

INFRASTRUCTURE QUALITY, DEPLOYMENT, AND OPERATIONS

Christian Kaestner

Required reading: Eric Breck, Shanqing Cai, Eric Nielsen, Michael Salib, D. Sculley. [The ML Test Score: A Rubric for ML Production Readiness and Technical Debt Reduction](#). Proceedings of IEEE Big Data (2017)

Recommended readings: Larysa Visengeriyeva. [Machine Learning Operations - A Reading List](#), InnoQ 2020

LEARNING GOALS

- Implement and automate tests for all parts of the ML pipeline
- Understand testing opportunities beyond functional correctness
- Automate test execution with continuous integration
- Deploy a service for models using container infrastructure
- Automate common configuration management tasks
- Devise a monitoring strategy and suggest suitable components for implementing it
- Diagnose common operations problems
- Understand the typical concerns and concepts of MLOps

BEYOND MODEL AND DATA QUALITY

POSSIBLE MISTAKES IN ML PIPELINES



Danger of "silent" mistakes in many phases



POSSIBLE MISTAKES IN ML PIPELINES

Danger of "silent" mistakes in many phases:

- Dropped data after format changes
- Failure to push updated model into production
- Incorrect feature extraction
- Use of stale dataset, wrong data source
- Data source no longer available (e.g web API)
- Telemetry server overloaded
- Negative feedback (telemtr.) no longer sent from app
- Use of old model learning code, stale hyperparameter
- Data format changes between ML pipeline steps

EVERYTHING CAN BE TESTED?



Speaker notes

Many qualities can be tested beyond just functional correctness (for a specification). Examples: Performance, model quality, data quality, usability, robustness, ... not all tests are equally easy to automate

TESTING STRATEGIES

- Performance
- Scalability
- Robustness
- Safety
- Security
- Extensibility
- Maintainability
- Usability

How to test for these? How automatable?

TEST AUTOMATION

FROM MANUAL TESTING TO CONTINUOUS INTEGRATION



The screenshot shows a web browser window displaying a Travis CI build log for repository `wyvernlang/wyvern`. The build number is #17, and it is marked as **passing**. The log details a successful build for branch `SimpleWyvern-devel`, which asserted a false condition. The commit was made by `fd7be1c` and compared against `0e2af1f`. The build ran for 16 seconds and completed 3 days ago. A note at the bottom indicates the job ran on legacy infrastructure. The log itself shows standard command-line output for cloning the repository, switching Java versions, running tests, and building the project.

```
1 Using worker: worker-linux-027f0490-1.bb.travis-ci.org:travis-linux-2
2
3 Build system information
67
68 $ git clone --depth=50 --branch=SimpleWyvern-devel
69 $ jdk_switcher use oraclejdk8
70 Switching to Oracle JDK8 (java-8-oracle), JAVA_HOME will be set to /usr/lib/jvm/java-8-oracle
71 $ java -Xmx32m -version
72 java version "1.8.0_31"
73 Java(TM) SE Runtime Environment (build 1.8.0_31-b13)
74 Java HotSpot(TM) 64-Bit Server VM (build 25.31-b07, mixed mode)
75 $ java -J-Xmx32m -version
76 javac 1.8.0_31
77 $ cd tools
78
79 The command "cd tools" exited with 0.
80 $ ant test
81 Buildfile: /home/travis/build/wyvernlang/wyvern/tools/build.xml
82
83 copper-compose-compile:
84     [mkdir] Created dir: /home/travis/build/wyvernlang/wyvern/tools/copper-composer/bin
85     [javac] /home/travis/build/wyvernlang/wyvern/tools/build.xml:18: warning: 'includeantruntime'
86     was not set, defaulting to build.sysclasspath=last; set to false for repeatable builds
```

UNIT TEST, INTEGRATION TESTS, SYSTEM TESTS



Speaker notes

Software is developed in units that are later assembled. Accordingly we can distinguish different levels of testing.

Unit Testing - A unit is the "smallest" piece of software that a developer creates. It is typically the work of one programmer and is stored in a single file. Different programming languages have different units: In C++ and Java the unit is the class; in C the unit is the function; in less structured languages like Basic and COBOL the unit may be the entire program.

Integration Testing - In integration we assemble units together into subsystems and finally into systems. It is possible for units to function perfectly in isolation but to fail when integrated. For example because they share an area of the computer memory or because the order of invocation of the different methods is not the one anticipated by the different programmers or because there is a mismatch in the data types. Etc.

System Testing - A system consists of all of the software (and possibly hardware, user manuals, training materials, etc.) that make up the product delivered to the customer. System testing focuses on defects that arise at this highest level of integration. Typically system testing includes many types of testing: functionality, usability, security, internationalization and localization, reliability and availability, capacity, performance, backup and recovery, portability, and many more.

Acceptance Testing - Acceptance testing is defined as that testing, which when completed successfully, will result in the customer accepting the software and giving us their money. From the customer's point of view, they would generally like the most exhaustive acceptance testing possible (equivalent to the level of system testing). From the vendor's point of view, we would generally like the minimum level of testing possible that would result in money changing hands. Typical strategic questions that should be addressed before acceptance testing are: Who defines the level of the acceptance testing? Who creates the test scripts? Who executes the tests? What is the pass/fail criteria for the acceptance test? When and how do we get paid?

ANATOMY OF A UNIT TEST

```
import org.junit.Test;
import static org.junit.Assert.assertEquals;

public class AdjacencyListTest {
    @Test
    public void testSanityTest(){
        // set up
        Graph g1 = new AdjacencyListGraph(10);
        Vertex s1 = new Vertex("A");
        Vertex s2 = new Vertex("B");
        // check expected results (oracle)
        assertEquals(true, g1.addVertex(s1));
        assertEquals(true, g1.addVertex(s2));
        assertEquals(true, g1.addEdge(s1, s2));
        assertEquals(s2, g1.getNeighbors(s1)[0]);
    }
}
```

INGREDIENTS TO A TEST

- Specification
- Controlled environment
- Test inputs (calls and parameters)
- Expected outputs/behavior (oracle)

UNIT TESTING PITFALLS

- Working code, failing tests
- Smoke tests pass
- Works on my (some) machine(s)
- Tests break frequently

How to avoid?

HOW TO UNIT TEST COMPONENT WITH DEPENDENCY ON OTHER CODE?



EXAMPLE: TESTING PARTS OF A SYSTEM



```
Model learn() {  
    Stream stream = openKafkaStream(...)  
    DataTable output = getData(testStream, new DefaultCleaner())  
    return Model.learn(output);  
}
```

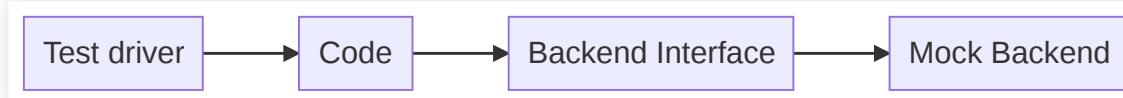
EXAMPLE: USING TEST DATA



```
DataTable getData(Stream stream, DataCleaner cleaner) { ... }

@Test void test() {
    Stream stream = openKafkaStream(...)
    DataTable output = getData(testStream, new DefaultCleaner())
    assert(output.length==10)
}
```

EXAMPLE: USING TEST DATA



```
DataTable getData(Stream stream, DataCleaner cleaner) { ... }

@Test void test() {
    Stream testStream = new Stream() {
        int idx = 0;
        // hardcoded or read from test file
        String[] data = [ ... ]
        public void connect() { }
        public String getNext() {
            return data[++idx];
        }
    }
    DataTable output = getData(testStream, new DefaultCleaner())
    assertEquals(10, output.length)
}
```

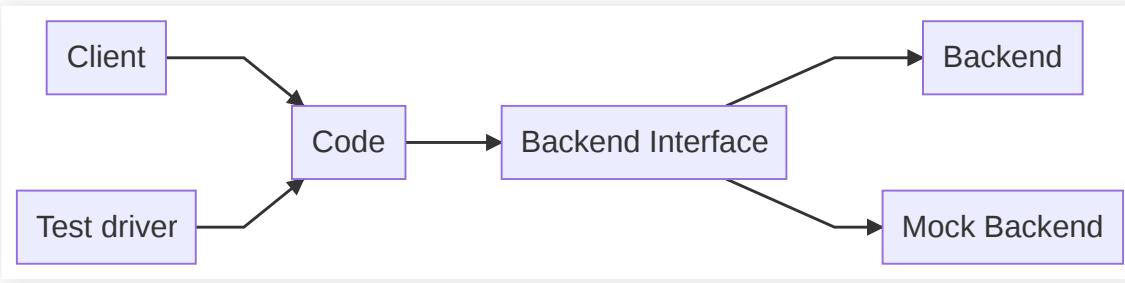
EXAMPLE: MOCKING A DATACLEANER OBJECT

```
DataTable getData(KafkaStream stream, DataCleaner cleaner) { ...  
  
@Test void test() {  
    DataCleaner dummyCleaner = new DataCleaner() {  
        boolean isValid(String row) { return true; }  
        ...  
    }  
    DataTable output = getData(testStream, dummyCleaner);  
    assert(output.length==10)  
}
```

EXAMPLE: MOCKING A DATACLEANER OBJECT

```
DataTable getData(KafkaStream stream, DataCleaner cleaner) { ...  
  
@Test void test() {  
    DataCleaner dummyCleaner = new DataCleaner() {  
        int counter = 0;  
        boolean isValid(String row) {  
            counter++;  
            return counter!=3;  
        }  
        ...  
    }  
    DataTable output = getData(testStream, dummyCleaner);  
    assert(output.length==9)  
}
```

Mocking frameworks provide infrastructure for expressing such tests compactly.



