Reliable Infrastructure as Code for Decentralized Organizations

Daniel Sokolowski

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Soko2D

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Programming Group

Joint works with:

Guido Salvaneschi

Pascal Weisenburger

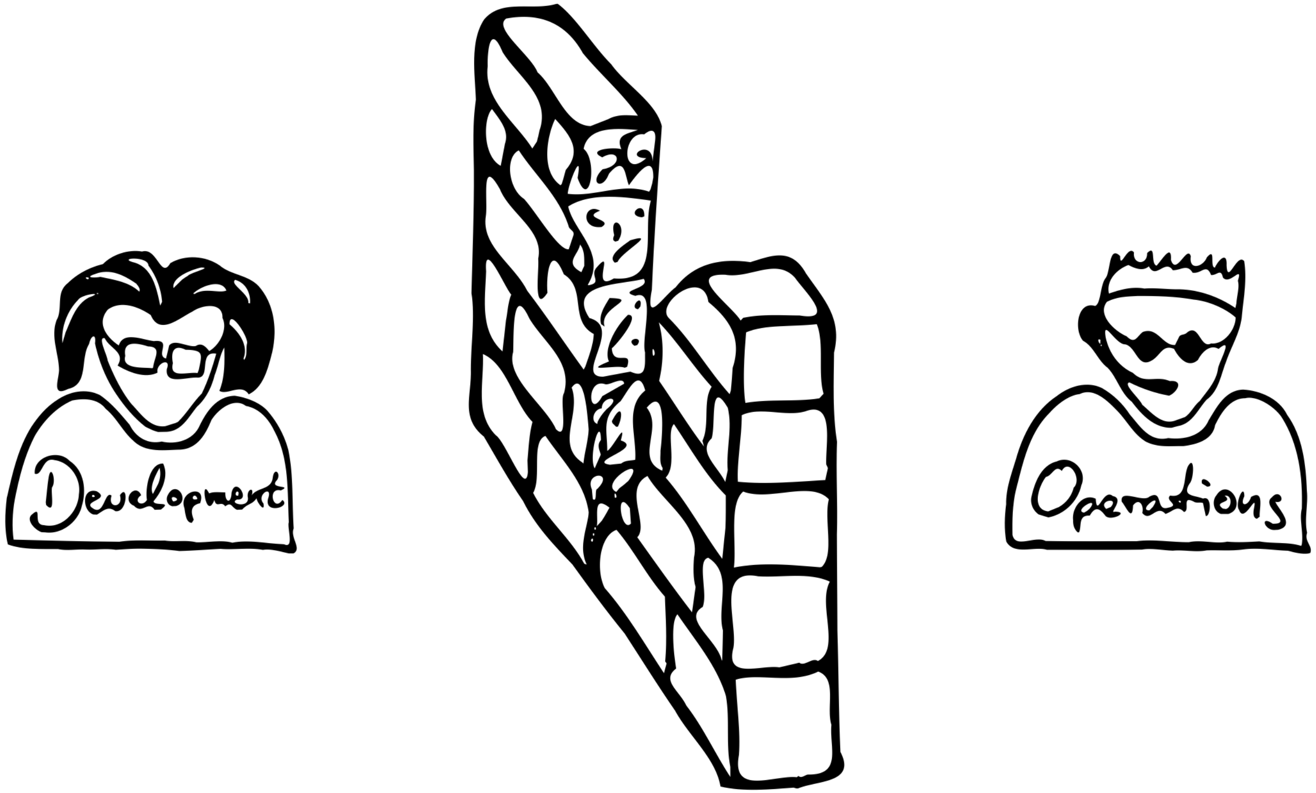
David Spielmann

Change is Ubiquitous

Operations

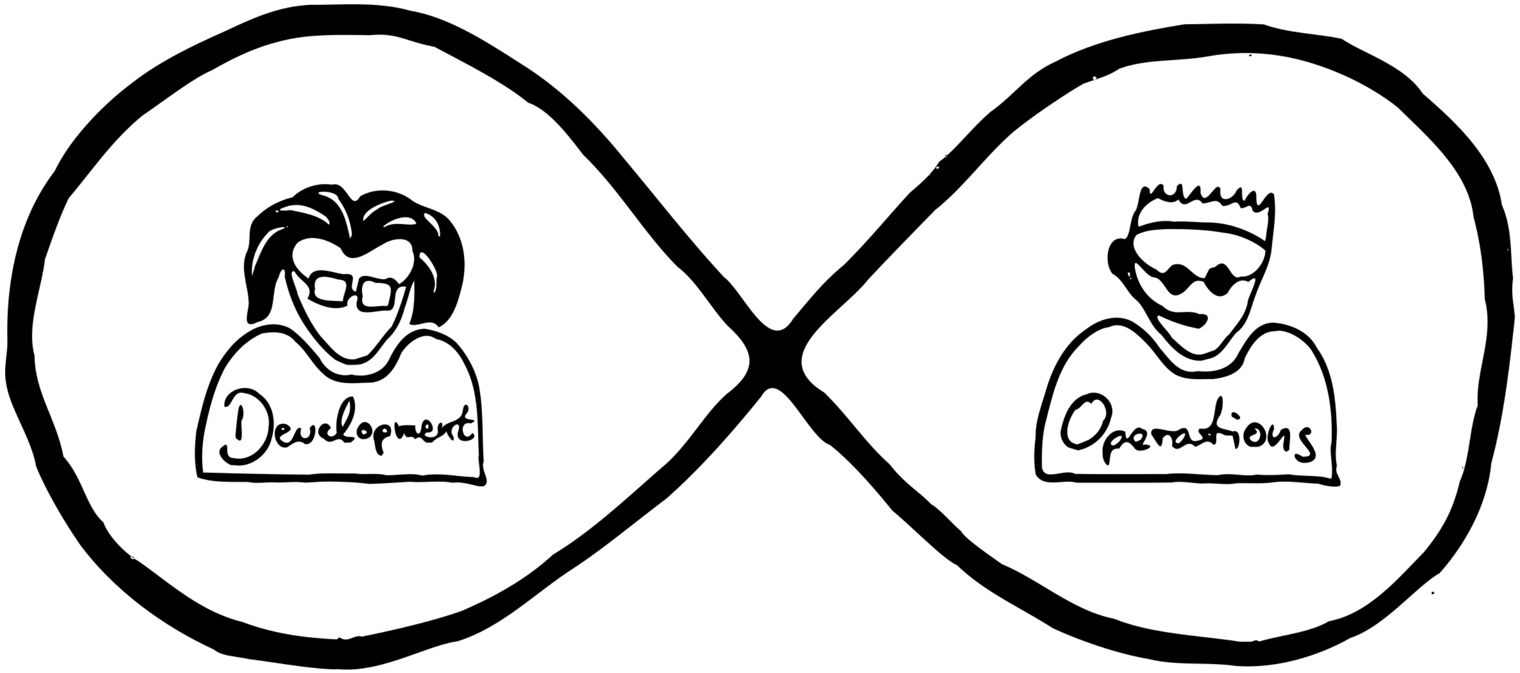
Software must
adapt quickly
and be reliable.

Wall of Confusion



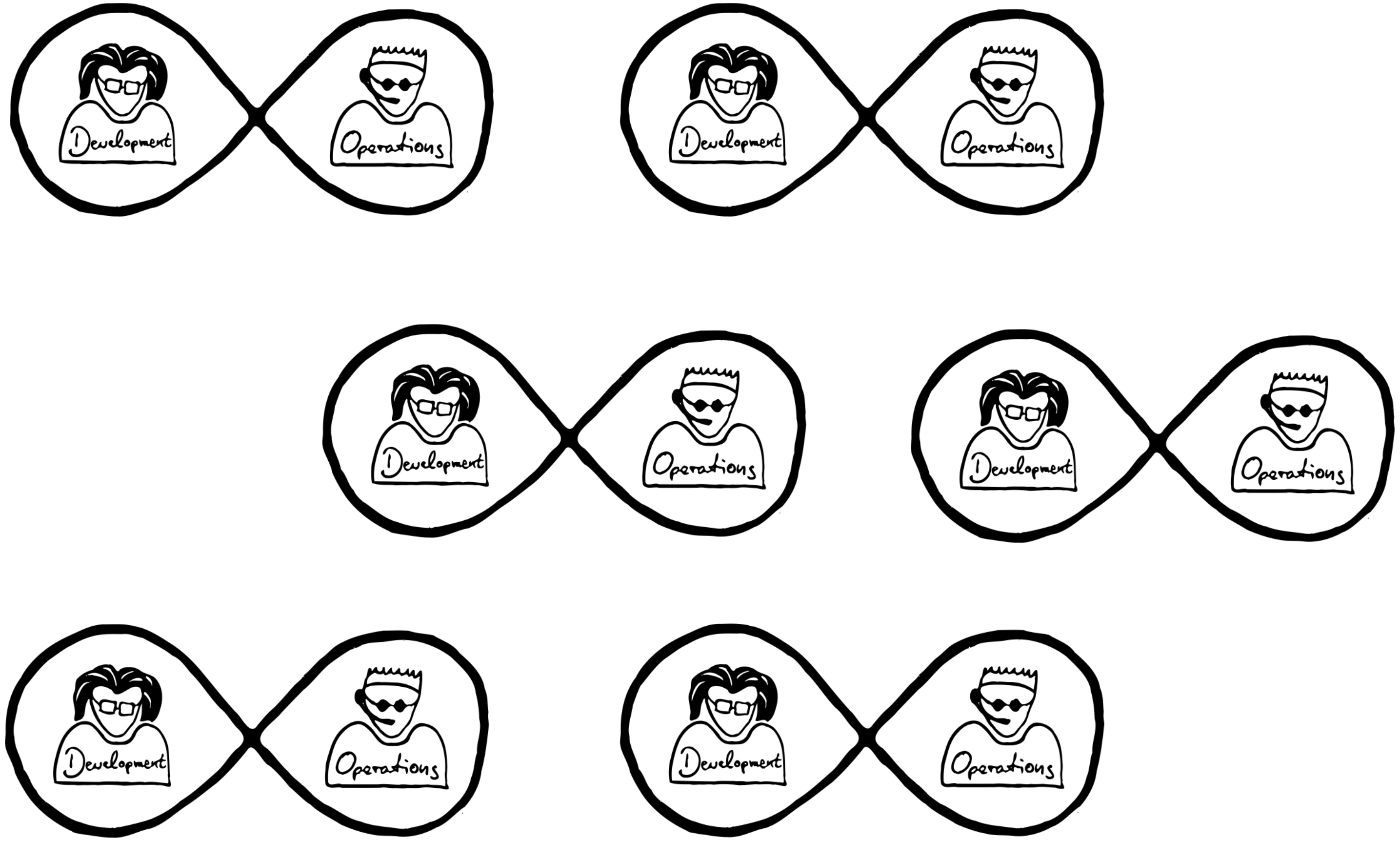
Development, operations, and others were separated.

DevOps: Cross-functional Teams



DevOps unites the responsibilities in cross-functional teams.

Decentralized Organizations



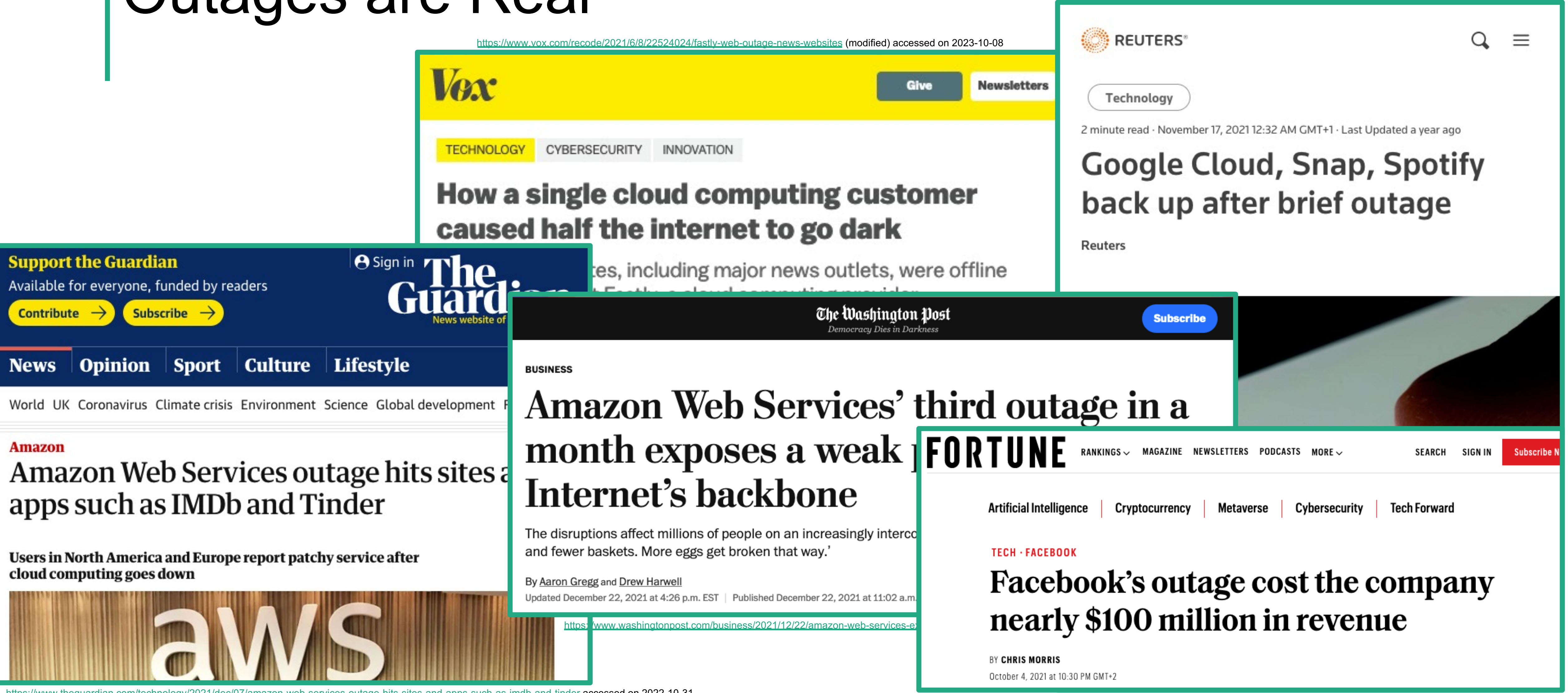
Many teams, each independently working on their applications.

Automation is Key

Infrastructure as Code (IaC) automates software operations.

DALL·E 2022-09-29 15.06.41 - In a neon room, multiple persons work quickly with devices and do mistakes in a hurry

Outages are Real



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Amazon Web Services' third outage in a month exposes a weak … Internet's backbone

The disruptions affect millions of people on an increasingly interco… and fewer baskets. More eggs get broken that way.'

By Aaron Gregg and Drew Harwell

Updated December 22, 2021 at 4:26 p.m. EST | Published December 22, 2021 at 11:02 a.m.

