and so on. To enable better simulation of these more-probable actions, yeager supports the notion of weighting edges.

An edge may be weighted by using a standalone function (`yeager.set_edge_weight`) or by using the weight kwarg with the actual state transition annotation (`@state_transition("st "state-b", weight=10)`). Notionally, an unweighted edge has a weight of 1. This edge gets one entry into the pool of candidates for selection by the walk algorithm. An edge with a weight of 5 gets five entries into the pool. A final edge with a weight of 2 gets two entries into the pool. From the combined pool (with eight entries), one is chosen entirely at random and executed.

2.3.7 Interpreting Results And Logs

what do logs look like anyways? (This may go away, or blow up into a whole new section. I don't know if "heres how bugs look when yeager finds them" is a relevant question. Yeager generates logs as if the system was just running, not like a normal test. Probably a whole paper there.)

Chapter 3

High Volume Automated Testing And Long Sequence Regression Testing In Context

Yeager is just one implementation of a technique called long sequence regression testing in a family of advanced testing techniques called High Volume Automated Testing, which we refer to sometimes as "High Volume Test Automation" and "HiVAT". This chapter aims to capture the wider context that Yeager exists in despite the relative novelty to academia that the field of high volume test automation provides: first through a detailed anatomy of what qualifies as such a test, second through a discussion of the craft's history as we are able to research, third through an overview of the family tree, and finally through a defense of the usefulness and reasonability of Yeager's particular branch. We conclude with a brief narrative summary of scenarios and cases in which Yeager's adoption may prove useful.

3.1 Anatomy Of A High Volume Automated Test

High Volume Automated Tests are software tests that, rather than exercising a particular set of preplanned scripts as a verification of a specific requirement's compliance, algorithmically generate, execute, evaluate, and potentially summarize the results of arbitrarily many test actions on a system under test, in such volume as to attain some or all of the following goals:

1. Exceed the volume of a reasonable testing staff to do manually.

2. Expose behaviors of the system not normally exposed during traditional testing techniques, eg. through loading and stressing the system in a manner akin to when a large numbers of users may interact with it.

3. Simulate (ab)use of the system more realistically and dynamicaly than would be attainable through traditional techniques.

4. Generate test scenarios that, while difficult to imagine by a tester, are not outside the realm of possiblity or even probability due to the high-availability nature of modern software systems.

While this is an extremely broad definition, this is due to the fact that these goals can be met through the arrangement of a large number of different test design factors. We propose six degrees of freedom, driven by technology choice, that combine exponentially to create a diverse and comprehensive family tree of test techniques.

3.1.1 Generation: What Actions Are Taken

The first degree of HiVAT test design freedom we propose is that of the test's generation. This is essentially an engineering question: how will the application under test be driven? In the case of yeager, tests are generated through the random selection and arrangement of pre-defined test code snippets according to a state model. Other HiVAT techniques may instead playback recorded user interactions, or send a truly random stream of input to the system, or drive the system through any other method.

3.1.2 Interface: Black Box vs. White Box (And Shades Of Grey)

A prerequisite to the above degree of test design freedom, and one that itself drives a degree, is that of the testing interface. Tests, based on the tester's ability or intent to interact with the source code or build artifacts of the system under test, may be treated as white/glass box, or black box tests. The tradeoffs associated with testing decision are well-studied, and both have valid uses.

Despite the techniques' names' implication, this is actually not a black-and-white issue: Meaningful tests can be achieved by interacting with the internals of some classes of program while still treating these interactions as black-box, dfor instance by interacting directly with the http APIs associated with a web application under test without dealing with the weight of the webapp's user interface, potentially simplifying or accelerating the test's design and execution.[Hoffman, 2013]

3.1.3 Oracle: Determining Correct Behaviour

Purely manual testing verfies compliance through tester observation and judgement. That is, while a manual tester is working through their test script, they are looking for known indications of noncompliance, for instance bad application behavior, strange output, or system crashes. The high volume and speed of testing present in any automated test, let alone a high volume automated test, precludes human observation and therefore necessitates a computer "oracle" to verify the application under test is behaving correctly.

In the specific case of automated unit tests and related non-high-volume test techniques, testers write checkable assertions about the state of the system at various points during the test's script, which if found to be untrue are reported and treated as a test's failure. High Volume techniques may incorporate different oracles than just these assertions (though, notably, yeager doesn't). For instance, a HiVAT technique might compare the output of a system to the output generated by a previous version of the system, or a competitor's system, or a (simplistic) alternative implementation built by the tester. Or, a technique might entirely ignore the state of the system under test and might instead focus on observable metrics like system CPU load, or memory usage, or response time, or disk write patterns. The problem of "how do we know if the program is behaving correctly", also known as the "oracle problem", has many context-driven solutions, and drives this proposed degree of HiVAT design freedom.