TEST ERROR HANDLING

```
@Test void test() {  
    DataTable data = new DataTable();  
    try {  
        Model m = learn(data);  
        Assert.fail();  
    } catch (NoDataException e) { /* correctly thrown */ }  
}
```

Speaker notes

Code to test that the right exception is thrown

TESTING FOR ROBUSTNESS

manipulating the (controlled) environment: injecting errors into backend to test error handling

```
DataTable getData(Stream stream, DataCleaner cleaner) { ... }

@Test void test() {
    Stream testStream = new Stream() {
        ...
        public String getNext() {
            if (++idx == 3) throw new IOException();
            return data[++idx];
        }
    }
    DataTable output = retry(getData(testStream, ...));
    assert(output.length==10)
}
```

TEST LOCAL ERROR HANDLING (MODULAR PROTECTION)

```
@Test void test() {  
    Stream testStream = new Stream() {  
        int idx = 0;  
        public void connect() {  
            if (++idx < 3)  
                throw new IOException("cannot establish connection");  
        }  
        public String getNext() { ... }  
    }  
    DataLoader loader = new DataLoader(testStream, new DefaultClient());  
    ModelBuilder model = new ModelBuilder(loader, ...);  
    // assume all exceptions are handled correctly internally  
    assert(model.accuracy > .91)  
}
```

Speaker notes

Test that errors are correctly handled within a module and do not leak

Packages

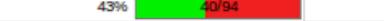
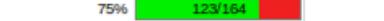
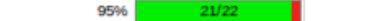
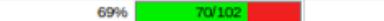
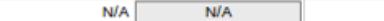
All
[net.sourceforge.cobertura.ant](#)
[net.sourceforge.cobertura.check](#)
[net.sourceforge.cobertura.coveragedata](#)
[net.sourceforge.cobertura.instrument](#)
[net.sourceforge.cobertura.merge](#)
[net.sourceforge.cobertura.reporting](#)
[net.sourceforge.cobertura.reporting.html](#)
[net.sourceforge.cobertura.reporting.html](#)
[net.sourceforge.cobertura.reporting.xml](#)
[net.sourceforge.cobertura.util](#)

All Packages

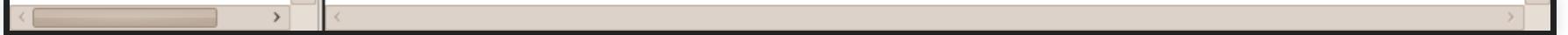
Classes

[AntUtil](#) (88%)
[Archive](#) (100%)
[ArchiveUtil](#) (80%)
[BranchCoverageData](#) (N/A)
[CheckTask](#) (0%)
[ClassData](#) (N/A)
[ClassInstrumenter](#) (94%)
[ClassPattern](#) (100%)
[CoberturaFile](#) (73%)
[CommandLineBuilder](#) (96%)
[CommonMatchingTask](#) (88%)
[ComplexityCalculator](#) (100%)
[ConfigurationUtil](#) (50%)
[CopyFiles](#) (87%)
[CoverageData](#) (N/A)
[CoverageDataContainer](#) (N/A)
[CoverageDataFileHandler](#) (N/A)
[CoverageRate](#) (0%)
[ExcludeClasses](#) (100%)
[FileFinder](#) (96%)
[FileLocker](#) (0%)
[FirstPassMethodInstrumenter](#) (100%)
[HTMLReport](#) (94%)
[HasBeenInstrumented](#) (N/A)
[Header](#) (80%)
[IOUtil](#) (62%)
[Ignore](#) (100%)
[IgnoreBranches](#) (0%)

Coverage Report - All Packages

Package /	# Classes	Line Coverage	Branch Coverage	Complexity
All Packages	55	75%  1625/2179	64%  472/738	2.319
net.sourceforge.cobertura.ant	11	52%  170/330	43%  40/94	1.848
net.sourceforge.cobertura.check	3	0%  0/150	0%  0/76	2.429
net.sourceforge.cobertura.coveragedata	13	N/A  N/A	N/A  N/A	2.277
net.sourceforge.cobertura.instrument	10	90%  460/510	75%  123/164	1.854
net.sourceforge.cobertura.merge	1	86%  30/35	88%  14/16	5.5
net.sourceforge.cobertura.reporting	3	87%  116/134	80%  43/54	2.882
net.sourceforge.cobertura.reporting.html	4	91%  475/523	77%  156/202	4.444
net.sourceforge.cobertura.reporting.html.files	1	87%  39/45	62%  5/8	4.5
net.sourceforge.cobertura.reporting.xml	1	100%  155/155	95%  21/22	1.524
net.sourceforge.cobertura.util	9	60%  175/291	69%  70/102	2.892
someotherpackage	1	83%  5/6	N/A  N/A	1.2

Report generated by [Cobertura](#) 1.9 on 6/9/07 12:37 AM.



TESTABLE CODE

- Think about testing when writing code
- Unit testing encourages you to write testable code
- Separate parts of the code to make them independently testable
- Abstract functionality behind interface, make it replaceable
- Test-Driven Development: A design and development method in which you write tests before you write the code

INTEGRATION AND SYSTEM TESTS



INTEGRATION AND SYSTEM TESTS

Test larger units of behavior

Often based on use cases or user stories -- customer perspective

```
@Test void gameTest() {  
    Poker game = new Poker();  
    Player p = new Player();  
    Player q = new Player();  
    game.shuffle(seed)  
    game.add(p);  
    game.add(q);  
    game.deal();  
    p.bet(100);  
    q.bet(100);  
    p.call();  
    q.fold();  
    assert(game.winner() == p);  
}
```

BUILD SYSTEMS & CONTINUOUS INTEGRATION

- Automate all build, analysis, test, and deployment steps from a command line call
 - Ensure all dependencies and configurations are defined
 - Ideally reproducible and incremental
 - Distribute work for large jobs
 - Track results
-
- Key CI benefit: Tests are regularly executed, part of process

Build #17 - wyvernlang

Jonathan

https://travis-ci.org/wyvernlang/wyvern/builds/79099642

Travis CI Blog Status Help Jonathan Aldrich

Search all repositories

My Repositories +

wyvernlang / wyvern build passing

Current Branches Build History Pull Requests Build #17 Settings

SimpleWyvern-devel Asserting false (works on Linux, so its OK). # 17 passed Commit fd7be1c Compare 0e2af1f..fd7be1c ran for 16 sec 3 days ago potanin authored and committed

This job ran on our legacy infrastructure. Please read [our docs on how to upgrade](#)

X Remove Log Download Log

```
1 Using worker: worker-linux-027f0490-1.bb.travis-ci.org:travis-linux-2
2
3 Build system information
67
68 $ git clone --depth=50 --branch=SimpleWyvern-devel
78 $ jdk_switcher use oraclejdk8
79 Switching to Oracle JDK8 (java-8-oracle), JAVA_HOME will be set to /usr/lib/jvm/java-8-oracle
80 $ java -Xmx32m -version
81 java version "1.8.0_31"
82 Java(TM) SE Runtime Environment (build 1.8.0_31-b13)
83 Java HotSpot(TM) 64-Bit Server VM (build 25.31-b07, mixed mode)
84 $ javac -J-Xmx32m -version
```

```
85 javac 1.8.0_31
86 $ cd tools
87
88 The command "cd tools" exited with 0.
89 $ ant test
90 Buildfile: /home/travis/build/wyvernlang/wyvern/tools/build.xml
91
92 copper-compose-compile:
93 [mkdir] Created dir: /home/travis/build/wyvernlang/wyvern/tools/copper-composer/bin
94 [javac] /home/travis/build/wyvernlang/wyvern/tools/build.xml:18: warning: 'includeantruntime'
was not set, defaulting to build.sysclasspath=last; set to false for repeatable builds
```

TRACKING BUILD QUALITY

Track quality indicators over time, e.g.,

- Build time
- Test coverage
- Static analysis warnings
- Performance results
- Model quality measures
- Number of TODOs in source code

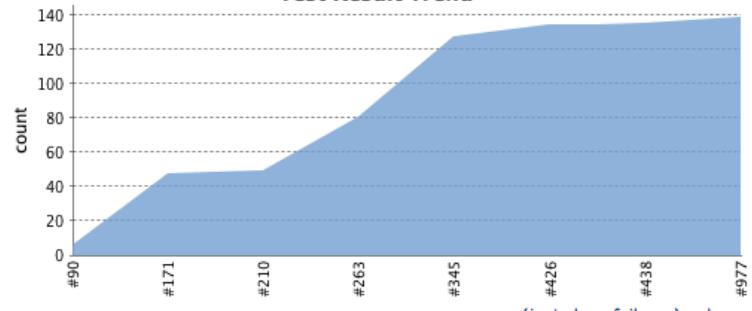
[Back to Dashboard](#)[Status](#)[Changes](#)[Workspace](#)[Build Now](#)[Delete Project](#)[Configure](#)[Set Next Build Number](#)[Duplicate Code](#)[Coverage Report](#)[SLOCCount](#)[Git Polling Log](#)

Project Stop-tabac dev

CI build

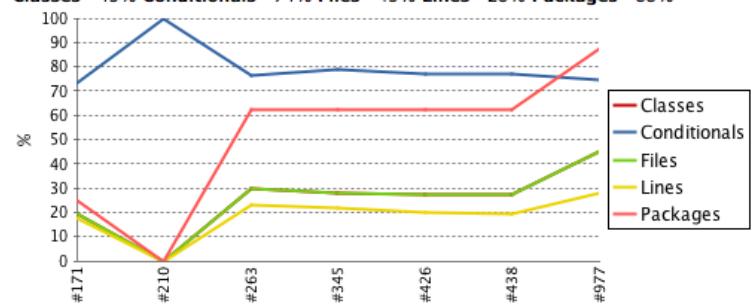
[Coverage Report](#)[Workspace](#)[Recent Changes](#)[Latest Test Result \(no failures\)](#)[Edit description](#)[Disable Project](#)

Test Result Trend

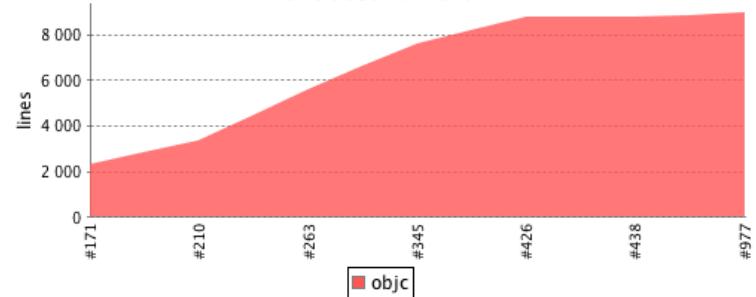
[\(just show failures\) enlarge](#)

Code Coverage

Classes 45% Conditionals 74% Files 45% Lines 28% Packages 88%



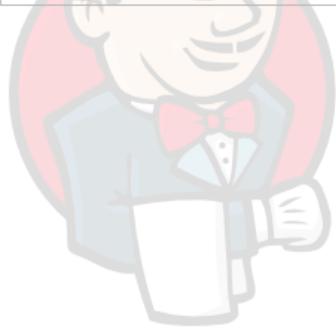
SLOCCount Trend

[objc](#)

Build History (trend)

Build	Date	Time
#977	Aug 27, 2012	4:37:27 PM
#438	Jun 28, 2012	8:47:42 AM
#426	Jun 26, 2012	1:39:39 PM
#345	Jun 19, 2012	9:02:20 AM
#263	Jun 6, 2012	9:14:42 PM
#210	May 31, 2012	8:42:29 AM
#171	May 23, 2012	9:58:18 PM
#90	May 15, 2012	11:49:41 AM

RSS for all RSS for failures



Source: <https://blog.octo.com/en/jenkins-quality-dashboard-ios-development/>

TEST MONITORING

- Inject/simulate faulty behavior
- Mock out notification service used by monitoring
- Assert notification

```
class MyNotificationService extends NotificationService {  
    public boolean receivedNotification = false;  
    public void sendNotification(String msg) { receivedNotificat  
}  
@Test void test() {  
    Server s = getServer();  
    MyNotificationService n = new MyNotificationService();  
    Monitor m = new Monitor(s, n);  
    s.stop();  
    s.request();  
    s.request();  
    wait();  
    assert(n.receivedNotification);  
}
```

TEST MONITORING IN PRODUCTION

- Like fire drills (manual tests may be okay!)
- Manual tests in production, repeat regularly
- Actually take down service or trigger wrong signal to monitor

CHAOS TESTING



<http://principlesofchaos.org>

Speaker notes

Chaos Engineering is the discipline of experimenting on a distributed system in order to build confidence in the system's capability to withstand turbulent conditions in production. Pioneered at Netflix

CHAOS TESTING ARGUMENT

- Distributed systems are simply too complex to comprehensively predict
- -> experiment on our systems to learn how they will behave in the presence of faults
- Base corrective actions on experimental results because they reflect real risks and actual events
- Experimentation != testing -- Observe behavior rather than expect specific results
- Simulate real-world problem in production (e.g., take down server, inject latency)
- *Minimize blast radius:* Contain experiment scope

NETFLIX'S SIMIAN ARMY

Chaos Monkey: randomly disable production instances

Latency Monkey: induces artificial delays in our RESTful client-server communication layer

Conformity Monkey: finds instances that don't adhere to best-practices and shuts them down

Doctor Monkey: monitors other external signs of health to detect unhealthy instances

Janitor Monkey: ensures that our cloud environment is running free of clutter and waste

Security Monkey: finds security violations or vulnerabilities, and terminates the offending instances

10–18 Monkey: detects problems in instances serving customers in multiple geographic regions

Chaos Gorilla is similar to Chaos Monkey, but simulates an outage of an entire Amazon availability zone.