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Facebook's outage cost the company nearly $100 million in revenue

BY CHRIS MORRIS

October 4, 2021 at 10:30 PM GMT+2

https://fortune.com/2021/10/04/facebook-outage-cost-revenue-instagram-whatsapp-not-working-stock/ accessed on 2022-10-31

Configuration Causes Outages

2016: Analyzes ~600 outages in 2009-2015, configuration bugs are a common cause

Why Does the Cloud Stop Computing? Lessons from Hundreds of Service Outages

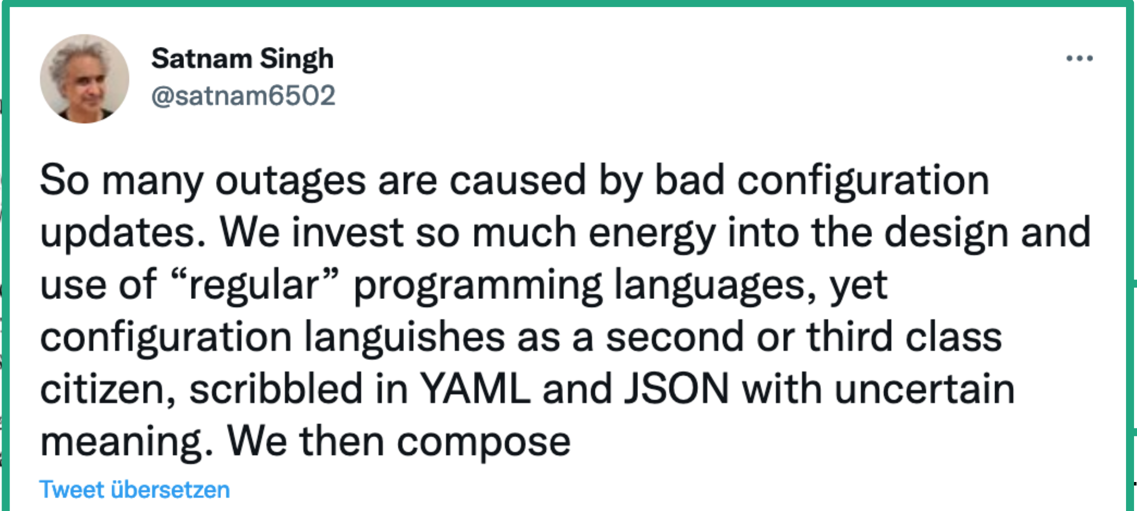
Haryadi S. Gunawi, Mingzhe Hao, and Riza O. Suminto
University of Chicago

Agung Laksono, Anang D. Satria, Jeffry Adityatama, and Kurnia J. Eliazar
Surya University

Abstract

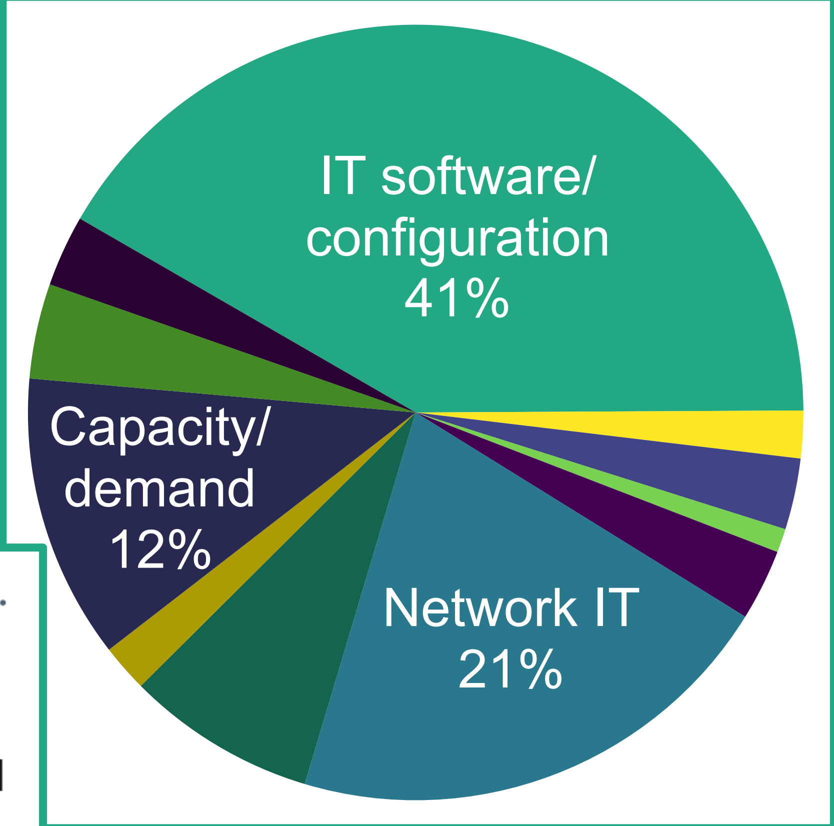
We conducted a cloud outage study (COS) of 32 popu ernet services. We analyzed 1247 headline news and ost-mortem reports that detail 597 unplanned outag ccurred within a 7-year span from 2009 to 2015. W yzed outage duration, root causes, impacts, and fix lures. This study reveals the broader availability lan f modern cloud services and provides answers to wh ges still take place even with pervasive redundancies

Categories and Subject Descriptors C.4 [*Compute ems Organization*]: Performance of Systems: Reli Availability, Serviceability



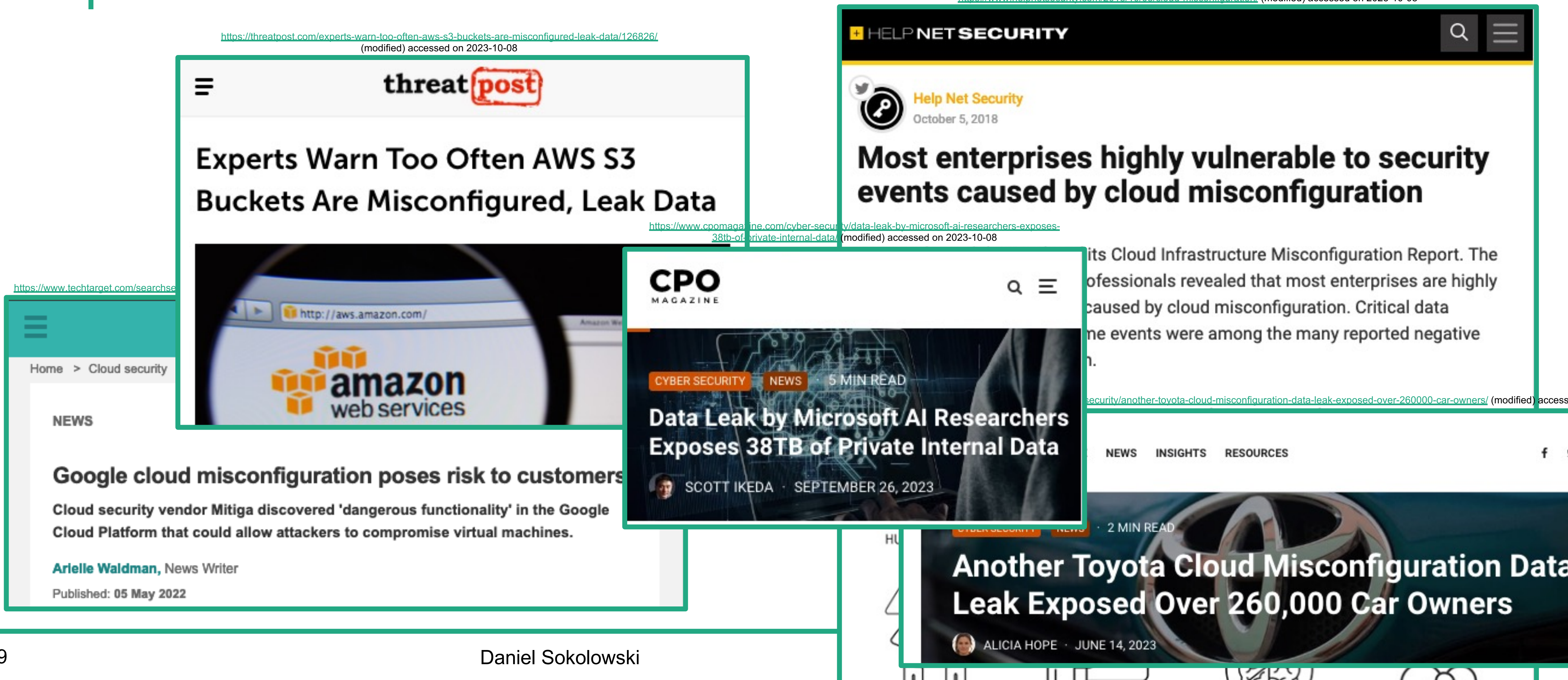
Satnam Singh
@satnam6502

So many outages are caused by bad configuration updates. We invest so much energy into the design and use of “regular” programming languages, yet configuration languishes as a second or third class citizen, scribbled in YAML and JSON with uncertain meaning. We then compose



Causes of publicly reported outages from various sources (n=119), 2020, Uptime Institute. Annual Outage Analysis 2021
https://uptimeinstitute.com/annual-outage-analysis-2021

Security Issues are Real



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Help Net Security
October 5, 2018

Most enterprises highly vulnerable to security events caused by cloud misconfiguration

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ofessionals revealed that most enterprises are highly
caused by cloud misconfiguration. Critical data
ne events were among the many reported negative
n.

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Google cloud misconfiguration poses risk to customers

Cloud security vendor Mitiga discovered 'dangerous functionality' in the Google Cloud Platform that could allow attackers to compromise virtual machines.

Arielle Waldman, News Writer

Published: 05 May 2022

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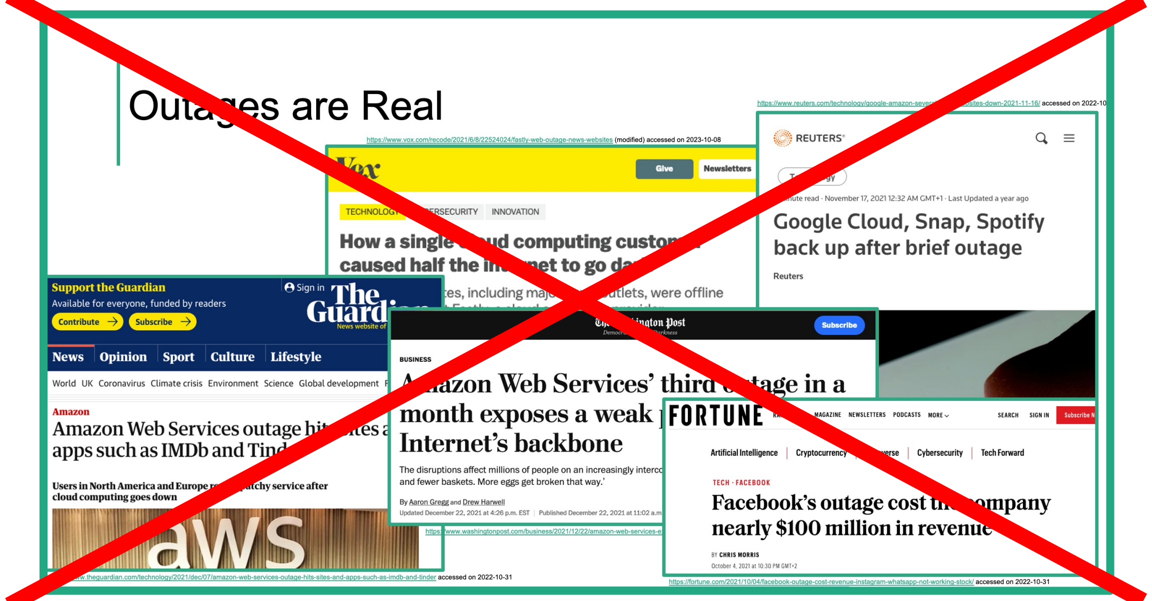

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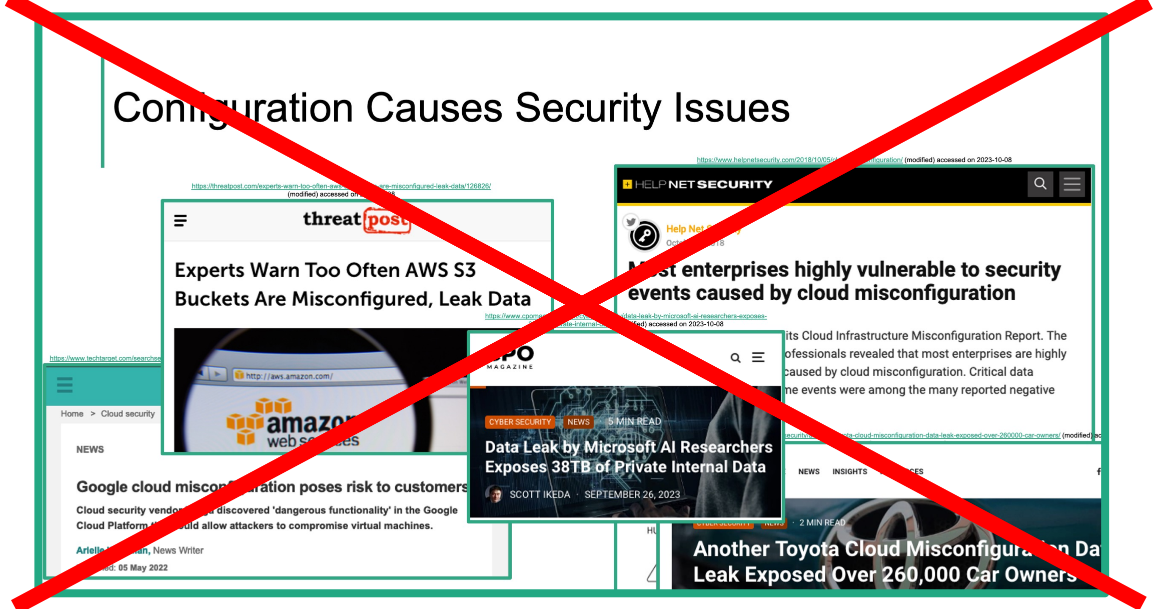

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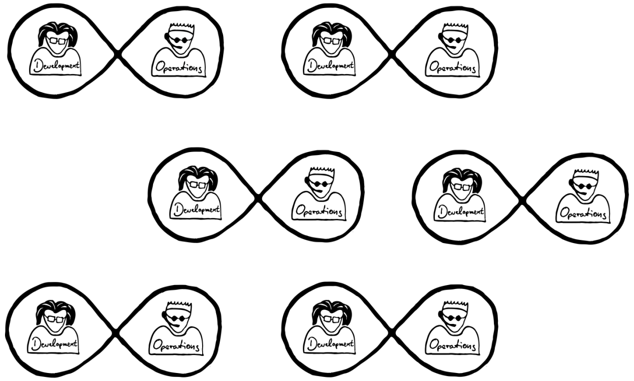
Motivation Summary

For software that is quickly adaptable and reliable,

DevOps embraces decentralized organizations and automation.

IaC automates deployments and must be reliable.



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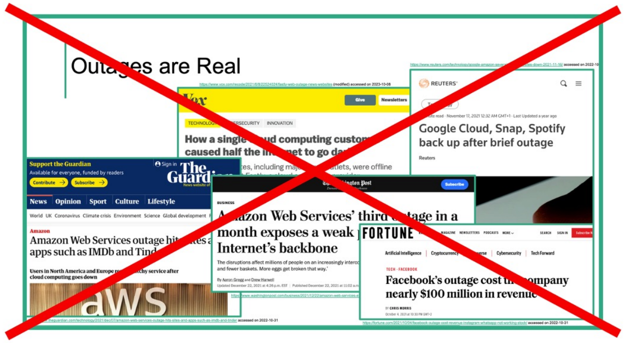

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Reliable Infrastructure as Code for Decentralized Organizations

Programming Languages IaC (PL-IaC)

Decentralized Coordination

- Dependencies in DevOps Survey
- Decentralized Deployment Coordination with µs [mju:z]
- Safe Dynamic Software Updating

Automated Testing of IaC Programs

- Current State and the Testing Dilemma
- Automated Configuration Testing and ProTI

DALL·E 2023-12-10 14.14.51 - A hiker is standing mid-way on a trail in the center of a vast valley. The hiker, wearing a purple jacket and carrying a backpack, is looking down the winding path of the valley. The scene is vibrant with lush green grass and patches of red foliage on either side of the trail. The valley is flanked by majestic mountains, and the sky is clear with a few fluffy clouds. The lighting is warm and golden, indicating either sunrise or sunset. The mood is peaceful and inspiring.