3.1.4 Loggers and Diagnostics: Figuring Out What Happened

Diagnostics are a unique case in that, while they can act as an oracle themselves, they overlap with the fundamental question (and degree of HiVAT test design freedom) of how the tester is to determine what circumstances fed into a detected fault.

There's a broad answer, in logging, but what kind of data gets logged and what form these logs take falls to the discretion of te tester. Some tests might need detailed accountings of allocated memory bytes for every millisecond recorded, while others might get by with just a summary list- function X got called 5623 times while function Z got called 2383 times. It might be the case that a log serves as a future test plan- eg a test tool consumes its own logs to playback a previously failed test, or a tool might just dump executable test code itself.

3.1.5 Testing Context: Cornering vs. Surveying vs. Abusing

No test exists in a vacuum, even spacecraft tests for NASA. Every test sets out to prove to some stakeholder(s) that some requirement(s) are met to their satisfaction.

HiVAT techniques are incredibly versatile in that they can be used as tools to show compliance with requirements that were very difficult or expensive to verify under traditional techniques. Their adaptation can help the tester to accomplish goals like ferreting out reliable reproduction cases for intermittent

"heisen"bugs, or generating leads on a breadth of bugs that might have been introduced in a new major revision, or tick the box on seemingly absurd-to-prove requirements like "the system shall not exceed a response time of 300 milliseconds more than twenty five times in thirteen million requests over the course of a one hour duration".

These testing goals, driven by the testing context, define a degree of HiVAT design freedom that exists at a higher level than the engineering and technology questions previously described.

3.1.6 Scalability: Parallelized vs. Sequential

The notion of "High Volume" does not necessitate the "high density" that is implied by the high availability of modern supercomputing, particularly inexpensive cloud systems or other massively parallel systems. That said, many systems under test are already relatively well-suited for this kind of testing, especially web API systems, and a compelling case can be made for the adoption of cloud testing techniques.[Parveen and Tilley, 2010] Other requirements might explictly preclude the usage of massively parallel testing techniques, for instance testing long-term use of a single-workstation native application.

This is perhaps the most limited of these six degrees of HiVAT test design freedom in that, while the decision is already made by the requirements of above design decisions, there are still (many) cases where both can apply and it becomes a design decision unto itself.

3.2 A Note On The Recorded History Of High Volume Automated Testing

It's hard to discuss the history of the

3.2.1 High Volume Automated Testing Has Been Invented Six Times

and here's where we list all the inventors we can find. [Miller et al., 1990; Kaner, 2013]

3.2.2 Every Industrial Inventor Thinks It's A Trade Secret

which is why I'm apologizing that this is sourced from a bunch of talks and interviews and less-than-academic sourcing.

3.2.3 A Call For HiVAT Documentation and Academic Consideration

so that the next poor sap who writes about it isn't going to have to do so much archaeology.

3.3 The High Volume Test Automation Family Tree

let's walk through some well-documented techniques

3.3.1 Long Sequence Regression Testing

uh, this is the one we're talking about [Lee and Yannakakis, 1996]

3.3.2 API Testing

i'm not sure if this belongs but i've seen it on some lists

3.3.3 Exhaustive Testing

ditto

3.3.4 "Fuzzing" And Other Monkey-Based Testing

"throw a fuzzer at it and see what happens"

3.3.5 Load-Based Testing

put one of the above techniques in a thread pool of a million or so

3.3.6 Testing In Production (Safely!)

Microsoft does this, siphons some user input from Bing to the live search engine and the next version of the search engine, comparing output from both versions. Sometimes users get output from the test version, even.

3.3.7 A/B Testing

An aggressive version of TIP invented by marketers to compare multiple versions of the same ad campaign.

3.3.8 Synthetic HiVAT Techniques

This is where I will wildly speculate about techniques not listed in above subsections (and therefore not discovered in literature review), but would make sense to implement in a context, as built from combinations of the building blocks listed in the Anatomy section.

3.4 High Volume Automated Testing Benefits and Drawbacks

this section might be merged into the above section simply due to the uniqueness of benefits and drawbacks among all the various HiVAT techniques. If, however, trends are apparent, they'll be discussed here.

3.5 The Case For Long Sequence Regression Testing

if there's something you could call a "conclusion", it's probably here. LSRT is a powerful, easy-to-adopt form of HiVAT in some scenarios, with otherwise-elusive bug discovery an eminently attainable outcome.

3.6 Scenarios For Yeager Adoption

A shameless ad for different ways Yeager can be adopted by different groups (a subsection per scenario)

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