CHAOS TOOLKIT

- Infrastructure for chaos experiments
- Driver for various infrastructure and failure cases
- Domain specific language for experiment definitions

```
{  
  "version": "1.0.0",  
  "title": "What is the impact of an expired certificate on ou  
  "description": "If a certificate expires, we should graceful  
  "tags": ["tls"],  
  "steady-state-hypothesis": {  
    "title": "Application responds",  
    "probes": [  
      {  
        "type": "probe",  
        "name": "the-astre-service-must-be-running",  
        "tolerance": true,  
        "provider": {  
          "type": "python",  
          "module": "os.path",  
          "func": "exists"  
        }  
      }  
    ]  
  }  
}
```


CHAOS EXPERIMENTS FOR ML INFRASTRUCTURE?



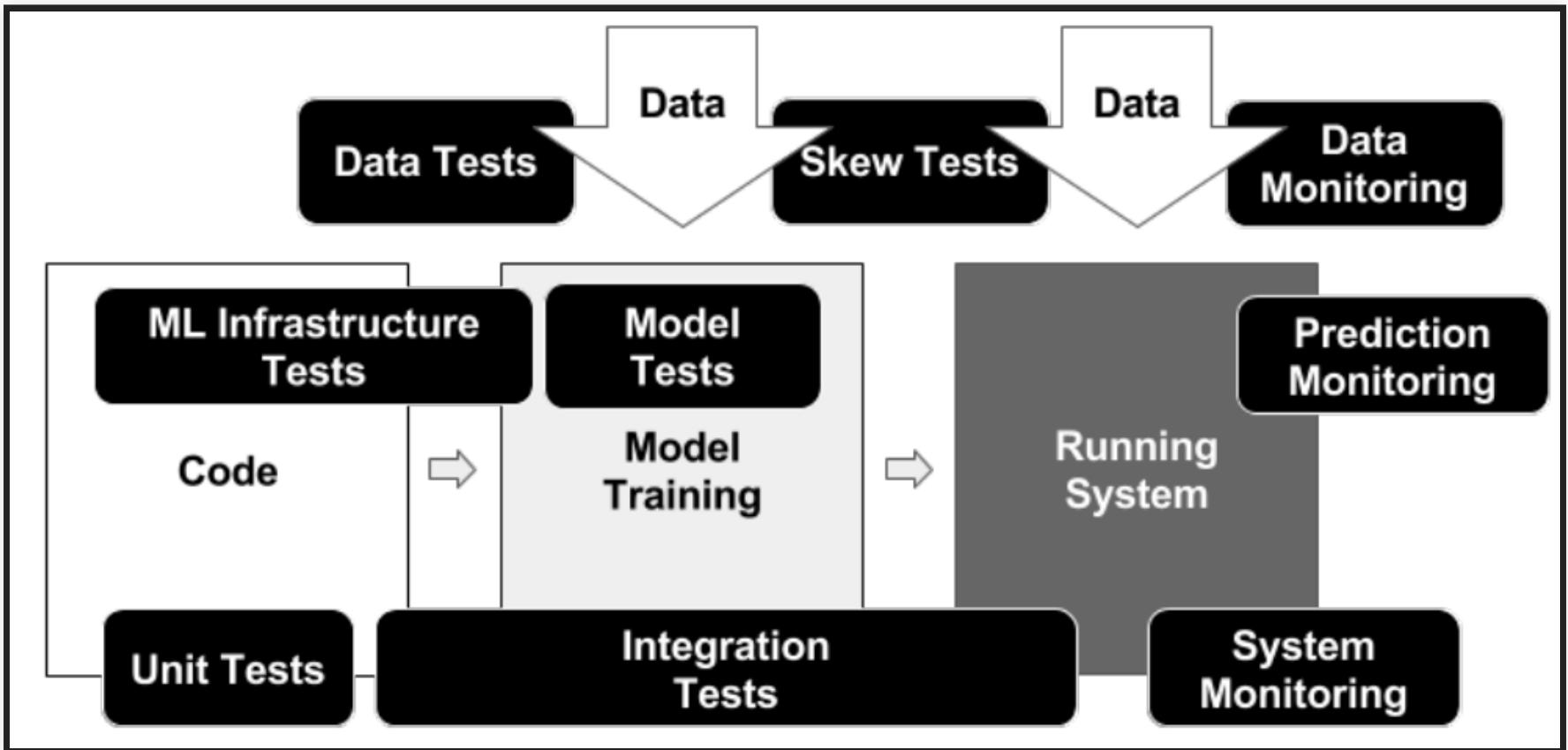
Speaker notes

Fault injection in production for testing in production. Requires monitoring and explicit experiments.

INFRASTRUCTURE TESTING



Eric Breck, Shanqing Cai, Eric Nielsen, Michael Salib, D. Sculley. [The ML Test Score: A Rubric for ML Production Readiness and Technical Debt Reduction](#). Proceedings of IEEE Big Data (2017)



Source: Eric Breck, Shanqing Cai, Eric Nielsen, Michael Salib, D. Sculley. [The ML Test Score: A Rubric for ML Production Readiness and Technical Debt Reduction](#). Proceedings of IEEE Big Data (2017)

CASE STUDY: SMART PHONE COVID-19 DETECTION



(from midterm; assume cloud or hybrid deployment)

DATA TESTS

1. Feature expectations are captured in a schema.
2. All features are beneficial.
3. No feature's cost is too much.
4. Features adhere to meta-level requirements.
5. The data pipeline has appropriate privacy controls.
6. New features can be added quickly.
7. All input feature code is tested.

Eric Breck, Shanqing Cai, Eric Nielsen, Michael Salib, D. Sculley. [The ML Test Score: A Rubric for ML Production Readiness and Technical Debt Reduction](#). Proceedings of IEEE Big Data (2017)

TESTS FOR MODEL DEVELOPMENT

1. Model specs are reviewed and submitted.
2. Offline and online metrics correlate.
3. All hyperparameters have been tuned.
4. The impact of model staleness is known.
5. A simpler model is not better.
6. Model quality is sufficient on important data slices.
7. The model is tested for considerations of inclusion.

Eric Breck, Shanqing Cai, Eric Nielsen, Michael Salib, D. Sculley. [The ML Test Score: A Rubric for ML Production Readiness and Technical Debt Reduction](#). Proceedings of IEEE Big Data (2017)

ML INFRASTRUCTURE TESTS

1. Training is reproducible.
2. Model specs are unit tested.
3. The ML pipeline is Integration tested.
4. Model quality is validated before serving.
5. The model is debuggable.
6. Models are canaried before serving.
7. Serving models can be rolled back.

Eric Breck, Shanqing Cai, Eric Nielsen, Michael Salib, D. Sculley. [The ML Test Score: A Rubric for ML Production Readiness and Technical Debt Reduction](#). Proceedings of IEEE Big Data (2017)

MONITORING TESTS

1. Dependency changes result in notification.
2. Data invariants hold for inputs.
3. Training and serving are not skewed.
4. Models are not too stale.
5. Models are numerically stable.
6. Computing performance has not regressed.
7. Prediction quality has not regressed.

Eric Breck, Shanqing Cai, Eric Nielsen, Michael Salib, D. Sculley. [The ML Test Score: A Rubric for ML Production Readiness and Technical Debt Reduction](#). Proceedings of IEEE Big Data (2017)

BREAKOUT GROUPS

- Discuss in groups:
 - Team 1 picks the data tests
 - Team 2 the model dev. tests
 - Team 3 the infrastructure tests
 - Team 4 the monitoring tests
- For 15 min, discuss each listed point in the context of the Covid-detection scenario: what would you do?
- Report back to the class

ASIDE: LOCAL IMPROVEMENTS VS OVERALL QUALITY

- Ideally unit tests catch bugs locally
- Some bugs emerge from interactions among system components
 - Missed local specifications -> more unit tests
 - Nonlocal effects, interactions -> integration & system tests

Known as **emergent properties** and **feature interactions**

FEATURE INTERACTION EXAMPLES



Speaker notes

Flood control and fire control work independently, but interact on the same resource (water supply), where flood control may deactivate the water supply to the sprinkler system in case of a fire

FEATURE INTERACTION EXAMPLES



Speaker notes

Electronic parking brake and AC are interacting via the engine. Electronic parking brake gets released over a certain engine speed and AC may trigger that engine speed (depending on temperature and AC settings).

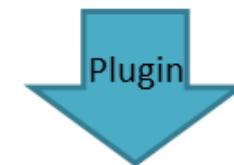
FEATURE INTERACTION EXAMPLES

[:weather:]



WORDPRESS

:) 8-) ;-)



Today's weather: [:weather:] 😎

Speaker notes

Weather and smiley plugins in WordPress may work on the same tokens in a blog post (overlapping preconditions)

FEATURE INTERACTION EXAMPLES



Call Waiting

Speaker notes

Call forwarding and call waiting in a telecom system react to the same event and may result in a race condition. This is typically a distributed system with features implemented by different providers.

FEATURE INTERACTIONS

Failure in compositionality: Components developed and tested independently, but they are not fully independent

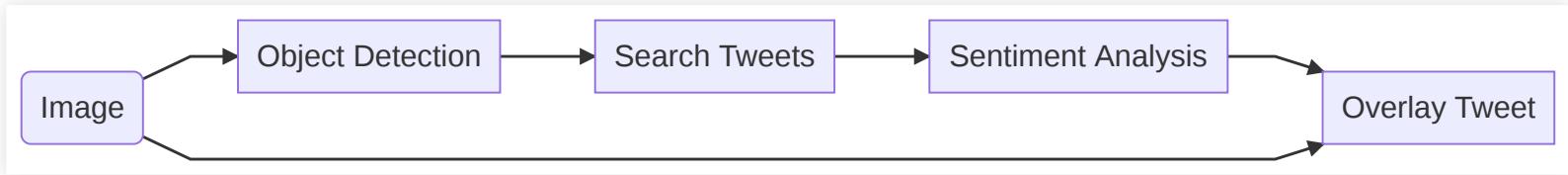
Detection and resolution challenging:

- Analysis of requirements (formal methods or inspection), e.g., overlapping preconditions, shared resources
- Enforcing isolation (often not feasible)
- Testing, testing, testing at the system level

Recommended reading: Nhlabatsi, Armstrong, Robin Laney, and Bashar Nuseibeh. [Feature interaction: The security threat from within software systems](#). Progress in Informatics 5 (2008): 75-89.