Programming Languages Infrastructure as Code (PL-IaC)

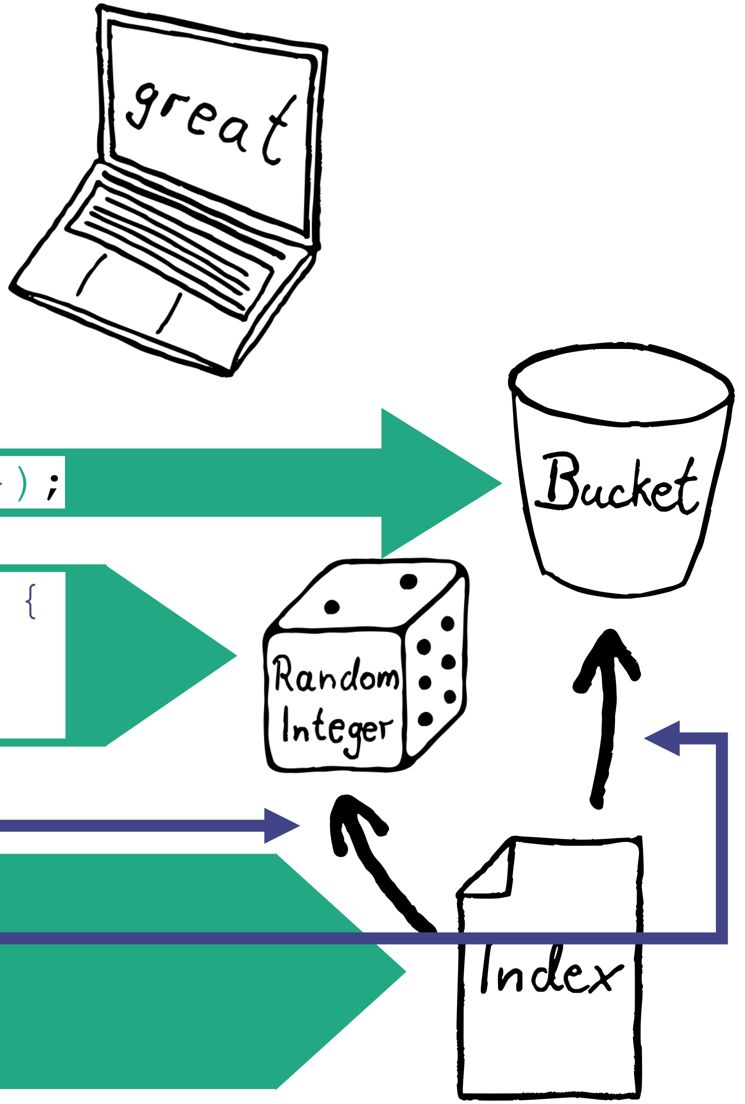
aws Cloud Development Kit

Pulumi

CDK for Terraform

µs [mju:z]

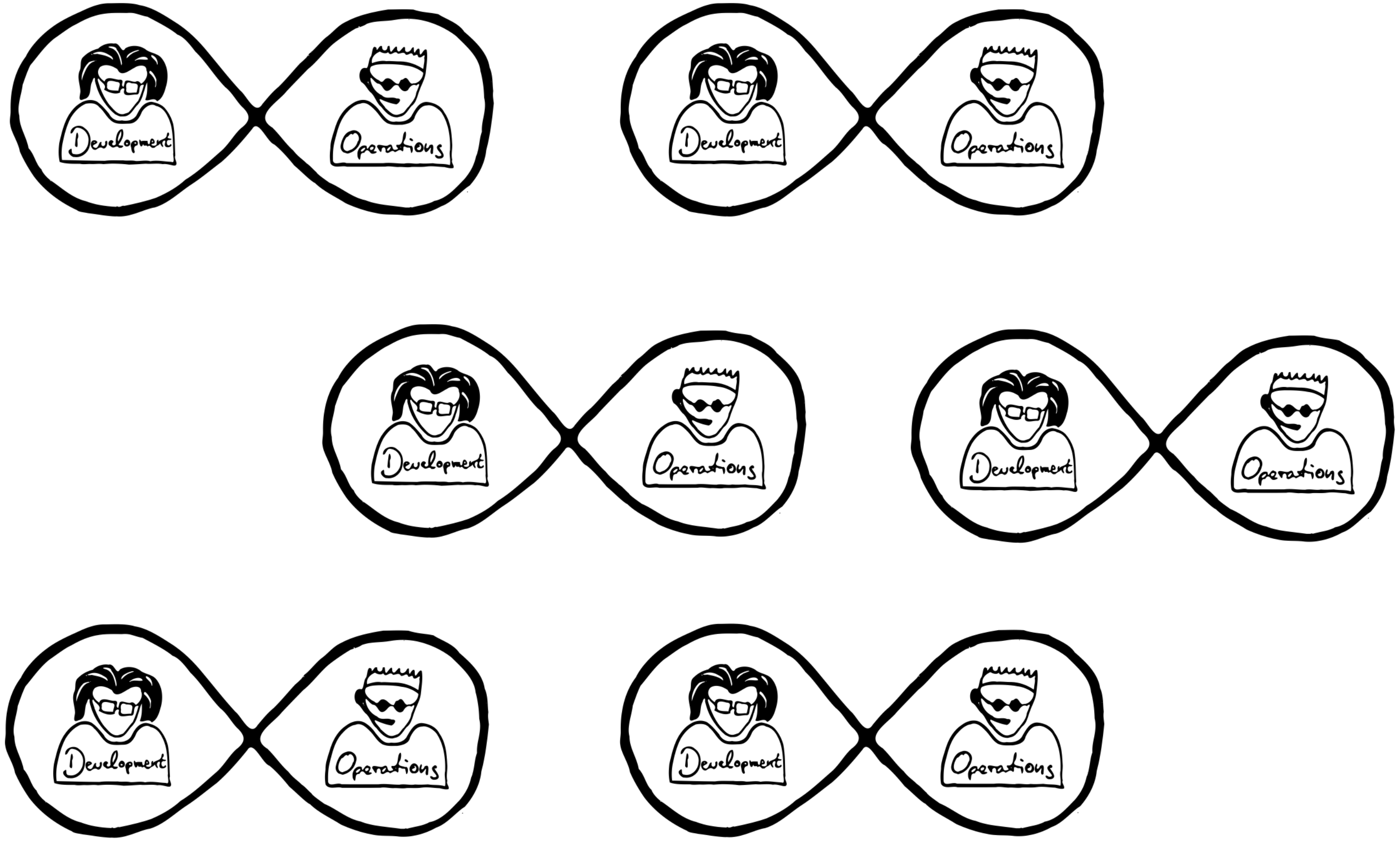
Example: Random Word Website

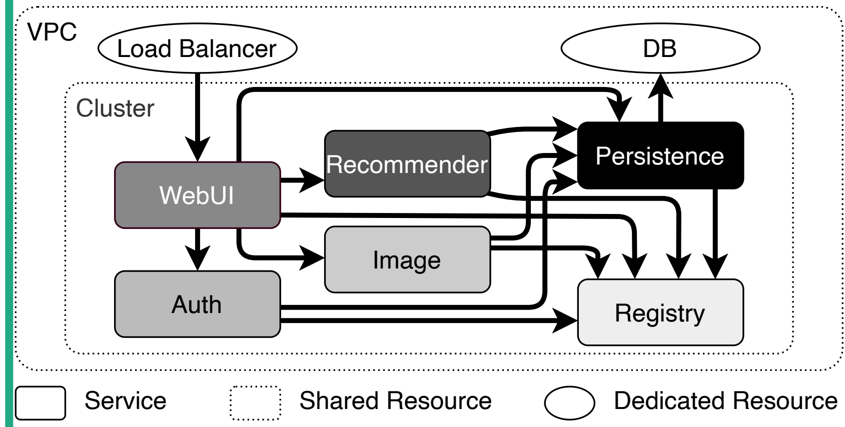


```
const words = ["software", "is", "great"]

const bucket = new s3.Bucket("website", { /* ... */ });

const rng = new random.RandomInteger ("word-id", {
  min: 0, max: words.length
});

rng.result.apply((id) => {
  new s3.BucketObject("index", {
    bucket: bucket, /* ... */
    content: /* ... */ + words[id].toLowerCase()
  });
});

export const url = bucket.websiteEndpoint;
```

```
pulumi up -y --skip-preview
Updating (demo):
     Type                              Name                        Status                  Info
 +   pulumi:pulumi:Stack               random-word-webpage-demo
 +   ├─ aws:s3:Bucket                  website
 +   ├─ random:index:RandomInteger     word-id
 +   └─ aws:s3:BucketObject            index

Outputs:
    url: "website-178809d.s3-website-us-east-1.amazonaws.com"

Resources:
    + 4 created

Duration: 7s
```

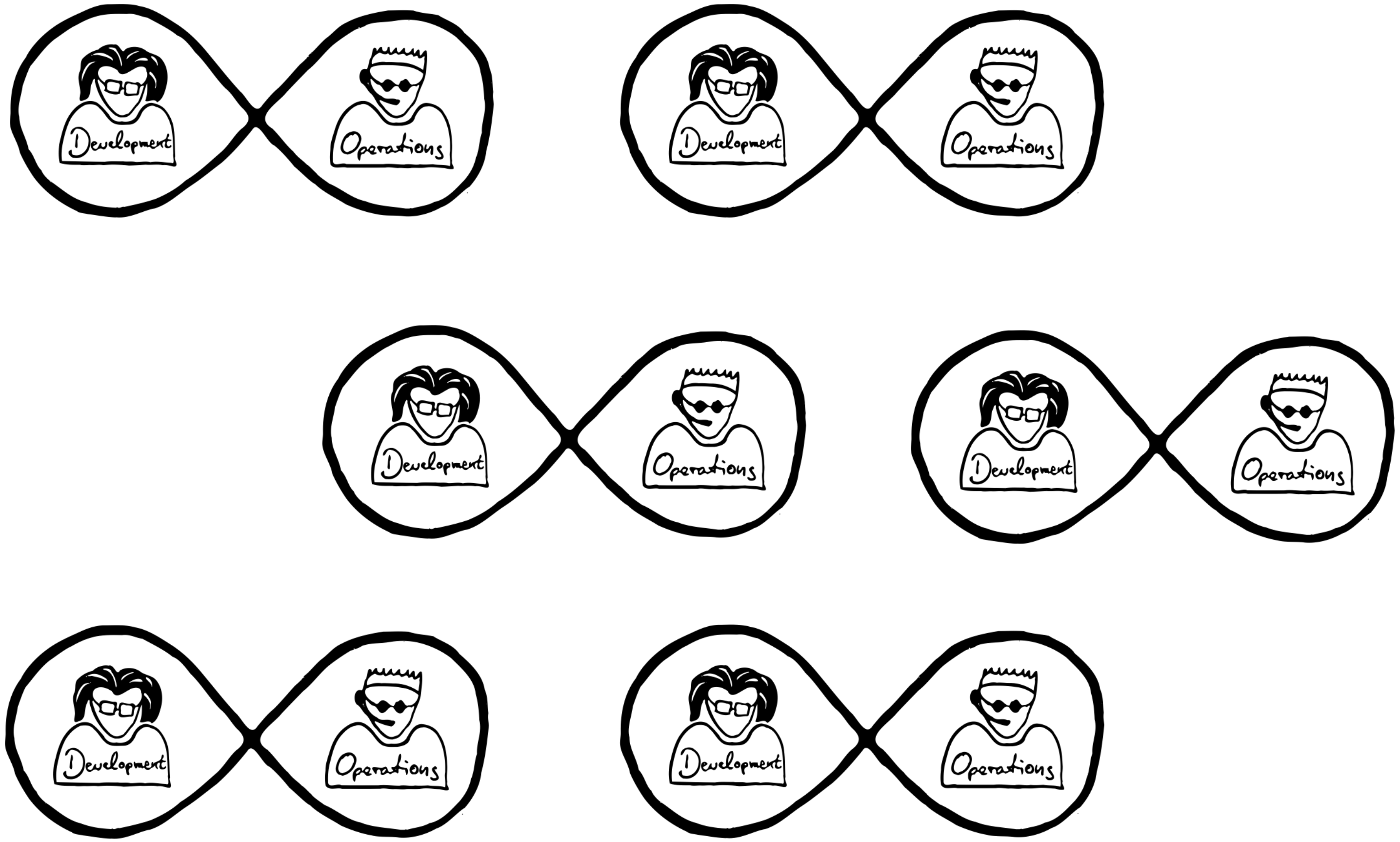
Decentralized Organizations: Really Independent Operations?

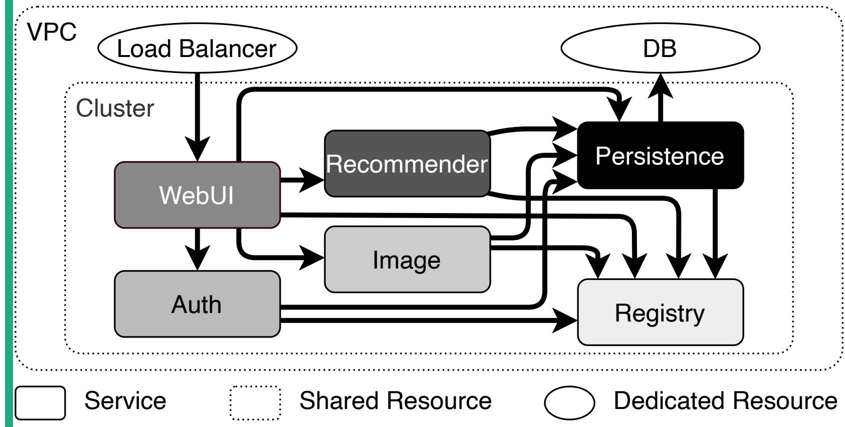




TeaStore services and dependencies.

Decentralized Organizations: Really Independent Operations?