MODEL CHAINING

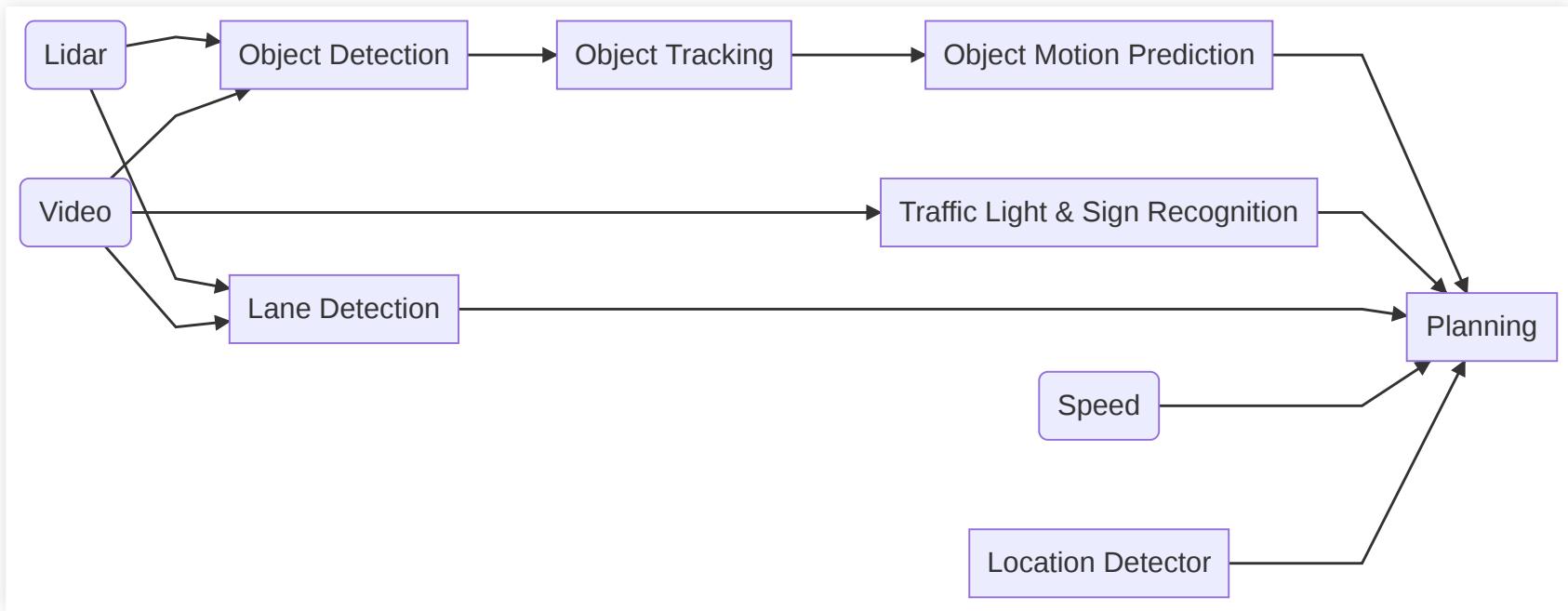
automatic meme generator



Example adapted from Jon Peck. [Chaining machine learning models in production with Algorithmia](#). Algorithmia blog, 2019

ML MODELS FOR FEATURE EXTRACTION

self driving car



Example: Zong, W., Zhang, C., Wang, Z., Zhu, J., & Chen, Q. (2018). [Architecture design and implementation of an autonomous vehicle](#). IEEE access, 6, 21956-21970.

NONLOCAL EFFECTS IN ML SYSTEMS?



Speaker notes

Improvement in prediction quality in one component does not always increase overall system performance. Have both local model quality tests and global system performance measures.

Examples: Slower but more accurate face recognition not improving user experience for unlocking smart phone.

Example: Chaining of models -- second model (language interpretation) trained on output of the first (parts of speech tagging) depends on specific artifacts and biases

Example: More accurate model for common use cases, but more susceptible to gaming of the model (adversarial learning)

RECALL: BETA TESTS AND TESTING IN PRODUCTION

- Test the full system in a realistic setting
- Collect telemetry to identify bugs



RECALL: THE WORLD VS THE MACHINE

- Be explicit about interfaces between world and machine (assumptions, both sensors and actuators)
- No clear specifications between models, limits modular reasoning

RECALL: DETECTING DRIFT

- Monitor data distributions and detect drift
 - Detect data drift between ML components
- Document interfaces in terms of distributions and expectations

DEV VS. OPS



COMMON RELEASE PROBLEMS?



COMMON RELEASE PROBLEMS (EXAMPLES)

- Missing dependencies
- Different compiler versions or library versions
- Different local utilities (e.g. unix grep vs mac grep)
- Database problems
- OS differences
- Too slow in real settings
- Difficult to roll back changes
- Source from many different repositories
- Obscure hardware? Cloud? Enough memory?

DEVELOPERS

- Coding
- Testing, static analysis, reviews
- Continuous integration
- Bug tracking
- Running local tests and scalability experiments
- ...

OPERATIONS

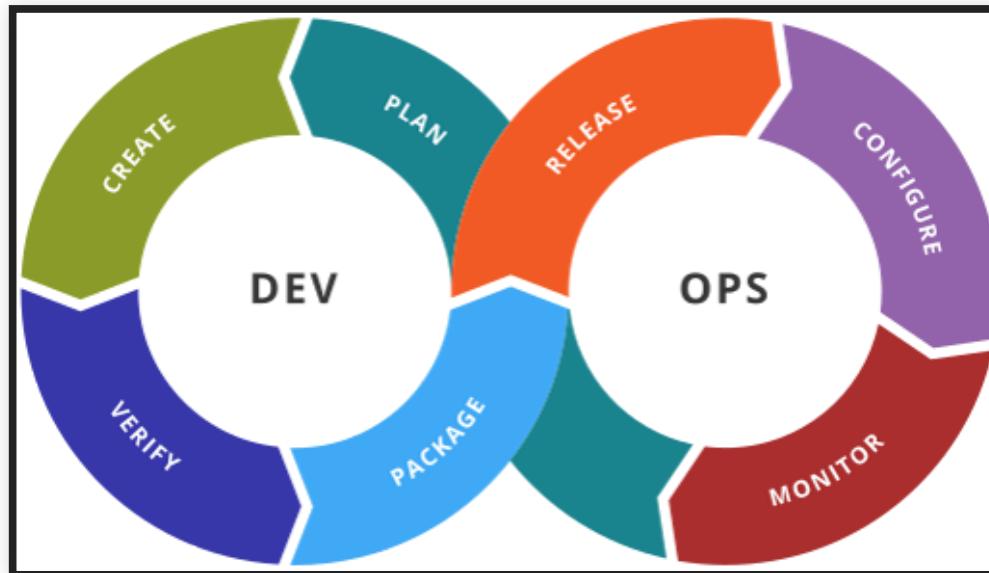
- Allocating hardware resources
- Managing OS updates
- Monitoring performance
- Monitoring crashes
- Managing load spikes, ...
- Tuning database performance
- Running distributed at scale
- Rolling back releases
- ...

QA responsibilities in both roles

QUALITY ASSURANCE DOES NOT STOP IN DEV

- Ensuring product builds correctly (e.g., reproducible builds)
- Ensuring scalability under real-world loads
- Supporting environment constraints from real systems (hardware, software, OS)
- Efficiency with given infrastructure
- Monitoring (server, database, Dr. Watson, etc)
- Bottlenecks, crash-prone components, ... (possibly thousands of crash reports per day/minute)

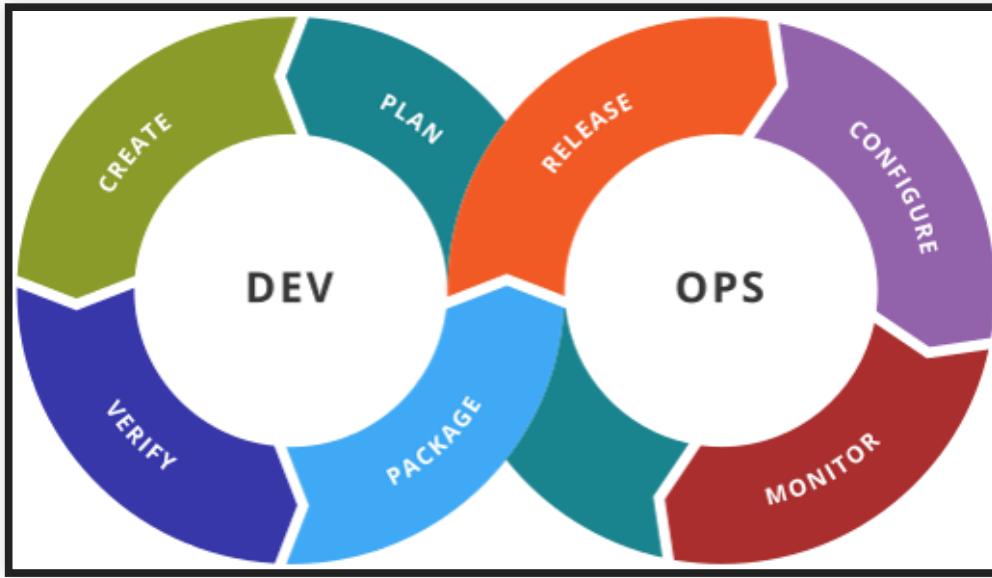
DEVOPS



KEY IDEAS AND PRINCIPLES

- Better coordinate between developers and operations (collaborative)
- Key goal: Reduce friction bringing changes from development into production
- Considering the *entire tool chain* into production (holistic)
- Documentation and versioning of all dependencies and configurations ("configuration as code")
- Heavy automation, e.g., continuous delivery, monitoring
- Small iterations, incremental and continuous releases

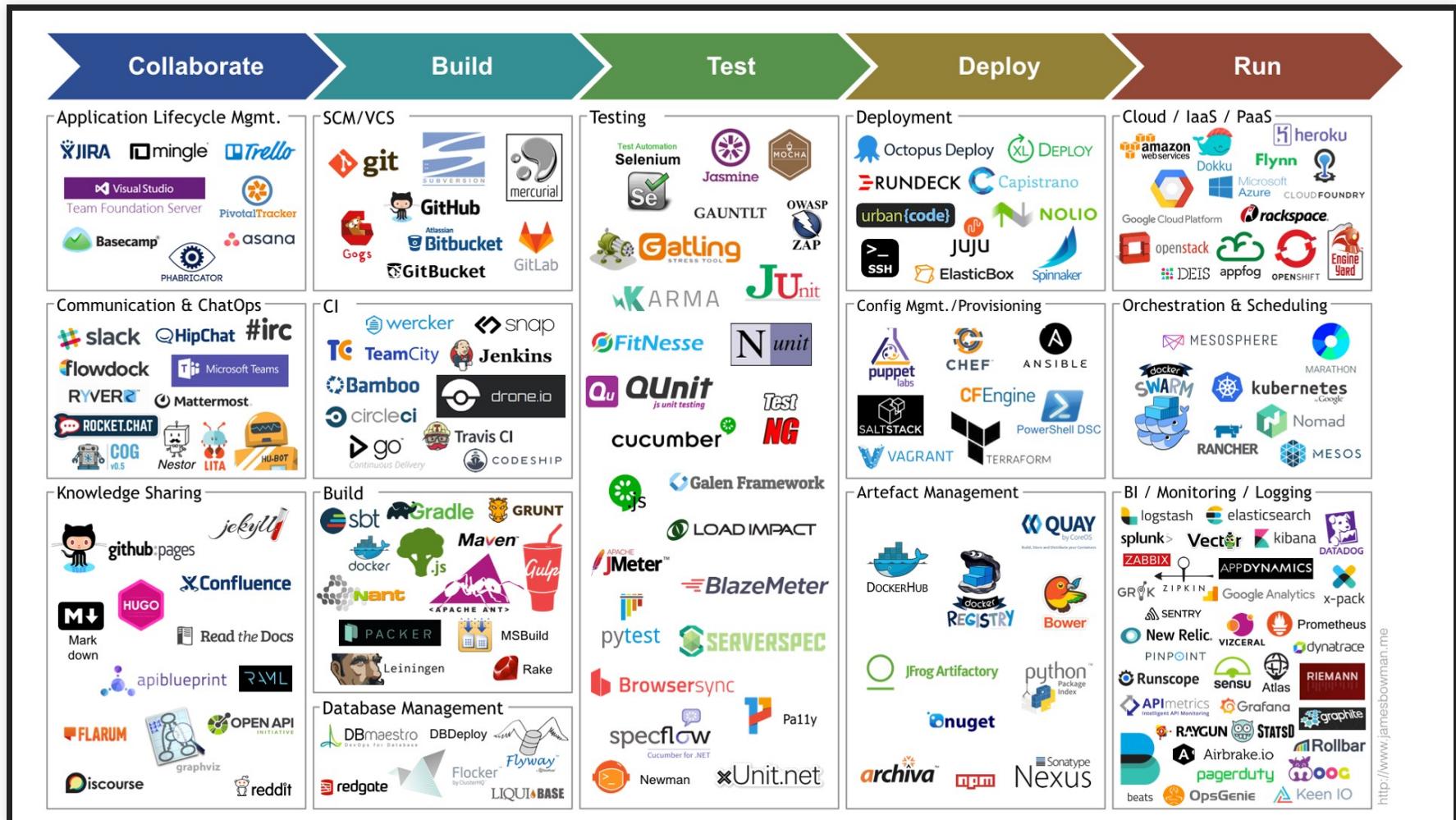
- Buzz word!