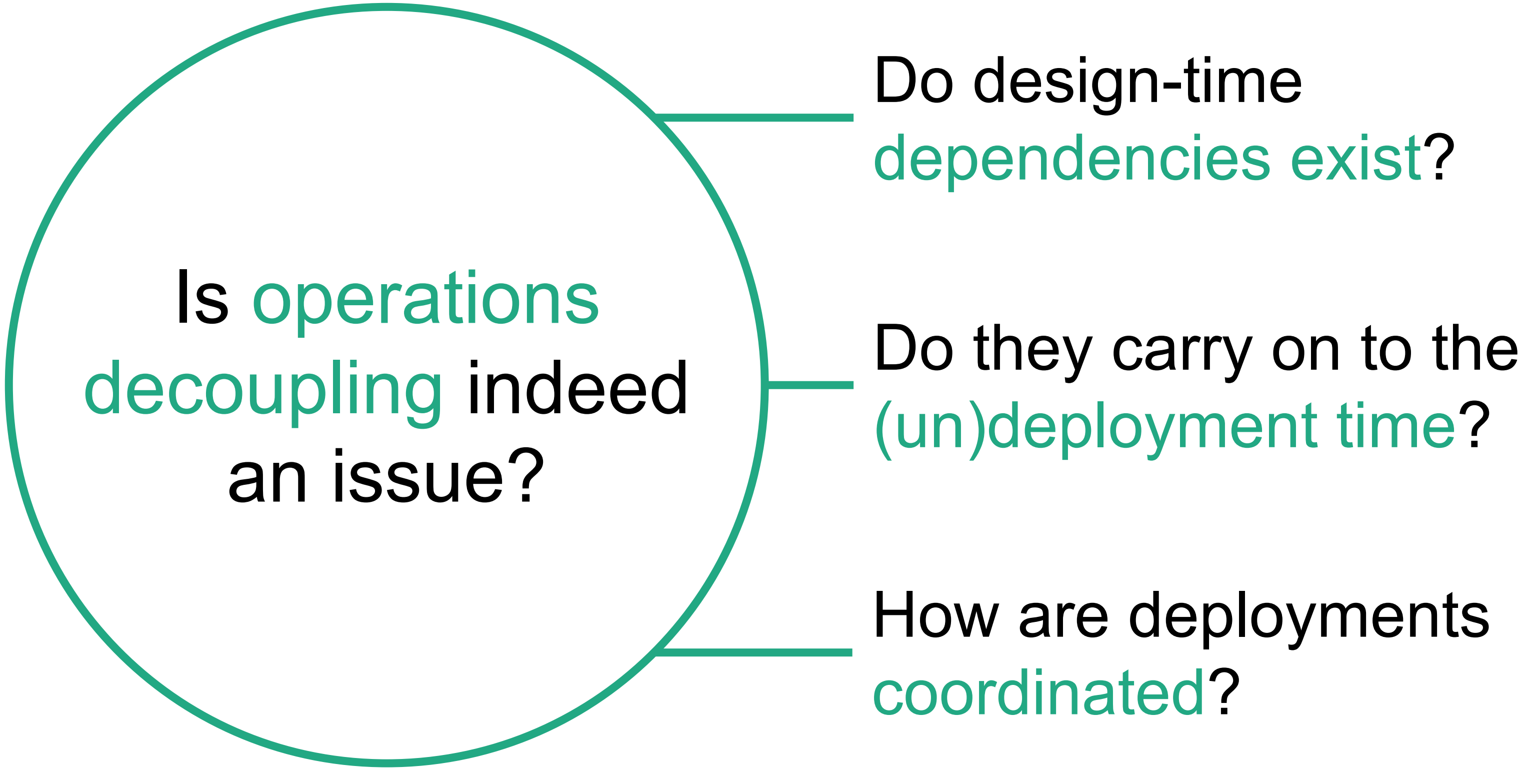




TeaStore services and dependencies.

Dependencies in DevOps Survey

Decentralized Organizations: Really Independent Operations?



Is operations decoupling indeed an issue?

Do design-time dependencies exist?

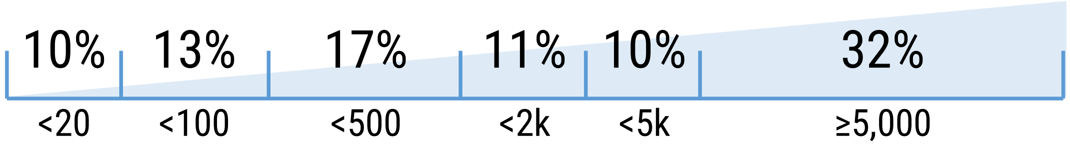
Do they carry on to the (un)deployment time?

How are deployments coordinated?

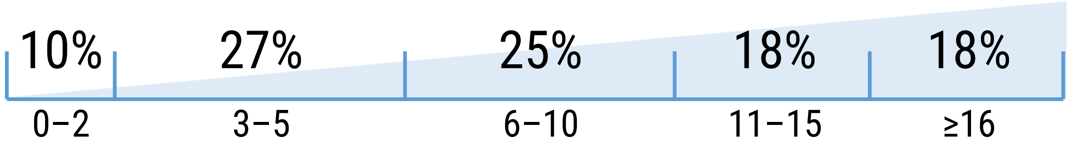
Dependencies in DevOps Survey 2021

134 IT professionals from various background.

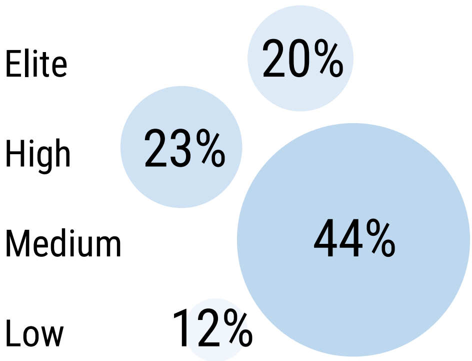
Number of Employees



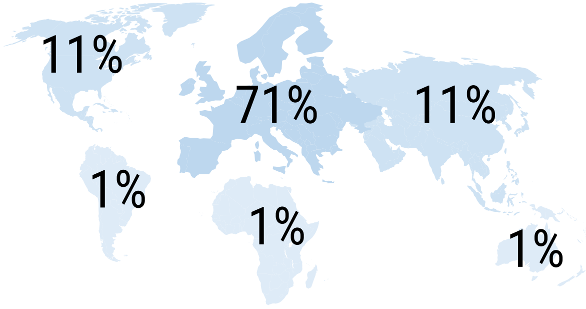
Years of Experience



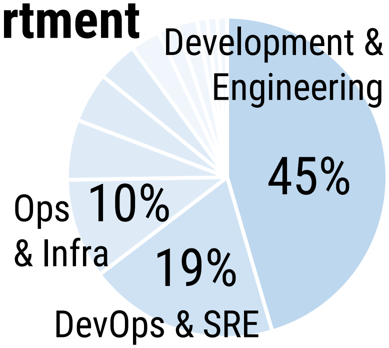
SDO Performance



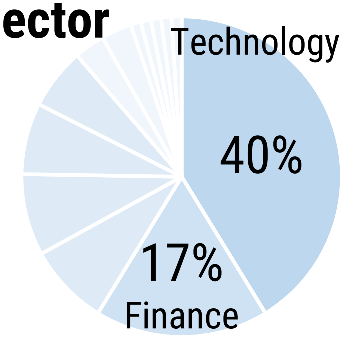
Location



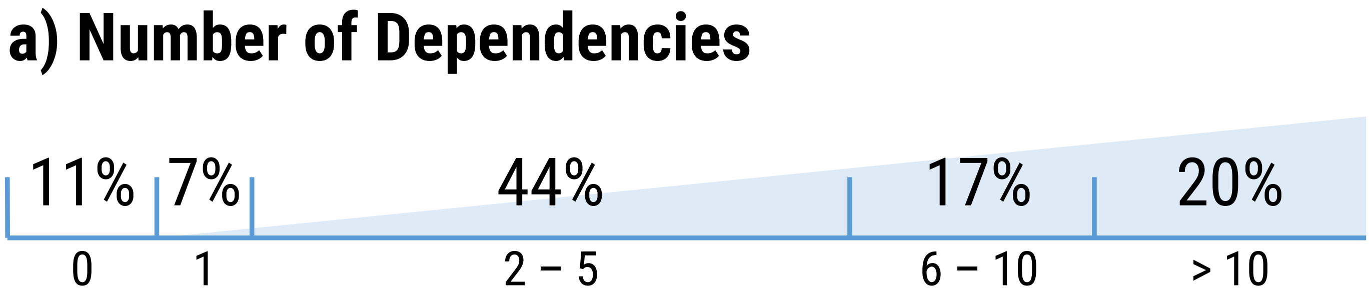
Department



Industry Sector



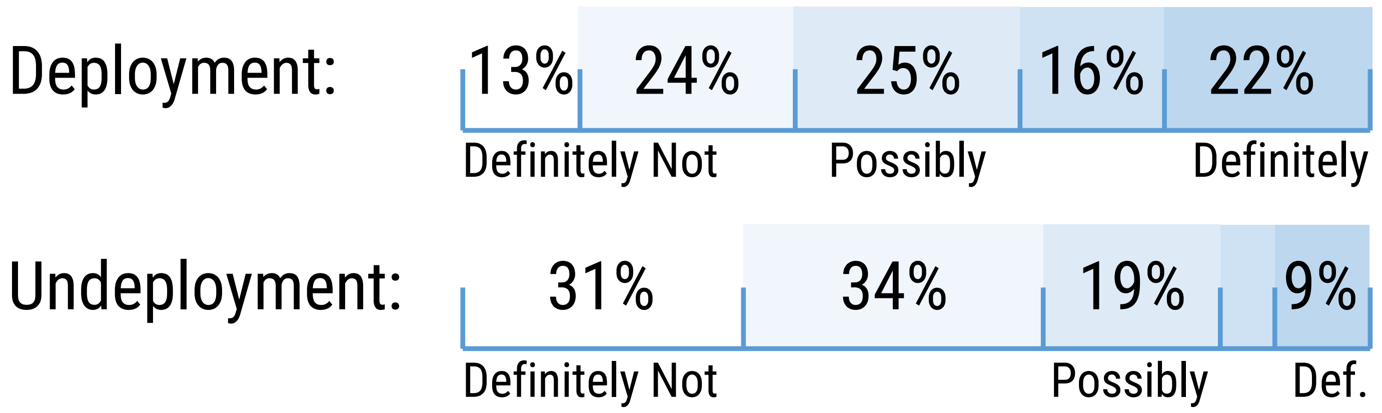
Dependencies in DevOps Survey 2021



Most applications depend on other applications.

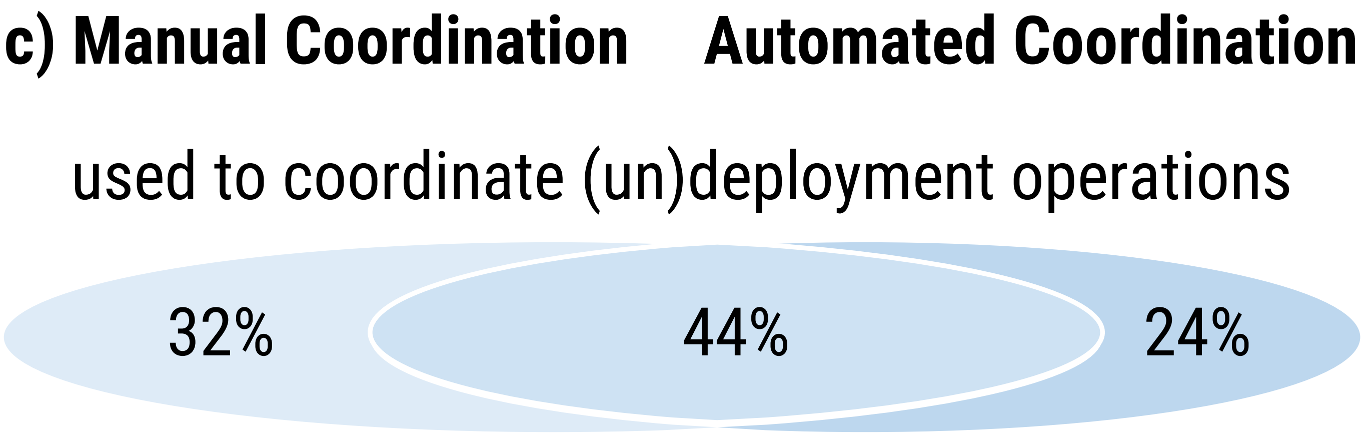
Dependencies in DevOps Survey 2021

b) Dependencies Constrain the Order of …



Dependencies constrain the order of (un)deployments.

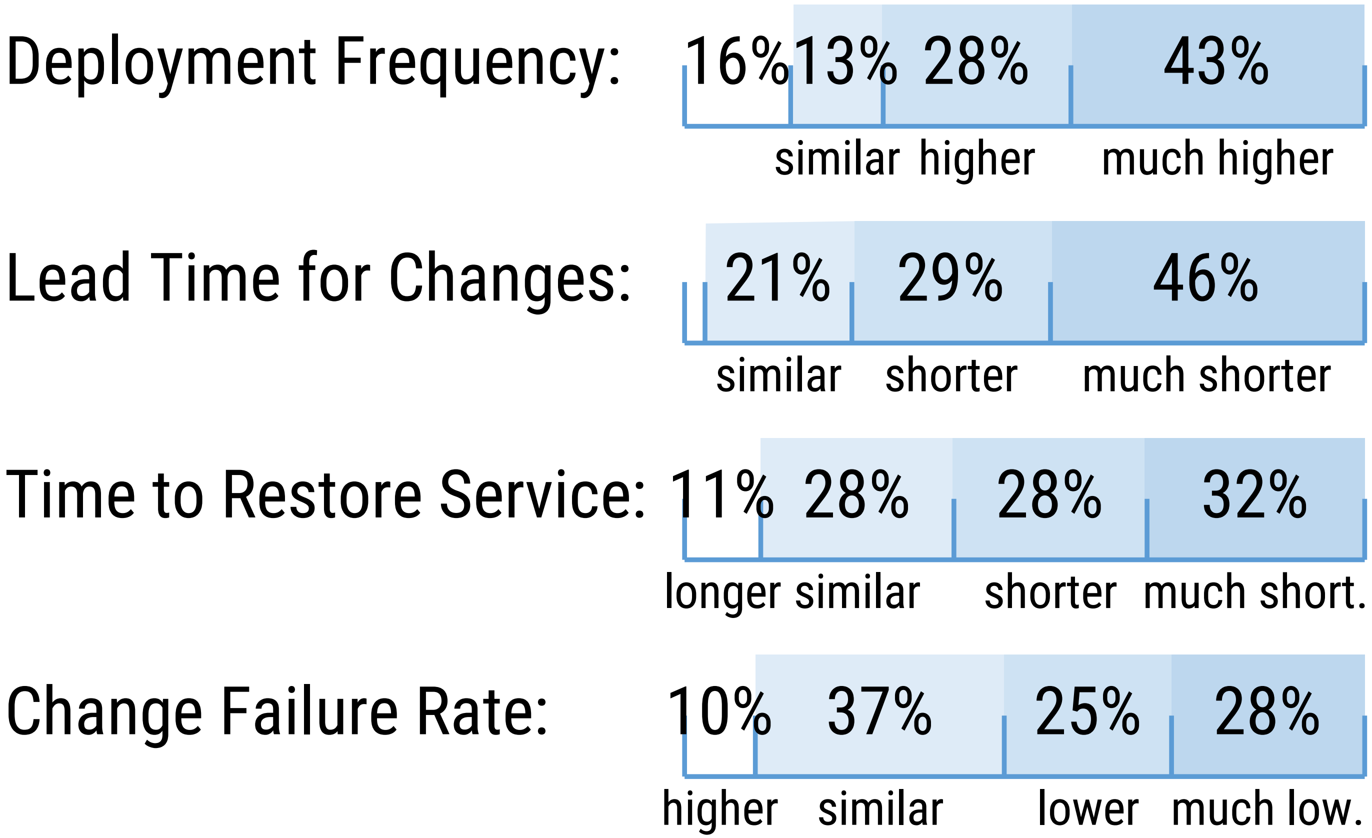
Dependencies in DevOps Survey 2021



Most organizations rely on manual coordination.

Dependencies in DevOps Survey 2021

d) Automated vs. Manual Coordination Promises



Automation promises better SDO performance.

Dependencies in DevOps Survey 2021

Most applications depend on other applications.

Dependencies constrain the order of (un)deployments.

Most organizations rely on manual coordination.

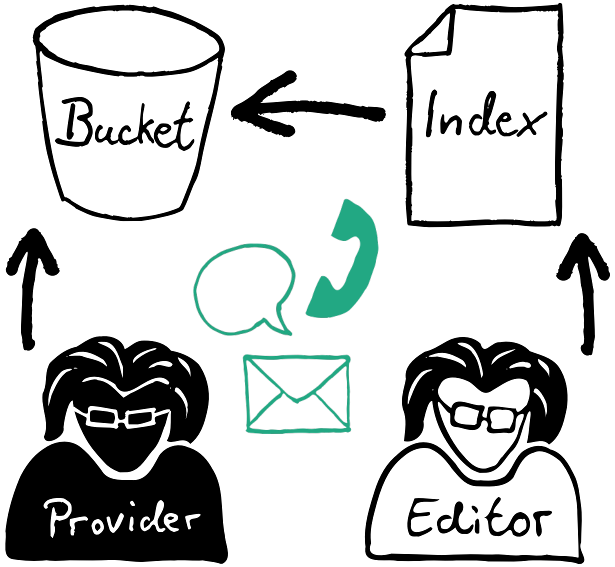
Automation promises better SDO performance.

❗ Automated solution for deployment coordination needed ❗

What is lacking today?

Deployment Coordination Today

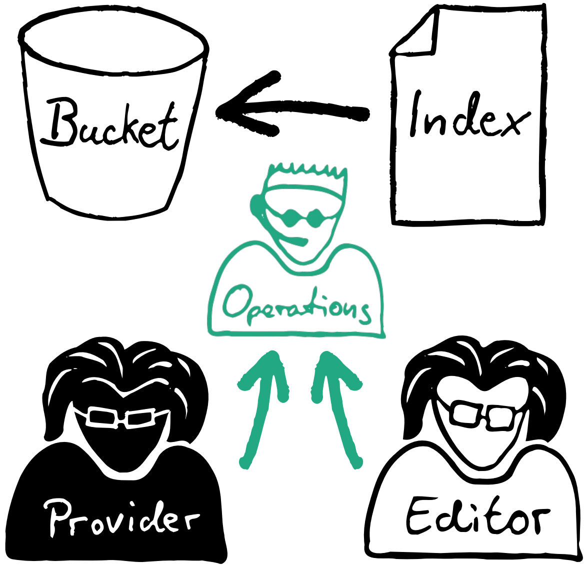
Manual Coordination



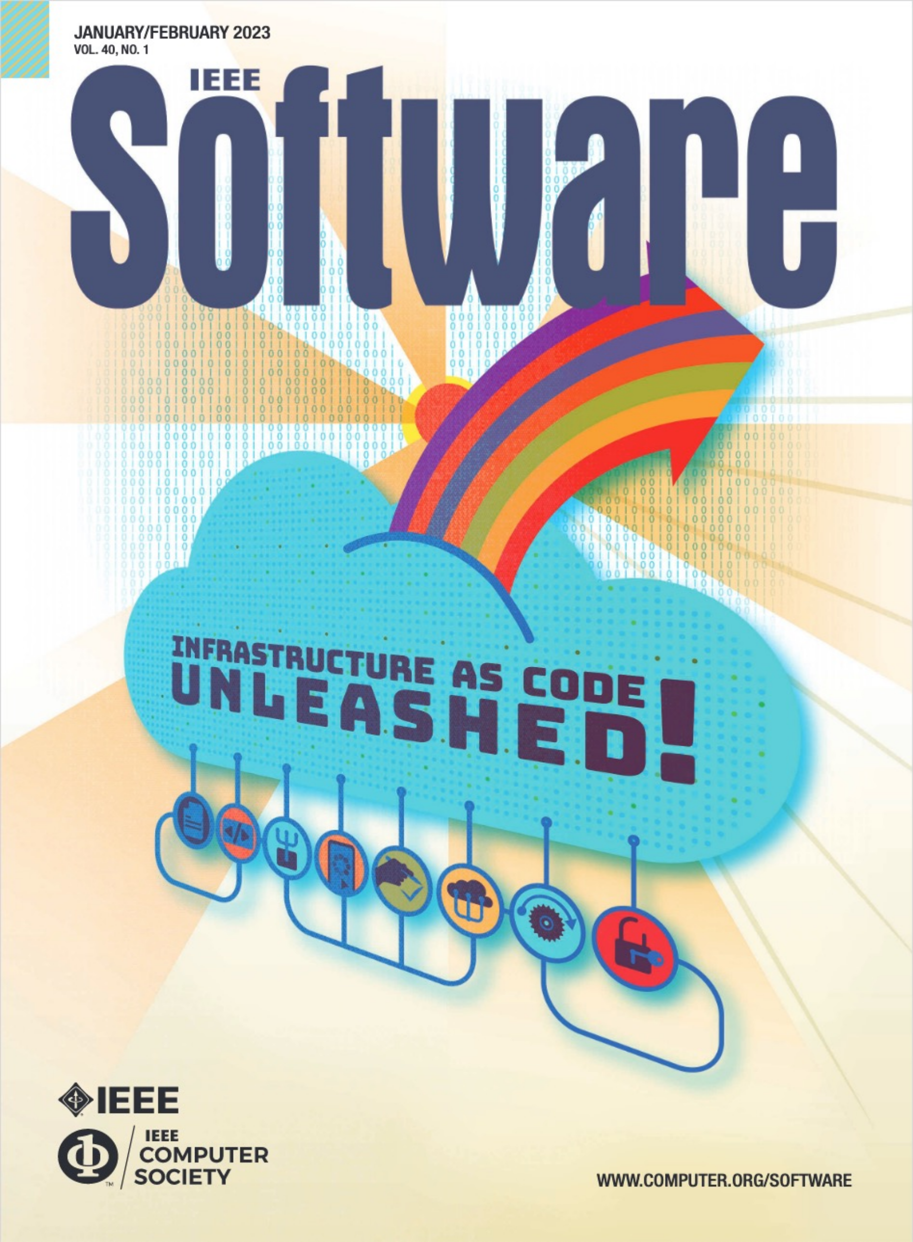
Slow, unreliable, synchronization, …

Decentralized Automation

Centralization



Limited independence, …



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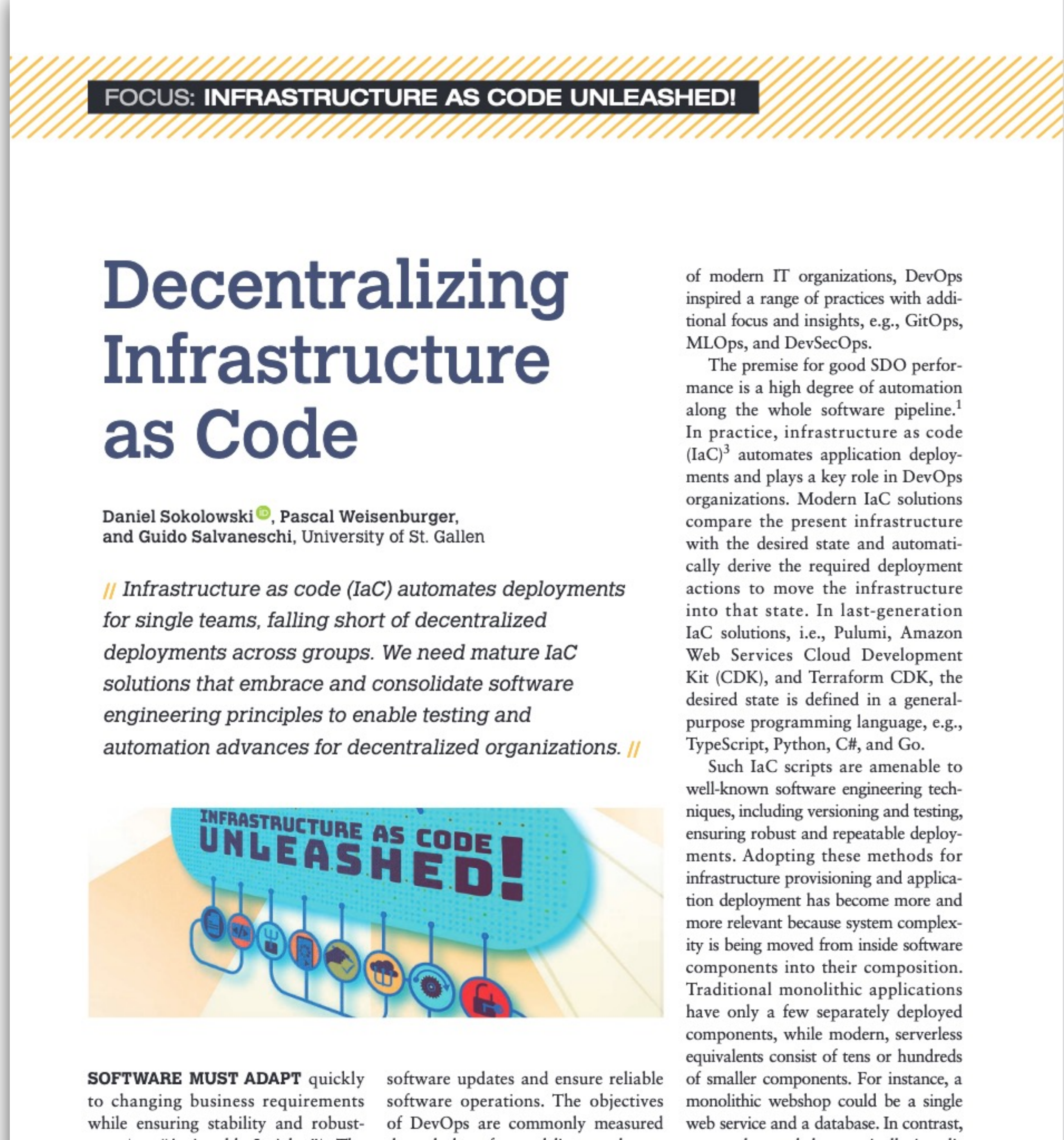


Decentralizing Infrastructure as Code

Daniel Sokolowski, Pascal Weisenburger, and Guido Salvaneschi, University of St. Gallen

// *Infrastructure as code (IaC) automates deployments for single teams, falling short of decentralized deployments across groups. We need mature IaC solutions that embrace and consolidate software engineering principles to enable testing and automation advances for decentralized organizations.* //

SOFTWARE MUST ADAPT quickly to changing business requirements while ensuring stability and robust-

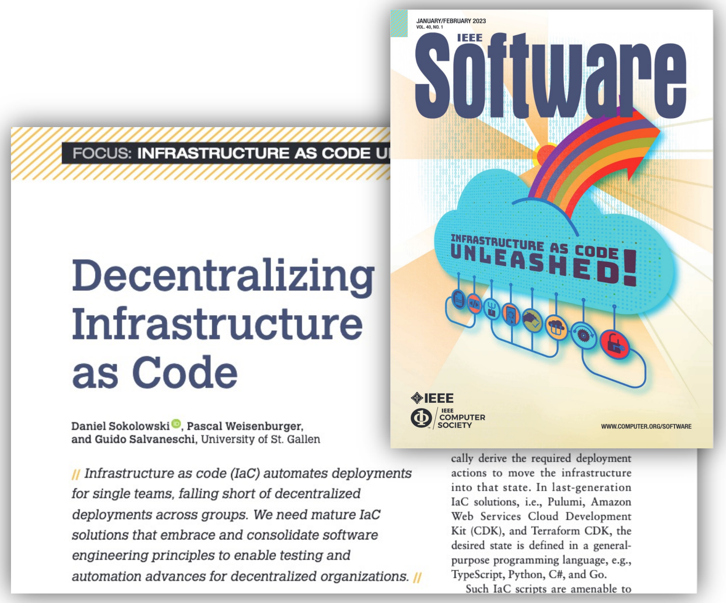
software updates and ensure reliable software operations. The objectives of DevOps are commonly measured

of modern IT organizations, DevOps inspired a range of practices with additional focus and insights, e.g., GitOps, MLOps, and DevSecOps.

The premise for good SDO performance is a high degree of automation along the whole software pipeline.[1] In practice, infrastructure as code (IaC)[3] automates application deployments and plays a key role in DevOps organizations. Modern IaC solutions compare the present infrastructure with the desired state and automatically derive the required deployment actions to move the infrastructure into that state. In last-generation IaC solutions, i.e., Pulumi, Amazon Web Services Cloud Development Kit (CDK), and Terraform CDK, the desired state is defined in a general-purpose programming language, e.g., TypeScript, Python, C#, and Go.

Such IaC scripts are amenable to well-known software engineering techniques, including versioning and testing, ensuring robust and repeatable deployments. Adopting these methods for infrastructure provisioning and application deployment has become more and more relevant because system complexity is being moved from inside software components into their composition. Traditional monolithic applications have only a few separately deployed components, while modern, serverless equivalents consist of tens or hundreds of smaller components. For instance, a monolithic webshop could be a single web service and a database. In contrast,

Call to Action



FOCUS: INFRASTRUCTURE AS CODE U

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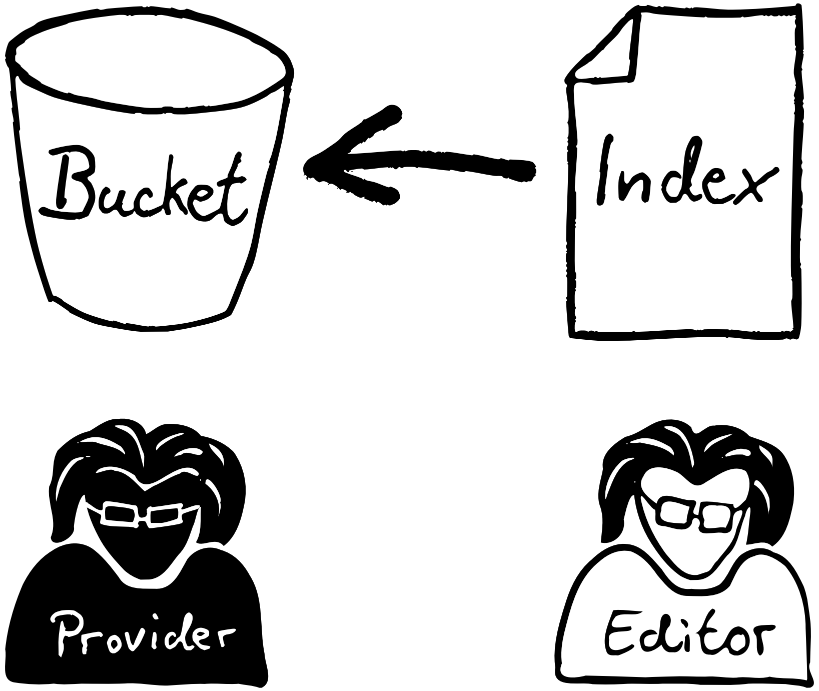
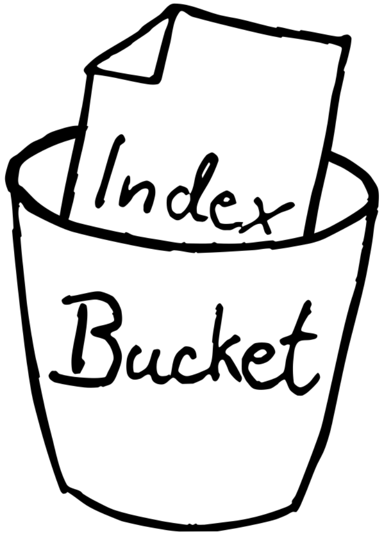
❗ We must improve the decentralized automation of operations ❗