COMMON PRACTICES

- All configurations in version control
- Test and deploy in containers
- Automated testing, testing, testing, ...
- Monitoring, orchestration, and automated actions in practice
- Microservice architectures
- Release frequently

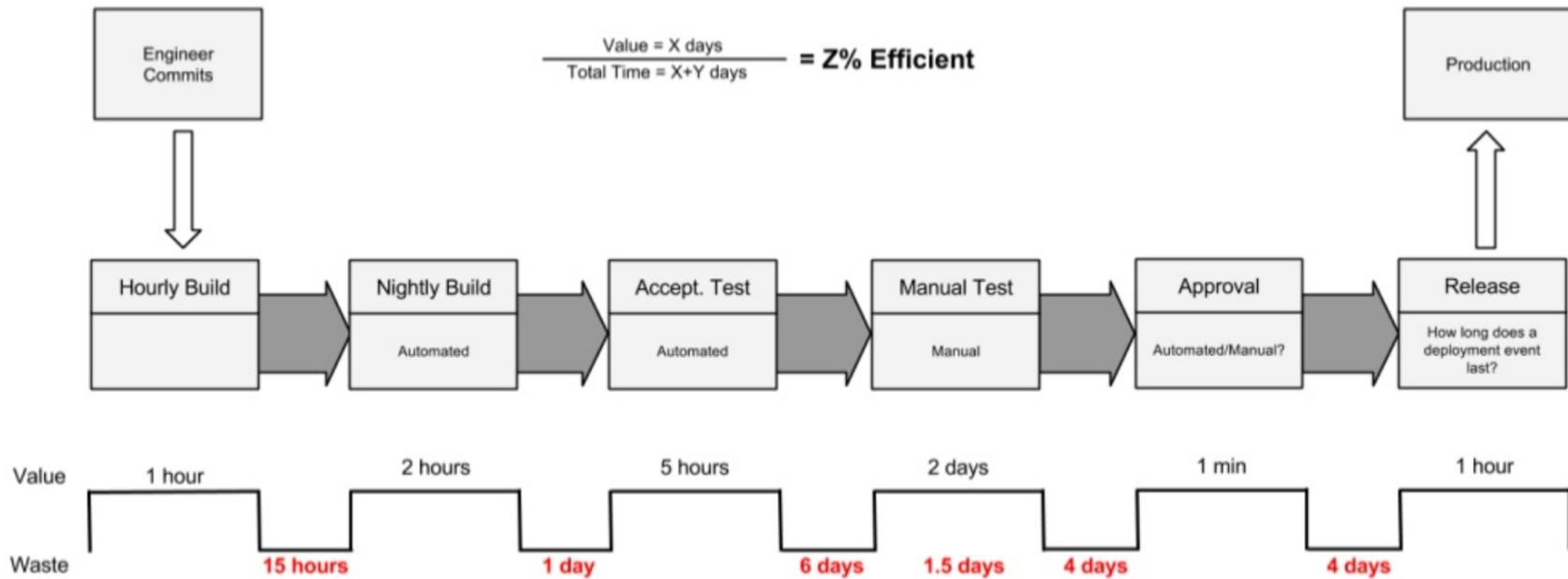
HEAVY TOOLING AND AUTOMATION



HEAVY TOOLING AND AUTOMATION -- EXAMPLES

- Infrastructure as code — Ansible, Terraform, Puppet, Chef
- CI/CD — Jenkins, TeamCity, GitLab, Shippable, Bamboo, Azure DevOps
- Test automation — Selenium, Cucumber, Apache JMeter
- Containerization — Docker, Rocket, Unik
- Orchestration — Kubernetes, Swarm, Mesos
- Software deployment — Elastic Beanstalk, Octopus, Vamp
- Measurement — Datadog, DynaTrace, Kibana, NewRelic, ServiceNow

CONTINUOUS DELIVERY



Source: <https://www.slideshare.net/jmcgarr/continuous-delivery-at-netflix-and-beyond>

TYPICAL MANUAL STEPS IN DEPLOYMENT?



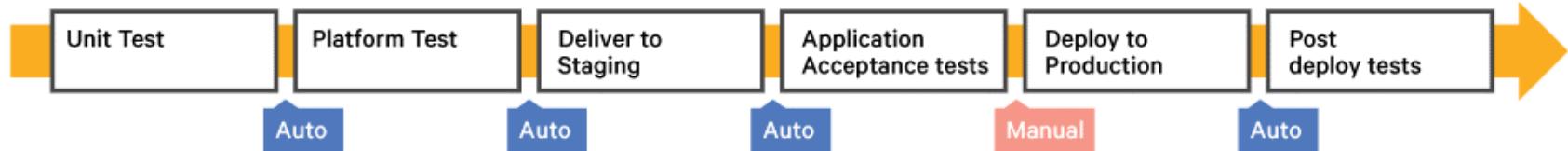
CONTINUOUS DELIVERY

- Full automation from commit to deployable container
- Heavy focus on testing, reproducibility and rapid feedback
- Deployment step itself is manual
- Makes process transparent to all developers and operators

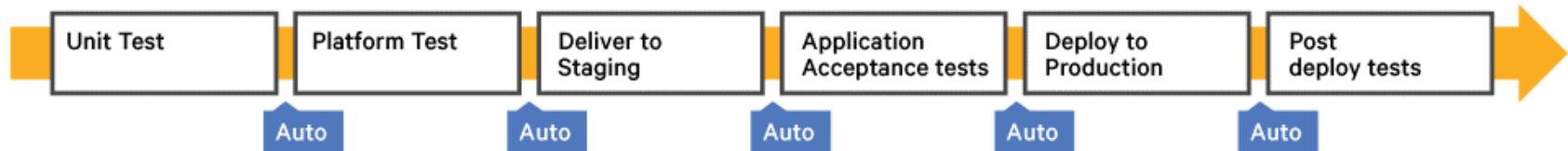
CONTINUOUS DEPLOYMENT

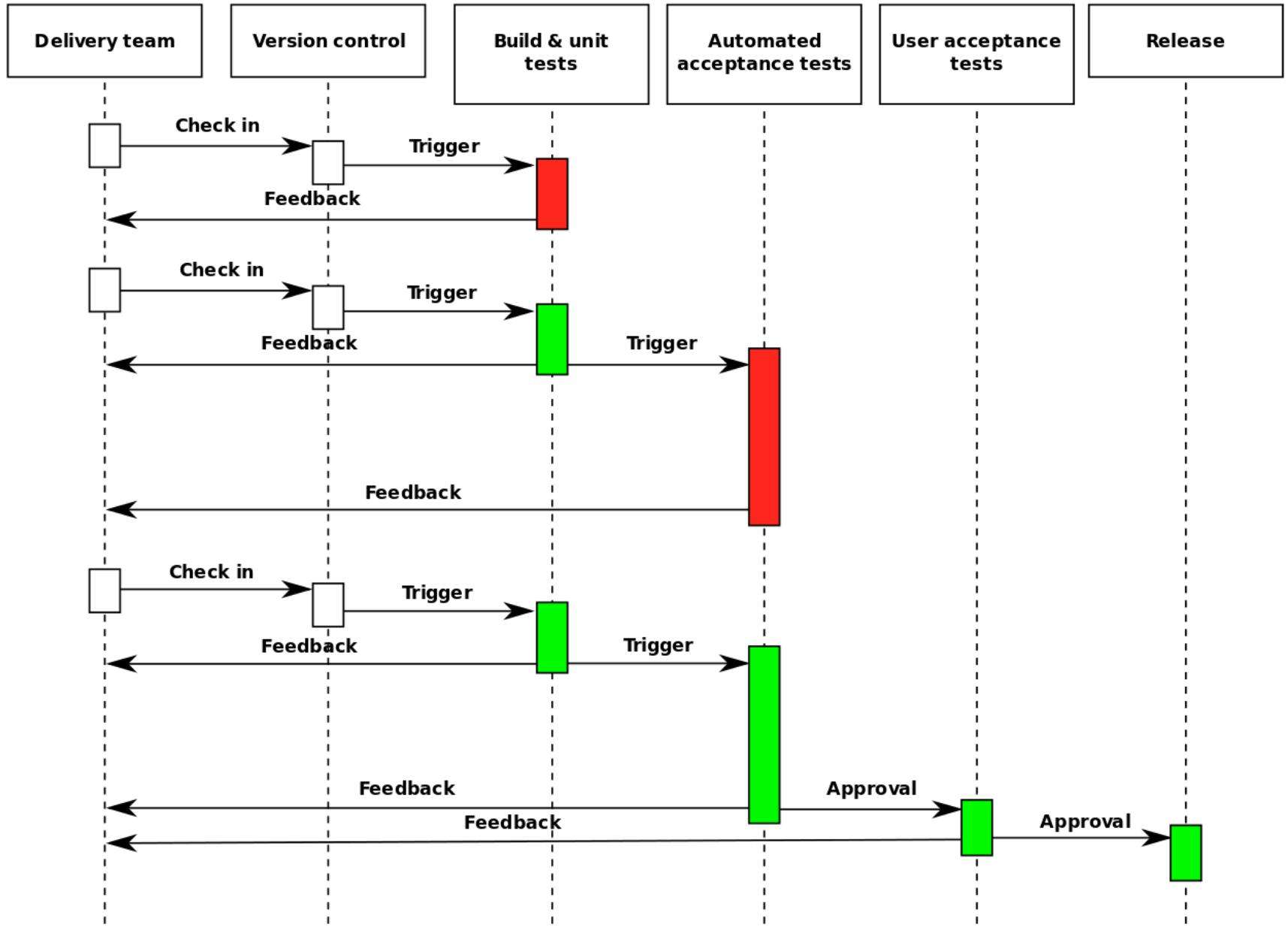
- Full automation from commit to deployment
- Empower developers, quick to production
- Encourage experimentation and fast incremental changes
- Commonly integrated with monitoring and canary releases