Example: Simple Website

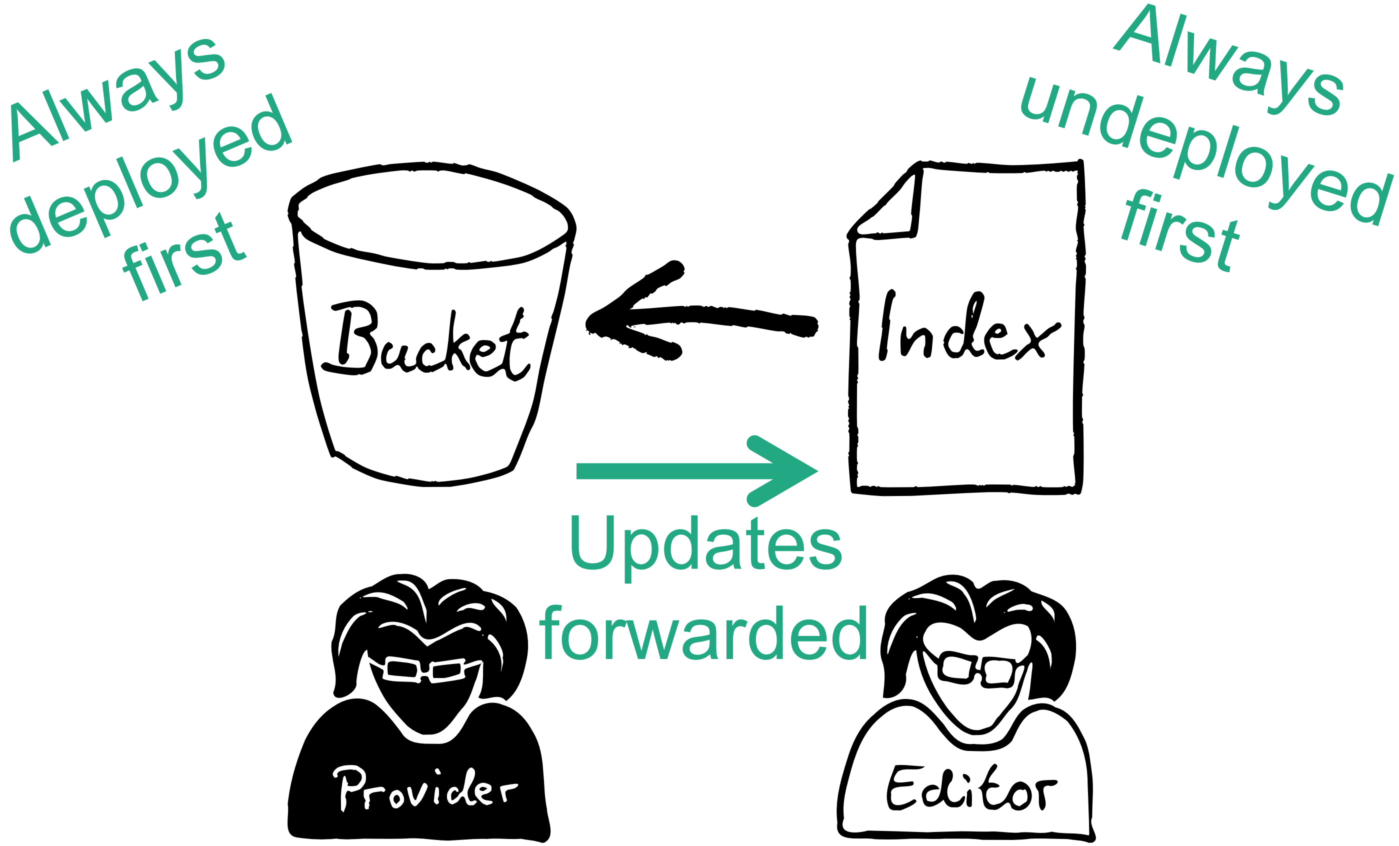
Resource Graph





Deployment

Use Cases for Deployment Coordination

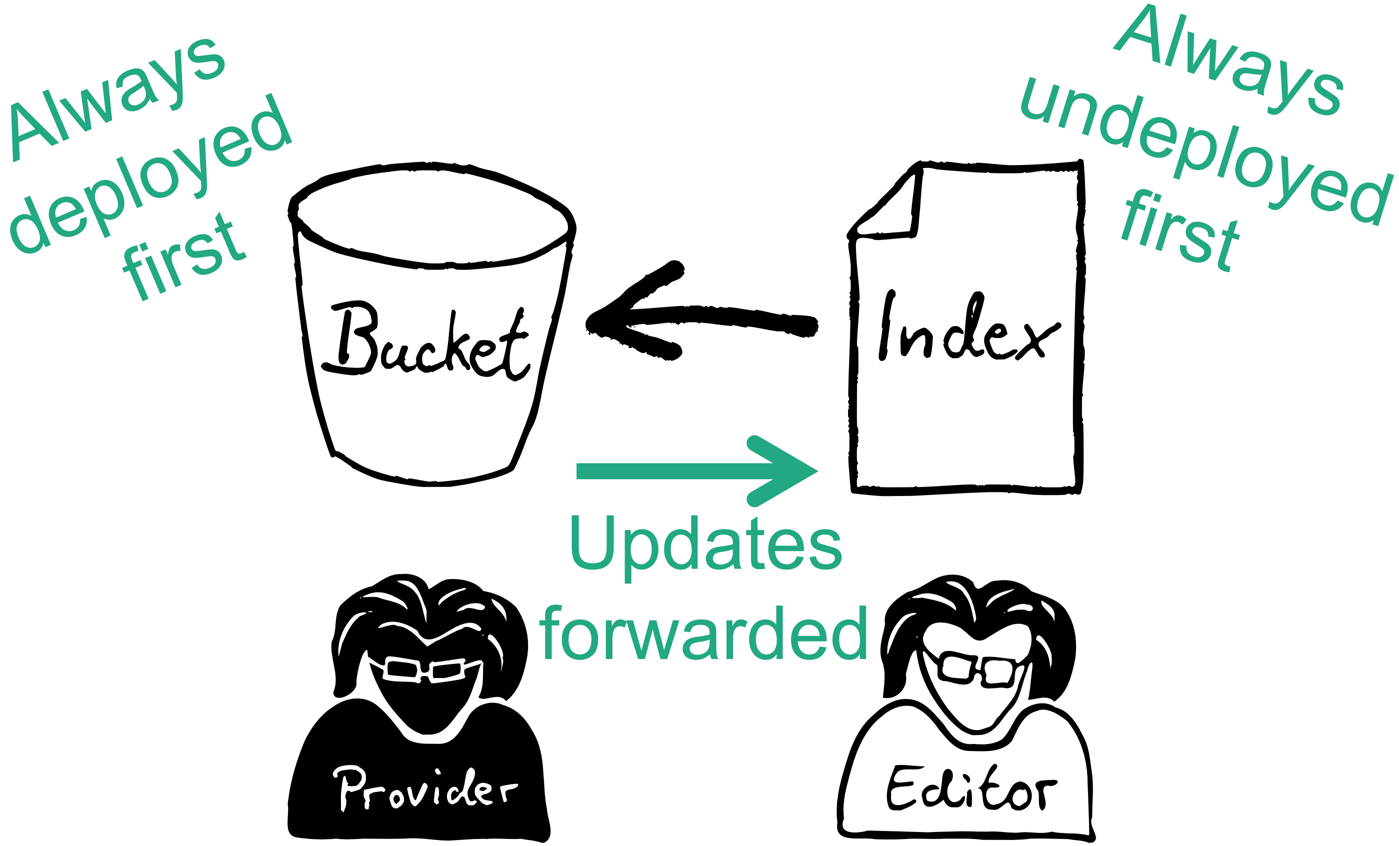


1. Asynchronous Deployment

2. Safe Undeployment

3. Reactive Updates

The Missing Ingredients 👨‍🍳



Always deployed first

Always undeployed first

Updates forwarded

Strong Interfaces

Decoupled Operations

Deployment Coordination with μs [mju:z]

Decentralized Deployment Coordination with µs

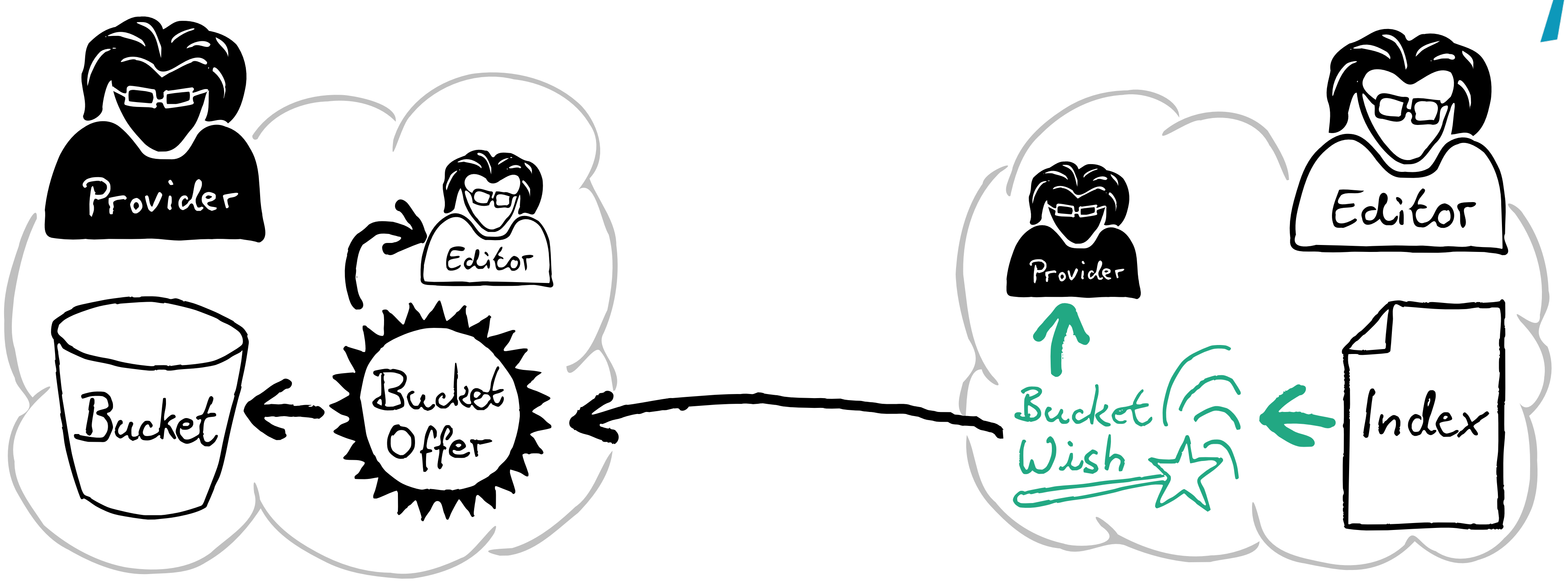
µs extends **Pulumi** TypeScript with:

1. Strong interfaces. Deployments define explicit Offers and Wishes.

2. Decoupled operations. µs deployments are long-running processes.

https://mjuz.rocks

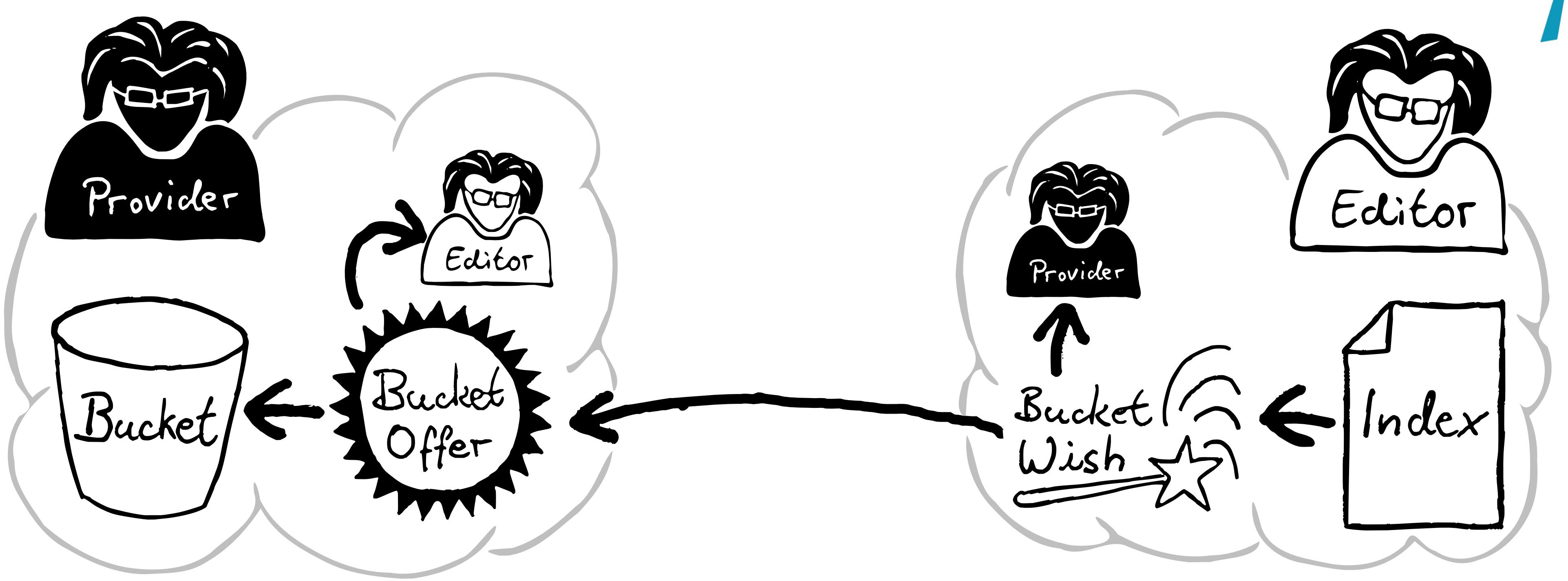
Decentralized Deployment Coordination with µs [mju:z]



```
const editor = new RemoteConnection("editor");
const bucket = new s3.Bucket("website", {
   /* … */
});
new Offer(editor, "bucket", bucket);
```

```
const provider = new RemoteConnection("provider");
const wish = new Wish<aws.s3.Bucket>(provider, "bucket");
new s3.BucketObject("index", {
    bucket: wish.offer, /* … */
});
```

Decentralized Deployment Coordination with µs [mju:z]



µs [mju:z] runtime enables and ensures:

1. Asynchronous Deployment 2. Safe Undeployment 3. Reactive Updates

Evaluation: Effectiveness

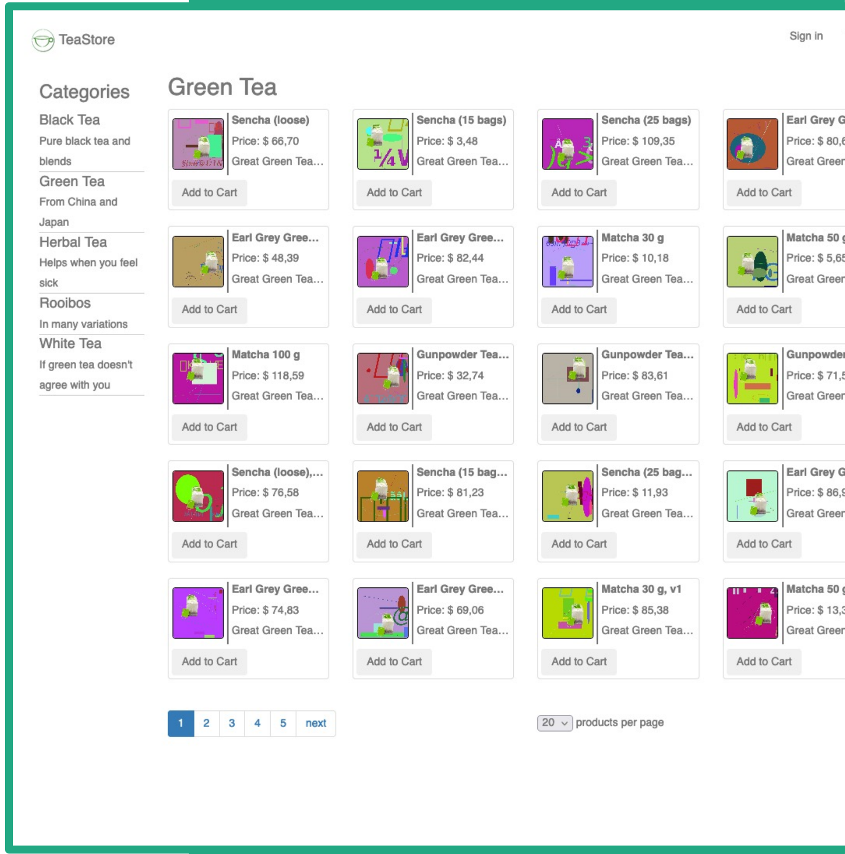
Re-implemented TeaStore Deployment.

Size of TeaStore deployments (SLOC).

Team	Auth	Image	Pers.	Recomm.	Registry	WebUI	Total
μS_ℓ	61	63	88	63	75	144	494
Pulumi	53	56	80	56	59	129	433
CDK	47	48	91	47	59	73	365

Negligible coding overhead.

µs is the only solution that automates the deployment coordination.



TeaStore

Sign in

Categories

Black Tea
Pure black tea and blends

Green Tea
From China and Japan

Herbal Tea
Helps when you feel sick

Rooibos
In many variations

White Tea
If green tea doesn't agree with you

Green Tea

Sencha (loose)
Price: $ 66,70
Great Green Tea...
Add to Cart

Sencha (15 bags)
Price: $ 3,48
Great Green Tea...
Add to Cart

Sencha (25 bags)
Price: $ 109,35
Great Green Tea...
Add to Cart

Earl Grey G
Price: $ 80,6
Great Green
Add to Cart

Earl Grey Gree...
Price: $ 48,39
Great Green Tea...
Add to Cart

Earl Grey Gree...
Price: $ 82,44
Great Green Tea...
Add to Cart

Matcha 30 g
Price: $ 10,18
Great Green Tea...
Add to Cart

Matcha 50 g
Price: $ 5,65
Great Green
Add to Cart

Matcha 100 g
Price: $ 118,59
Great Green Tea...
Add to Cart

Gunpowder Tea...
Price: $ 32,74
Great Green Tea...
Add to Cart

Gunpowder Tea...
Price: $ 83,61
Great Green Tea...
Add to Cart

Gunpowder
Price: $ 71,5
Great Green
Add to Cart

Sencha (loose),...
Price: $ 76,58
Great Green Tea...
Add to Cart

Sencha (15 bag...
Price: $ 81,23
Great Green Tea...
Add to Cart

Sencha (25 bag...
Price: $ 11,93
Great Green Tea...
Add to Cart

Earl Grey G
Price: $ 86,9
Great Green
Add to Cart

Earl Grey Gree...
Price: $ 74,83
Great Green Tea...
Add to Cart

Earl Grey Gree...
Price: $ 69,06
Great Green Tea...
Add to Cart

Matcha 30 g, v1
Price: $ 85,38
Great Green Tea...
Add to Cart

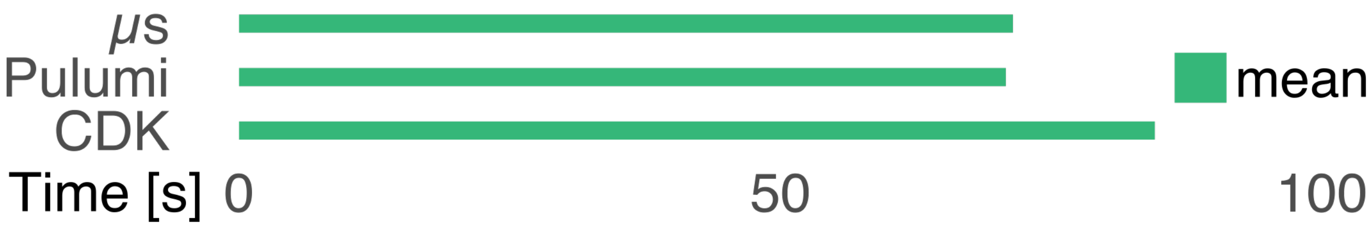
Matcha 50 g
Price: $ 13,3
Great Green
Add to Cart

1 2 3 4 5 next

20 products per page

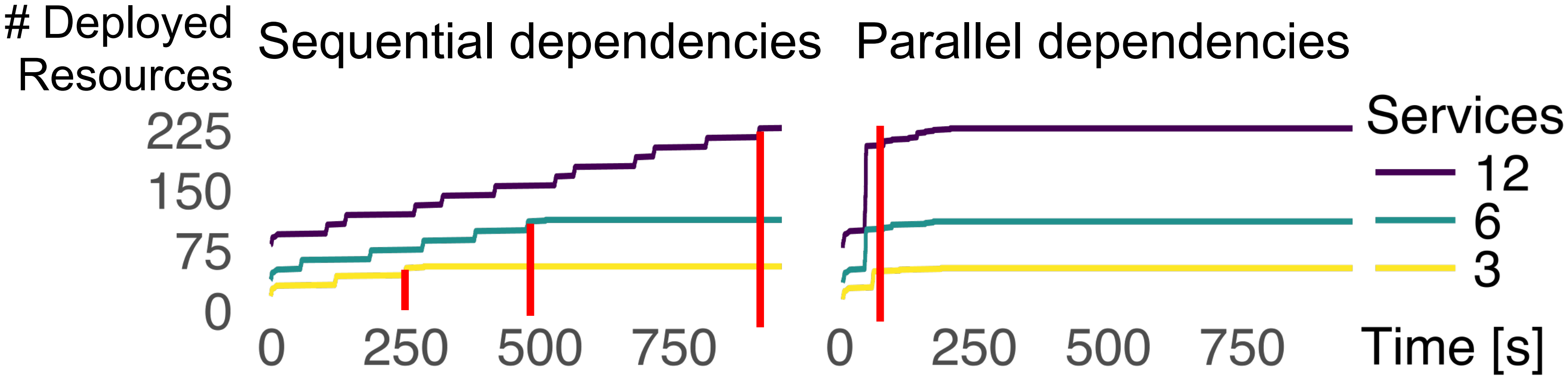
The TeaStore

Evaluation: Performance



Single service deployment duration.

Deployment time comparable to Pulumi, faster than CDK.



Deployment dependency scaling behavior.

Introduces no significant delay.

Evaluation: Applicability

64 public Pulumi TypeScript deployments using StackReferences on GitHub.

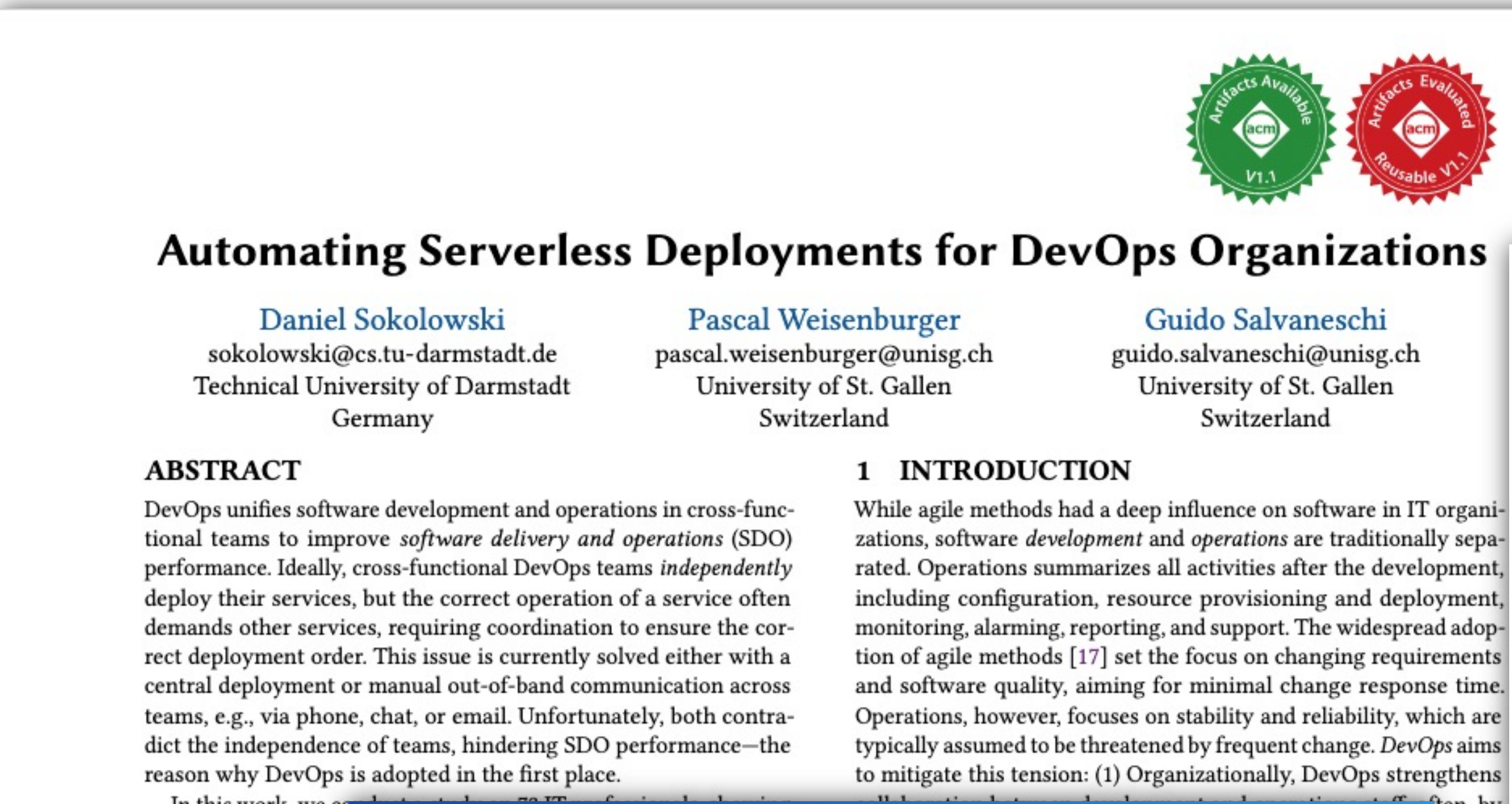
Migrated to support automated coordination:

1. Defined offers for supplied resources.
2. Replaced StackReferences by wishes.

Fully automated as AST transformation.

DALL·E 2022-10-23 21.41.46 - assembly line with many robot arms working on parts, digital art

ESEC/FSE 2021



Artifacts Available V1.1

Artifacts Evaluated Reusable V1.1

Automating Serverless Deployments for DevOps Organizations

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University of St. Gallen
Switzerland

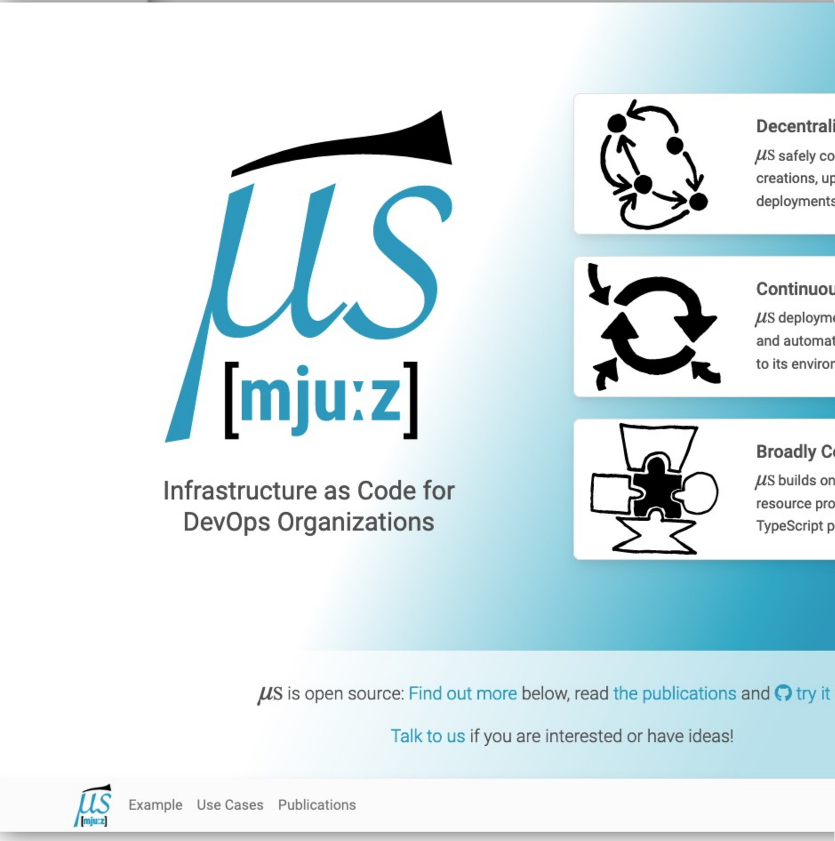
ABSTRACT

DevOps unifies software development and operations in cross-functional teams to improve *software delivery and operations* (SDO) performance. Ideally, cross-functional DevOps teams *independently* deploy their services, but the correct operation of a service often demands other services, requiring coordination to ensure the correct deployment order. This issue is currently solved either with a central deployment or manual out-of-band communication across teams, e.g., via phone, chat, or email. Unfortunately, both contradict the independence of teams, hindering SDO performance—the reason why DevOps is adopted in the first place.

In this work, we co
that, in practice, the
deployments even i
fully automated app
μS ([mju:z] *"muse"*)

1 INTRODUCTION

While agile methods had a deep influence on software in IT organizations, software *development* and *operations* are traditionally separated. Operations summarizes all activities after the development, including configuration, resource provisioning and deployment, monitoring, alarming, reporting, and support. The widespread adoption of agile methods [17] set the focus on changing requirements and software quality, aiming for minimal change response time. Operations, however, focuses on stability and reliability, which are typically assumed to be threatened by frequent change. *DevOps* aims to mitigate this tension: (1) Organizationally, DevOps strengthens
ften, by
nically,
hieving
ad to a
change



μS [mju:z]

Infrastructure as Code for DevOps Organizations

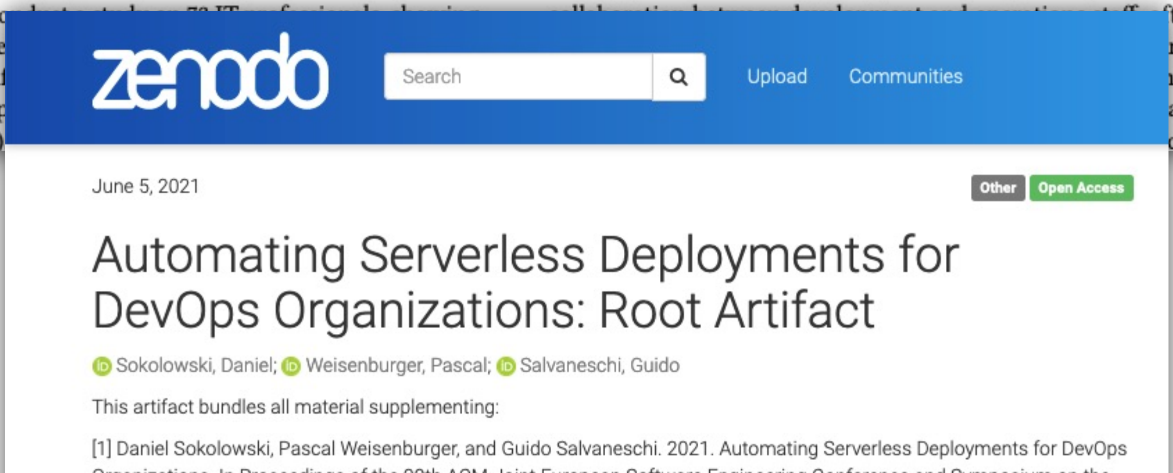
Decentrali
μS safely co
creations, up
deployments

Continuou
μS deployme
and automat
to its enviror

Broadly C
μS builds on
resource pro
TypeScript p

μS is open source: Find out more below, read the publications and try it

Talk to us if you are interested or have ideas!