Continuous Delivery



Continuous Deployment





FACEBOOK TESTS FOR MOBILE APPS

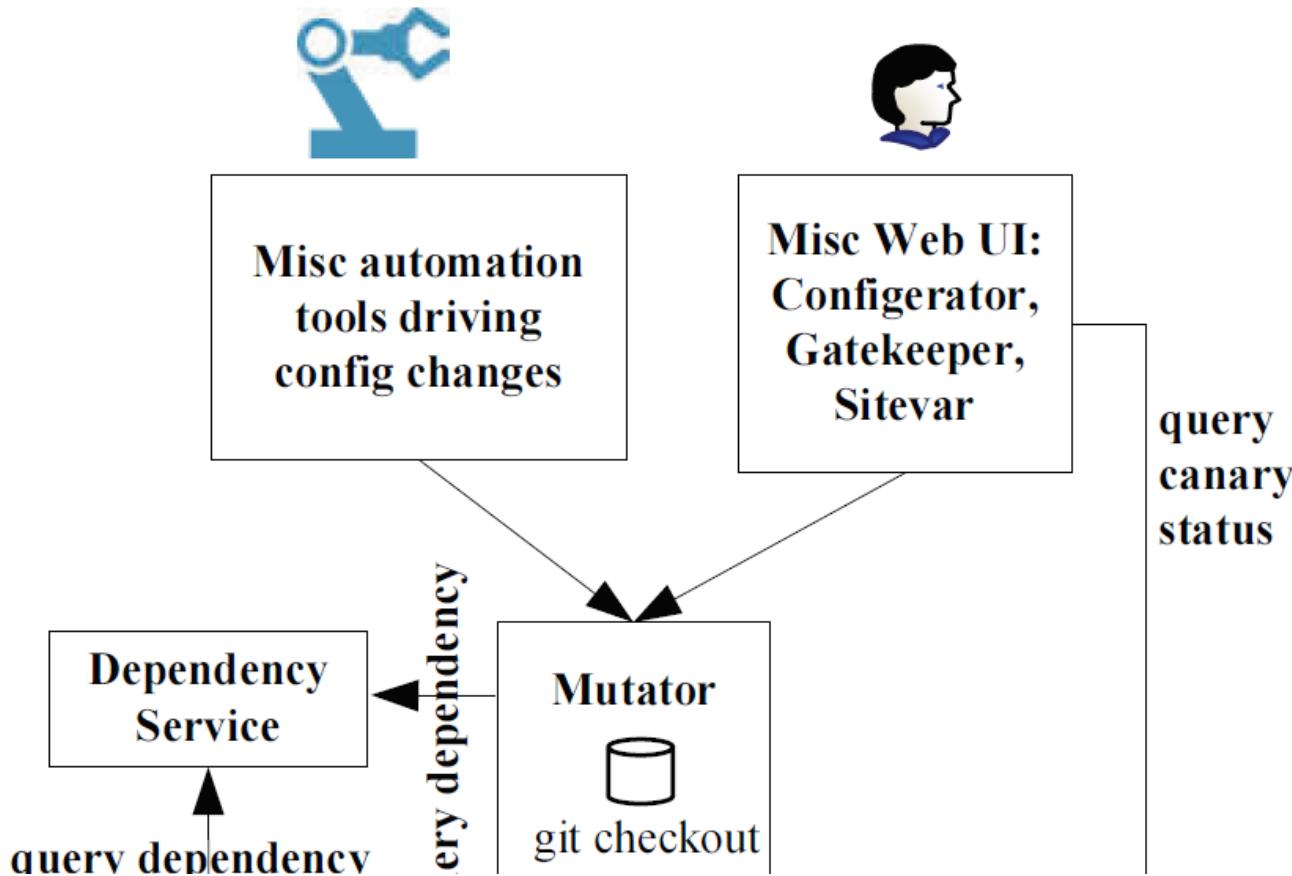
- Unit tests (white box)
- Static analysis (null pointer warnings, memory leaks, ...)
- Build tests (compilation succeeds)
- Snapshot tests (screenshot comparison, pixel by pixel)
- Integration tests (black box, in simulators)
- Performance tests (resource usage)
- Capacity and conformance tests (custom)

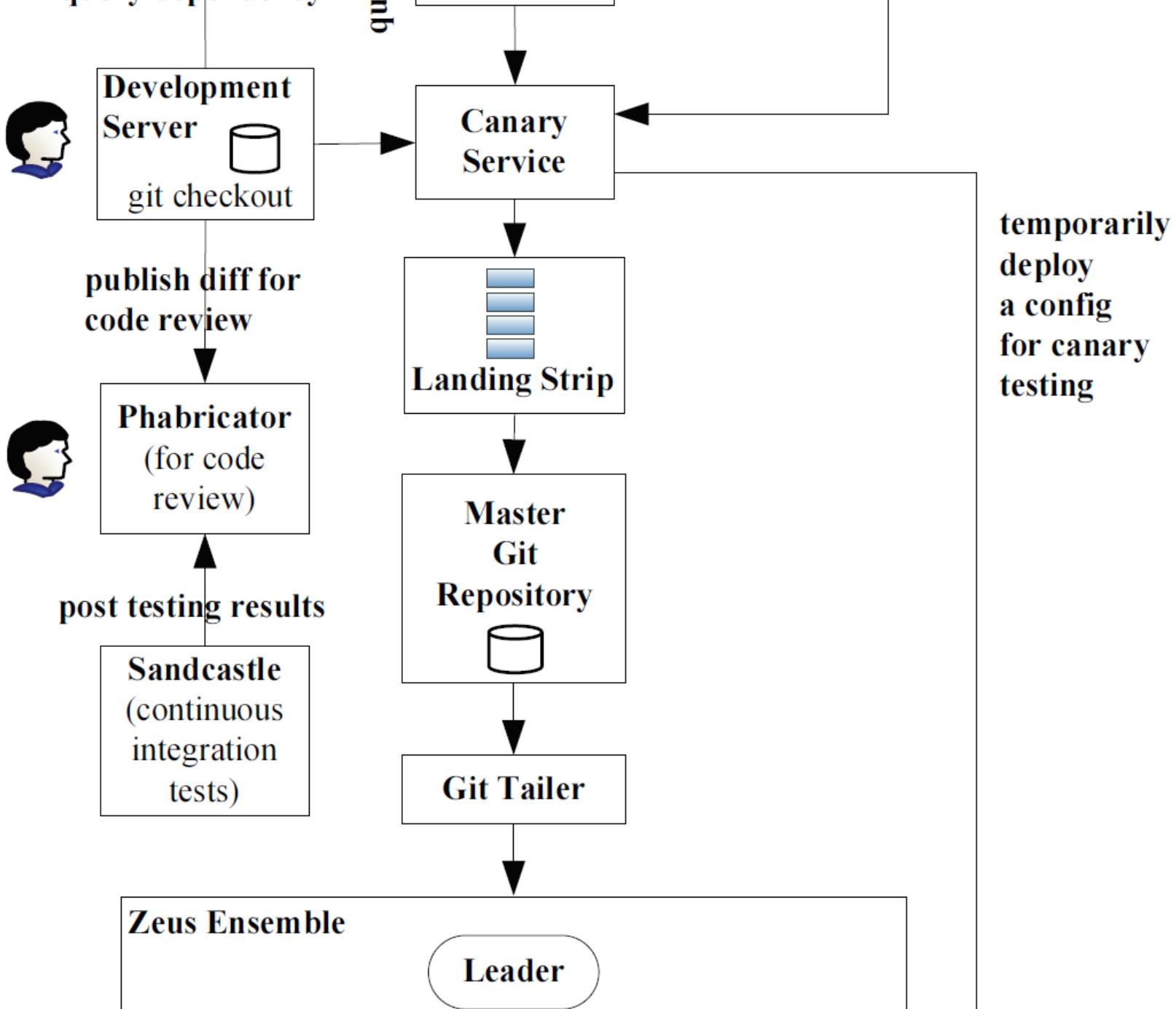
Further readings: Rossi, Chuck, Elisa Shibley, Shi Su, Kent Beck, Tony Savor, and Michael Stumm. [Continuous deployment of mobile software at facebook \(showcase\)](#). In Proceedings of the 2016 24th ACM SIGSOFT International Symposium on Foundations of Software Engineering, pp. 12-23. ACM, 2016.

RELEASE CHALLENGES FOR MOBILE APPS

- Large downloads
- Download time at user discretion
- Different versions in production
- Pull support for old releases?
- Server side releases silent and quick, consistent
- -> App as container, most content + layout from server

REAL-WORLD PIPELINES ARE COMPLEX





Follower

Follower

Follower

Follower

Multiple Observers in Each Cluster

Observer

Observer

Observer

Production Server

Product X

Product Y

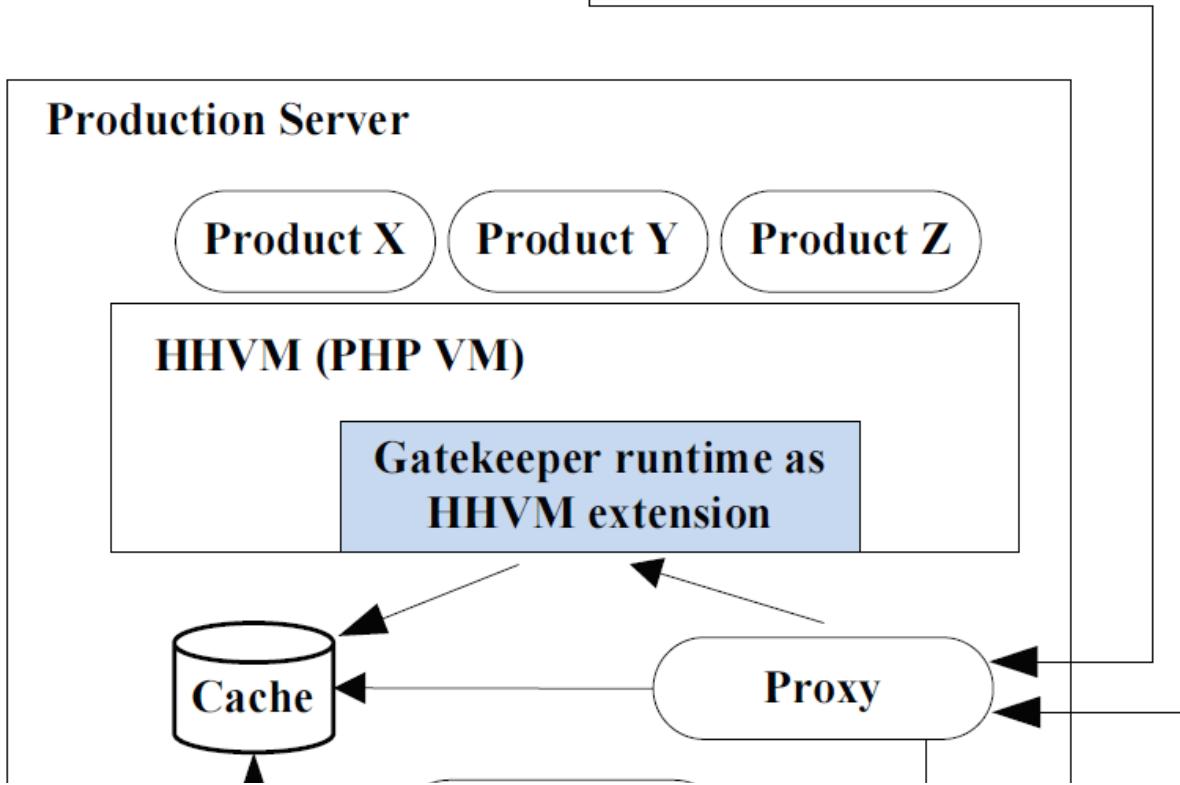
Product Z

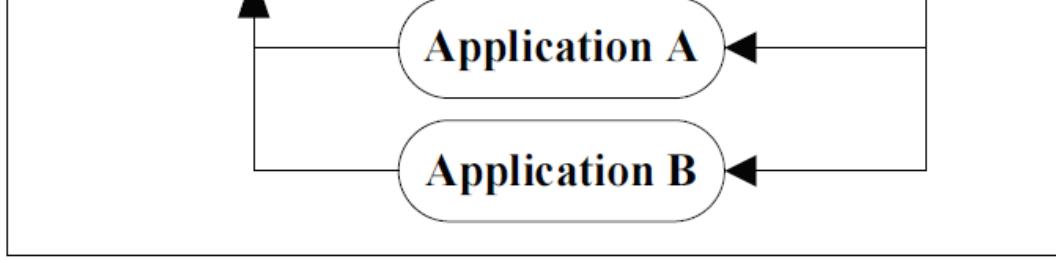
HHVM (PHP VM)

**Gatekeeper runtime as
HHVM extension**

Cache

Proxy

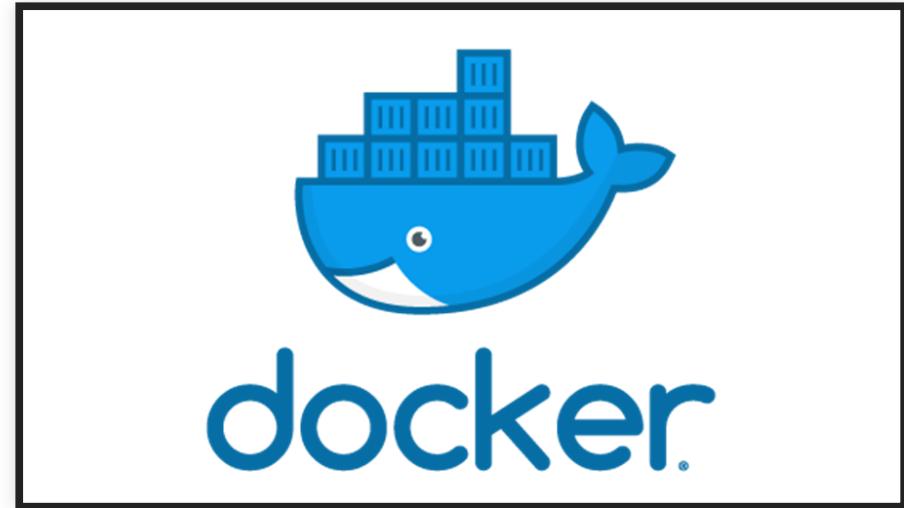




CONTAINERS AND CONFIGURATION MANAGEMENT

CONTAINERS

- Lightweight virtual machine
- Contains entire runnable software, incl. all dependencies and configurations
- Used in development and production
- Sub-second launch time
- Explicit control over shared disks and network connections



DOCKER EXAMPLE

```
FROM ubuntu:latest
MAINTAINER ...
RUN apt-get update -y
RUN apt-get install -y python-pip python-dev build-essential
COPY . /app
WORKDIR /app
RUN pip install -r requirements.txt
ENTRYPOINT ["python"]
CMD ["app.py"]
```

Source: <http://containertutorials.com/docker-compose/flask-simple-app.html>

COMMON CONFIGURATION MANAGEMENT QUESTIONS

- What runs where?
- How are machines connected?
- What (environment) parameters does software X require?
- How to update dependency X everywhere?
- How to scale service X?

ANSIBLE EXAMPLES

- Software provisioning, configuration management, and application-deployment tool
- Apply scripts to many servers

```
[webservers]
web1.company.org
web2.company.org
web3.company.org
```

```
[dbservers]
db1.company.org
db2.company.org
```

```
[replication_servers]
...
```

```
# This role deploys the mongod processes and
- name: create data directory for mongodb
  file: path={{ mongodb_datadir_prefix }}/{{ item }}
  delegate_to: '{{ item }}'
  with_items: groups.replication_servers

- name: create log directory for mongodb
  file: path=/var/log/mongo state=directory o

- name: Create the mongodb startup file
  template: src=mongod.j2 dest=/etc/init.d/mo
  delegate_to: '{{ item }}'
  with_items: groups.replication_servers

- name: Create the mongodb configuration file
```

PUPPET EXAMPLE

Declarative specification, can be applied to many machines

```
$doc_root = "/var/www/example"

exec { 'apt-get update':
  command => '/usr/bin/apt-get update'
}

package { 'apache2':
  ensure  => "installed",
  require => Exec['apt-get update']
}

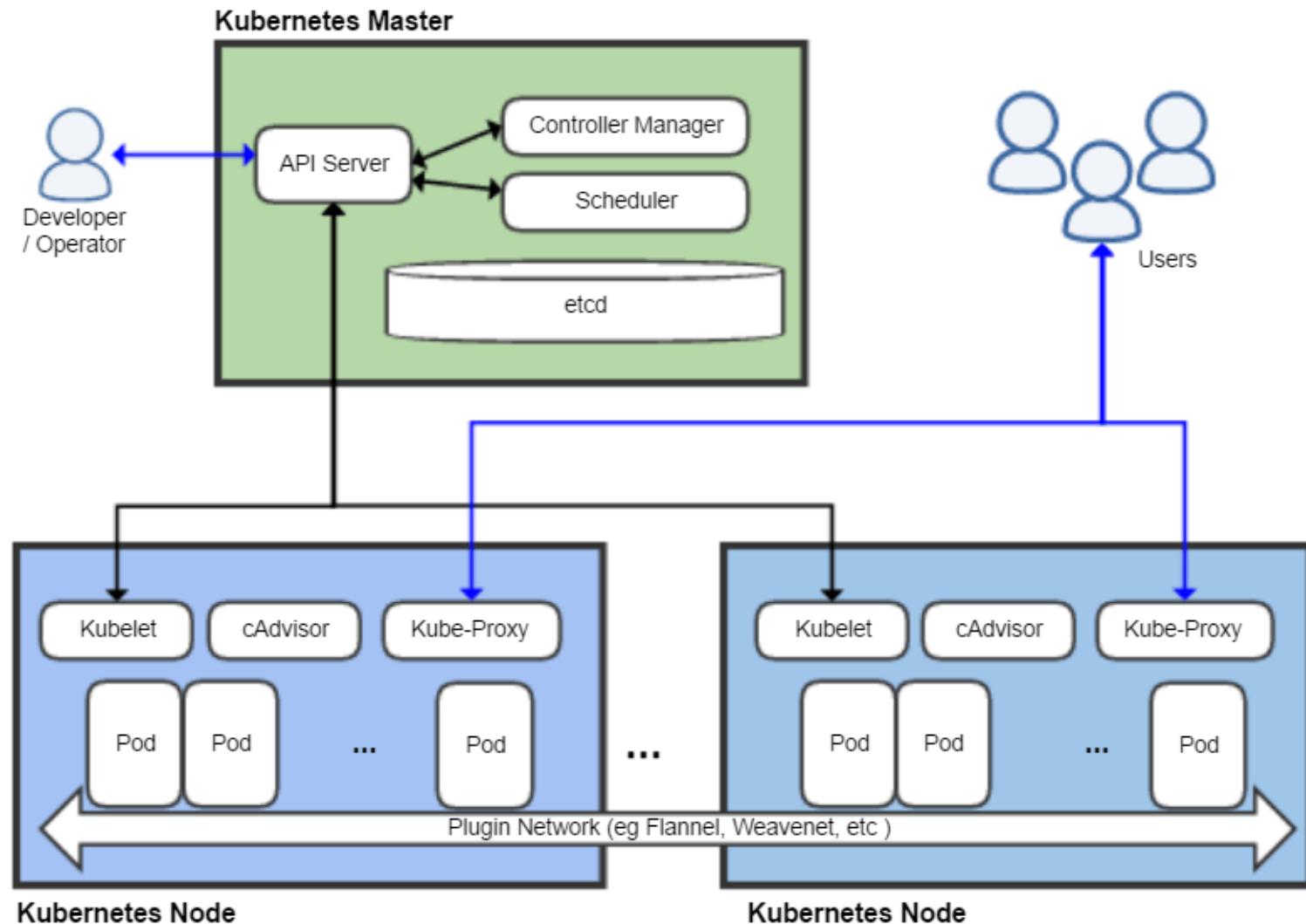
file { $doc_root:
  ensure => "directory",
  owner  => "www-data",
  group  => "www-data",
  mode   => 644
```

Speaker notes

source: <https://www.digitalocean.com/community/tutorials/configuration-management-101-writing-puppet-manifests>

CONTAINER ORCHESTRATION WITH KUBERNETES

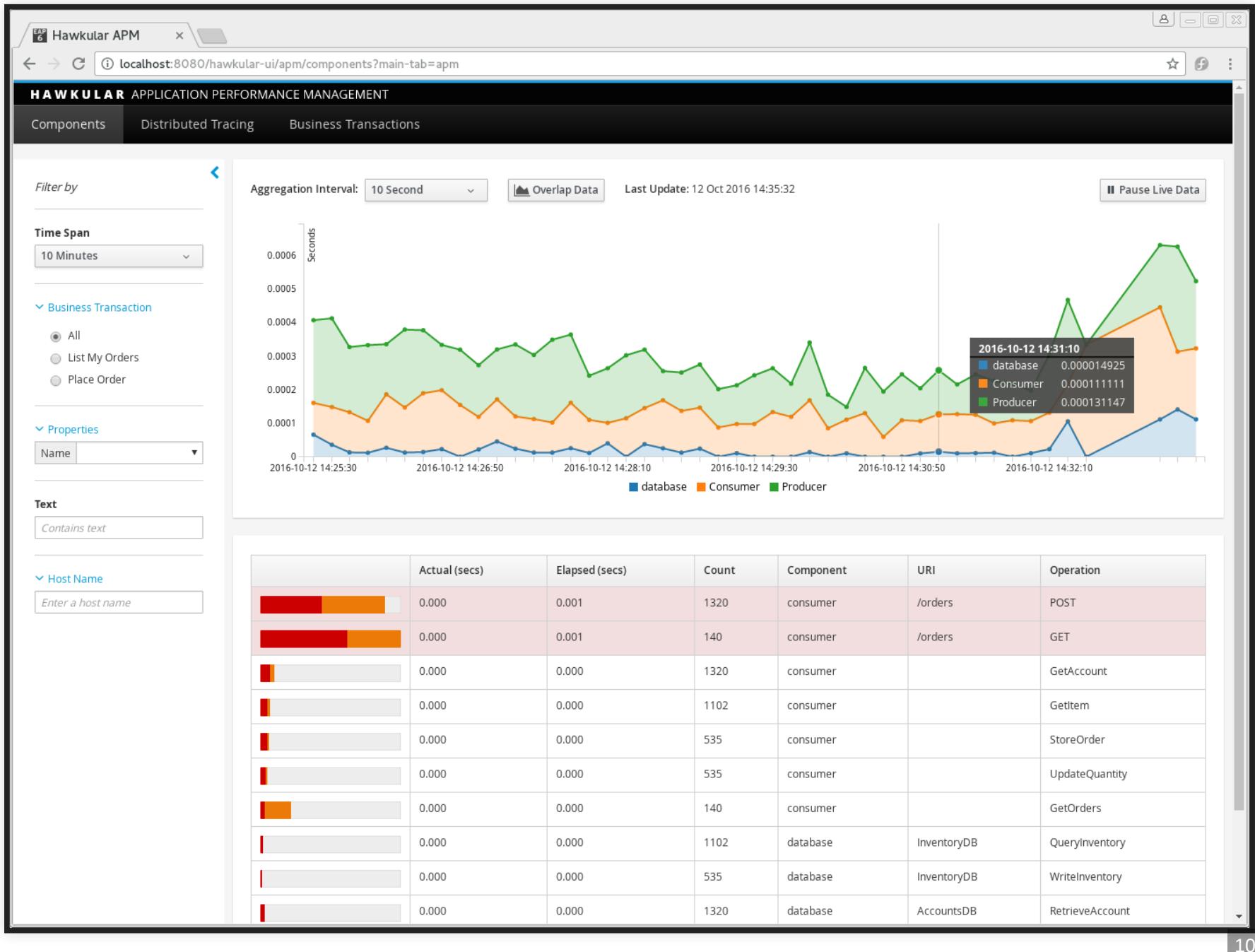
- Manages which container to deploy to which machine
- Launches and kills containers depending on load
- Manage updates and routing
- Automated restart, replacement, replication, scaling
- Kubernetes master controls many nodes



MONITORING

- Monitor server health
 - Monitor service health
 - Collect and analyze measures or log files
 - Dashboards and triggering automated decisions
-
- Many tools, e.g., Grafana as dashboard, Prometheus for metrics, Loki + ElasticSearch for logs
 - Push and pull models

HAWKULAR



HAWKULAR

Hawkular APM

localhost:8080/hawkular-ui/apm/tracing?main-tab=tracing

HAWKULAR APPLICATION PERFORMANCE MANAGEMENT

Components Distributed Tracing Business Transactions

Filter by

Initial Endpoint OrderManager: /orders[POST]

Show 2 Instance(s) Details

Reset Zoom

Time Span 1 Hour

Business Transaction All

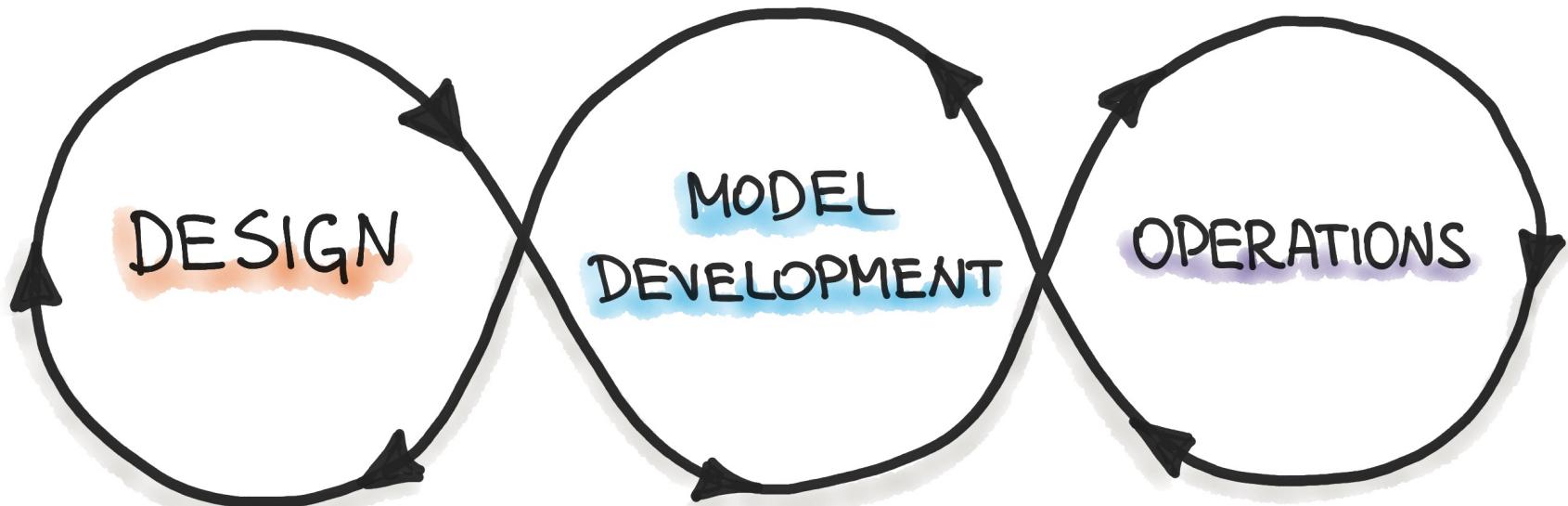
Properties Name

The diagram illustrates a distributed tracing trace starting from the initial endpoint `OrderManager: /orders[POST]`. This endpoint is shown in a dark grey box with a red vertical bar on its left, indicating a duration of `34.5ms` and two instances. Four arrows originate from this endpoint, each labeled with the number `2`, pointing to four separate service components:

- `InventoryManager [UpdateQuantity]`: Duration `0.116ms`, two instances.
- `InventoryManager [GetItem]`: Duration `0.078ms`, two instances.
- `OrderLog [StoreOrder]`: Duration `0.126ms`, two instances.
- `AccountManager [GetAccount]`: Duration `2ms`, two instances.

Each service component is represented by a green box with its name, method, and duration. To the right of each box, there is a small circular icon with a question mark and a square icon with the number `2`.

MLOps



<https://ml-ops.org/>

ON TERMINOLOGY

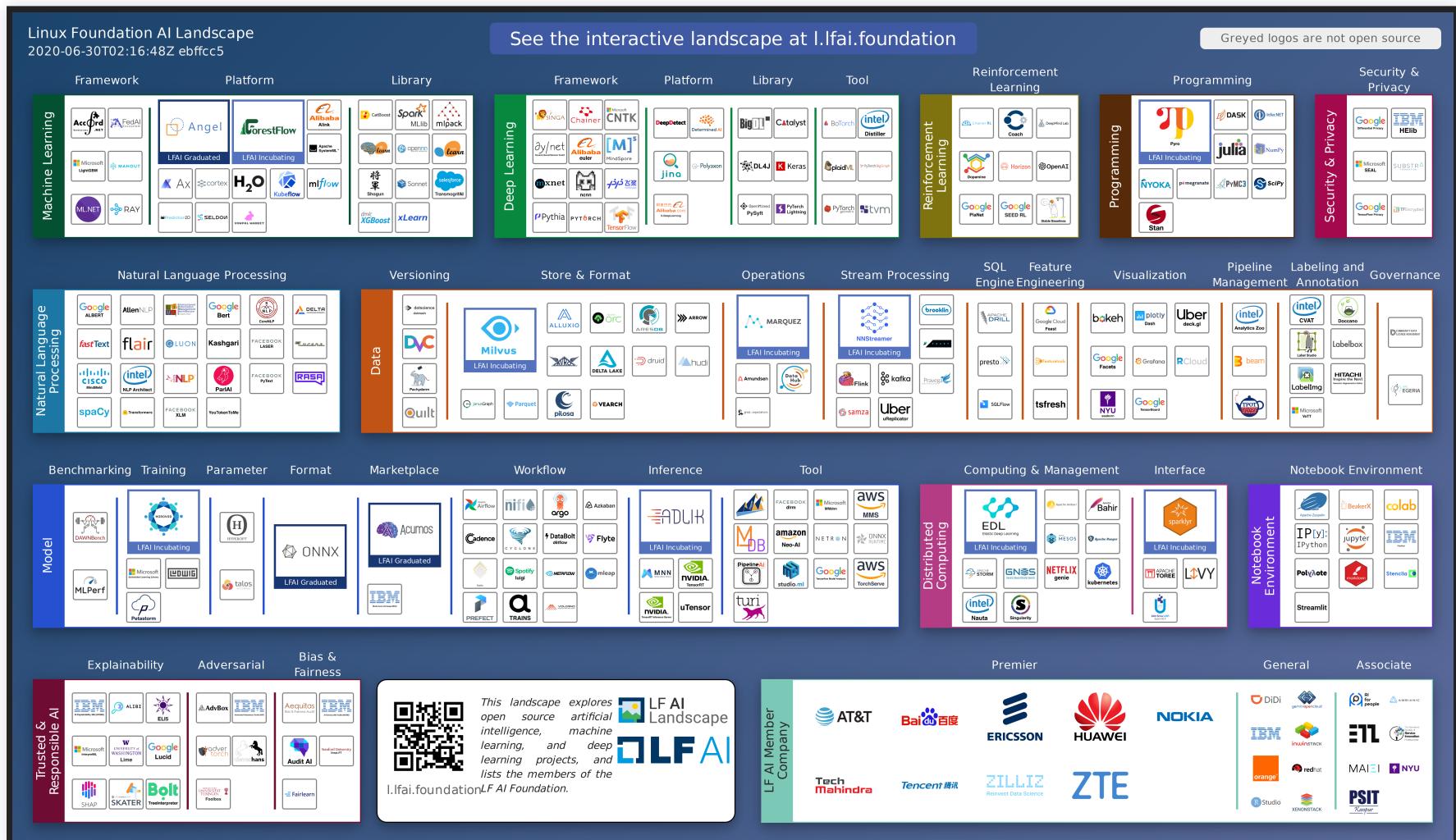
- Many vague buzzwords, often not clearly defined
- *MLOps*: Collaboration and communication between data scientists and operators, e.g.,
 - Automate model deployment
 - Model training and versioning infrastructure
 - Model deployment and monitoring
- *AIOps*: Using AI/ML to make operations decision, e.g. in a data center
- *DataOps*: Data analytics, often business setting and reporting
 - Infrastructure to collect data (ETL) and support reporting
 - Monitor data analytics pipelines
 - Combines agile, DevOps, Lean Manufacturing ideas

MLOPS OVERVIEW

- Integrate ML artifacts into software release process, unify process
- Automated data and model validation (continuous deployment)
- Data engineering, data programming
- Continuous deployment for ML models
 - From experimenting in notebooks to quick feedback in production
- Versioning of models and datasets
- Monitoring in production

Further reading: [MLOps principles](#)

TOOLING LANDSCAPE LF AI



SUMMARY

- Beyond model and data quality: Quality of the infrastructure matters, danger of silent mistakes
- Many SE techniques for test automation, testing robustness, test adequacy, testing in production useful for infrastructure quality
- Lack of modularity: local improvements may not lead to global improvements
- DevOps: Development vs Operations challenges
 - Automated configuration
 - Telemetry and monitoring are key
 - Many, many tools
- MLOps: Automation around ML pipelines, incl. training, evaluation, versioning, and deployment