June 5, 2021

Other Open Access

Automating Serverless Deployments for DevOps Organizations: Root Artifact

Sokolowski, Daniel; Weisenburger, Pascal; Salvaneschi, Guido

This artifact bundles all material supplementing:

[1] Daniel Sokolowski, Pascal Weisenburger, and Guido Salvaneschi. 2021. Automating Serverless Deployments for DevOps

GitHub

https://mjuz.rocks

From Deployment Safety to Transaction Safety

µs
[mju:z]

Dependency Availability

An application is only deployed if its dependencies are deployed.

→ Applications can be undeployed if no deployed application depends on them.

Safe DSU

Version Consistency

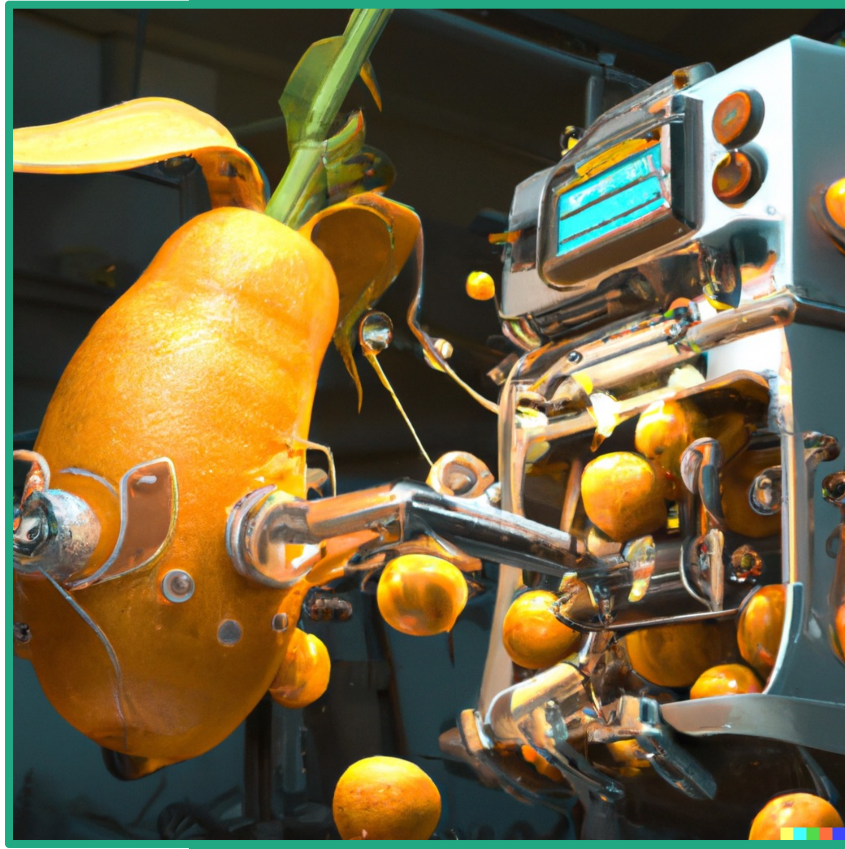
A transaction uses at most one version of an application.

→ Applications can be undeployed if no running transaction they participated in needs them again.

Safe Dynamic Software Updating for Decentralized Organizations

Safe Dynamic Software Updating

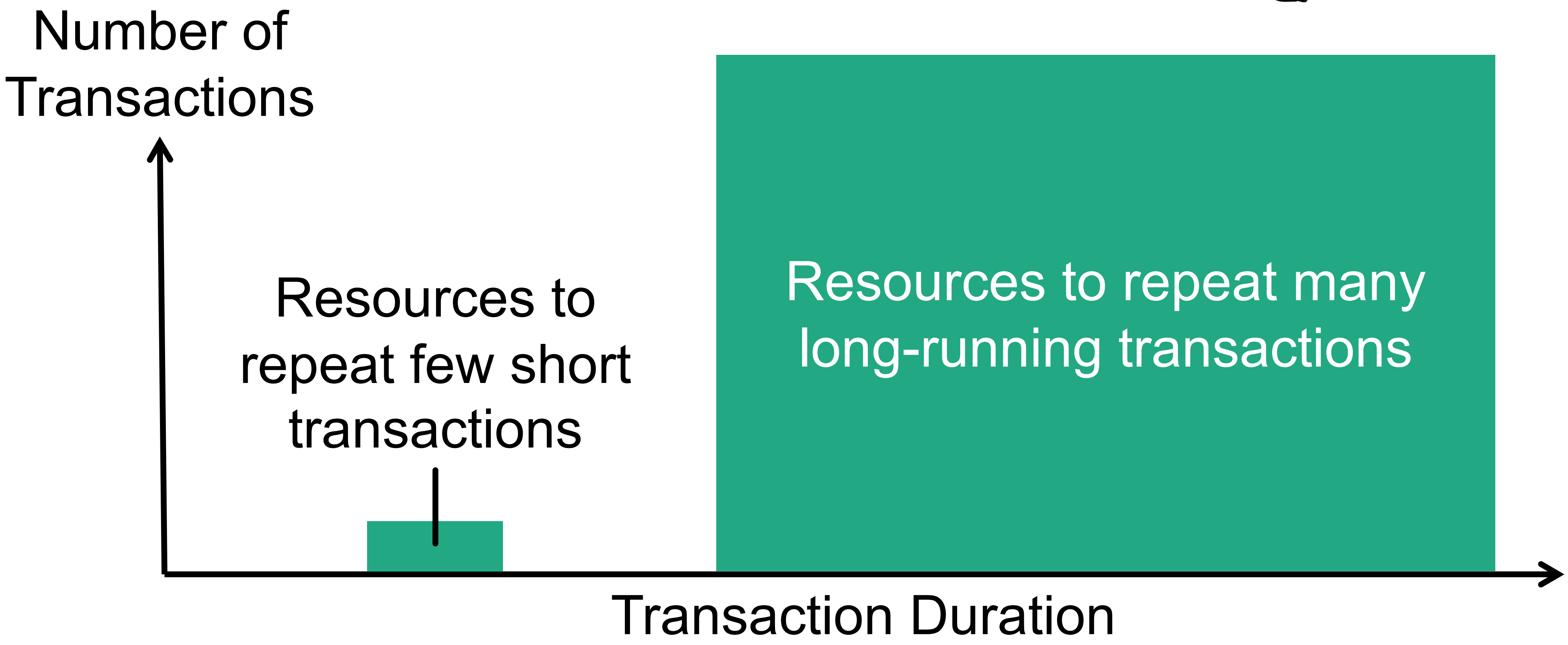
When is it safe to update
a component in a distributed system
without breaking a distributed transaction?



DALL·E 2022-10-23 21.35.08 - a machine transforms oranges to bananas, digital art

Repeating Broken Long-running Transactions

Workflows



Number of Transactions

Resources to repeat few short transactions

Resources to repeat many long-running transactions

Transaction Duration

ICSE 2022

2022 IEEE/ACM 44th International Conference on Software Engineering (ICSE)

Artifacts Evaluated Reusable V1.1

Artifacts Available V1.1

Change Is the Only Constant: Dynamic Updates for Workflows

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University of St. Gallen
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Guido Salvaneschi
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ABSTRACT

Software systems must be updated regularly to address changing requirements and urgent issues like security-related bugs. Traditionally, updates are performed by shutting down the system to replace certain components. In modern software organizations, updates are increasingly frequent—up to multiple times per day—hence, shutting down the entire system is unacceptable. *Safe* dynamic

1 INTROD

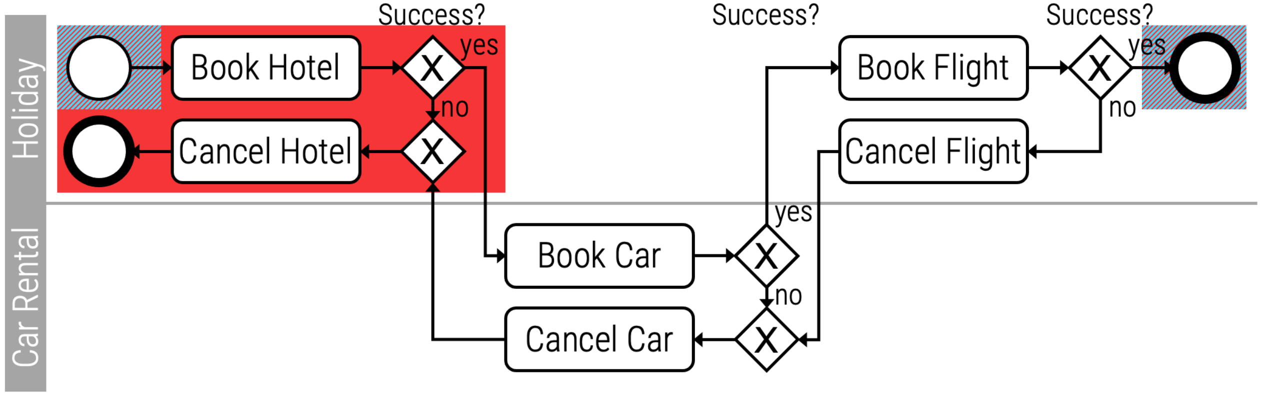
Updating long-
changing requi
timely manner.
development fo
requiring autor
system to preve

so-called *update condition*. It leverages
s the system topology and the progress

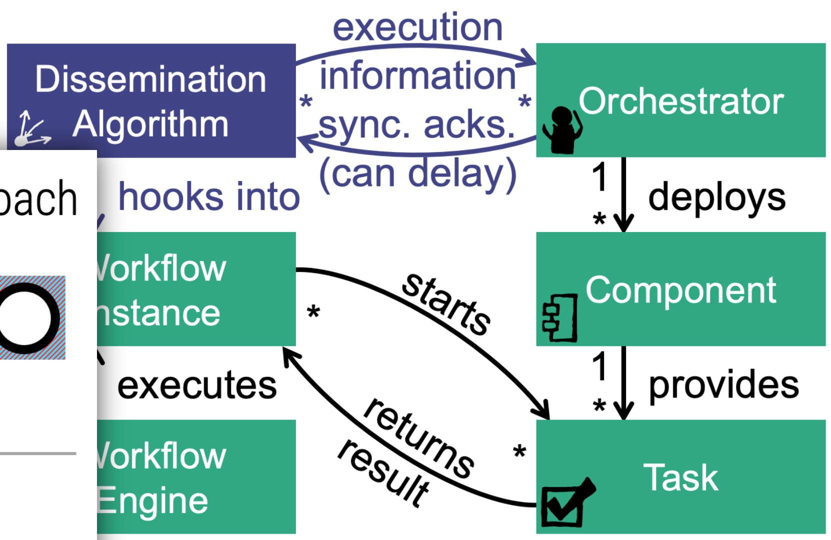
mplement long-running, frequent, and

Essential Safety

👑 Our Approach



Safe DSU for Workflows Setup

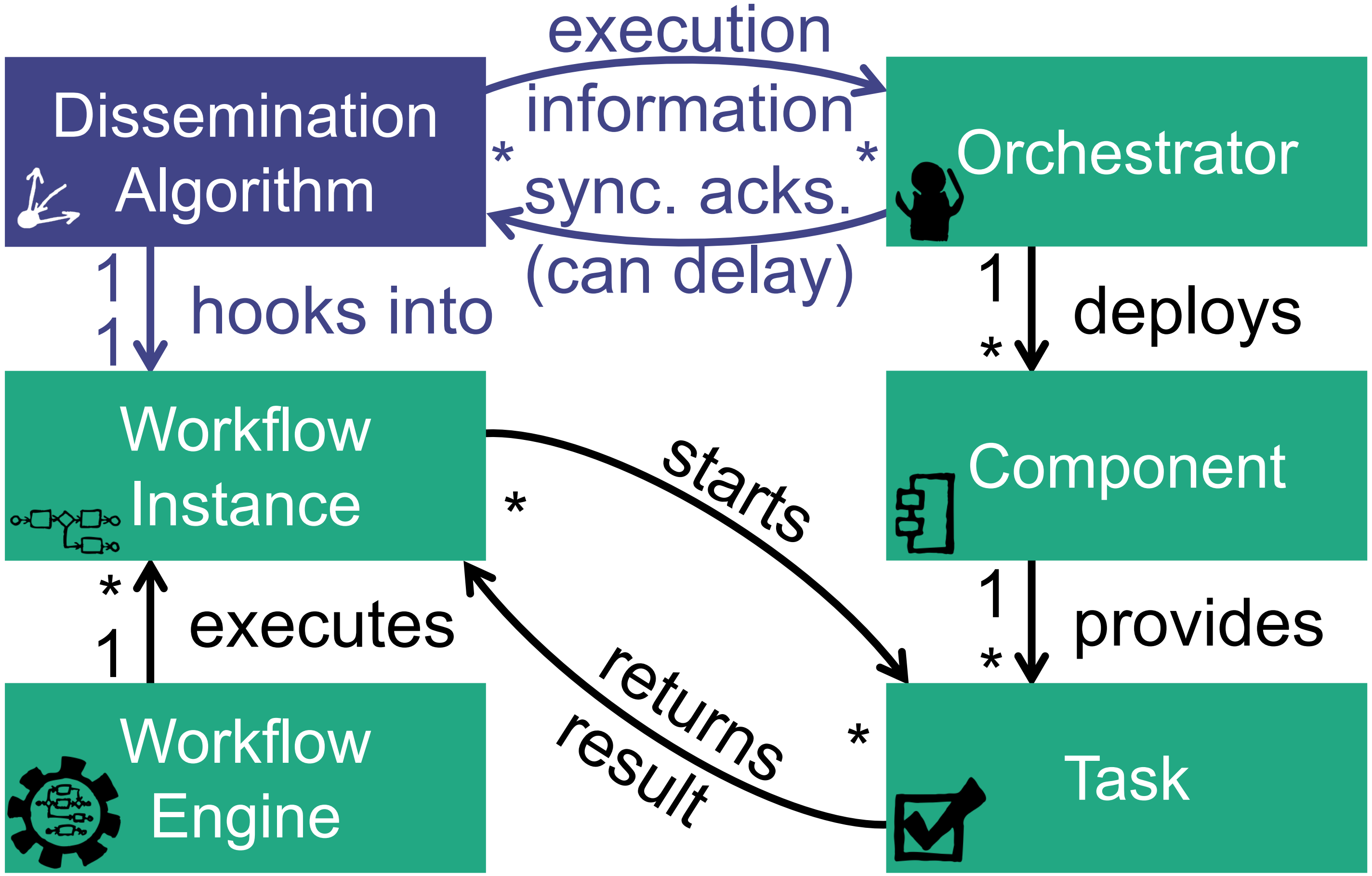


The dissemination algorithm mediates between workflow instance and the components' orchestrators.

It enables that orchestrators can:

1. identify safe update intervals.
2. delay workflow instances.

Safe DSU for Workflows Setup



The dissemination algorithm mediates between workflow instance and the components' orchestrators.

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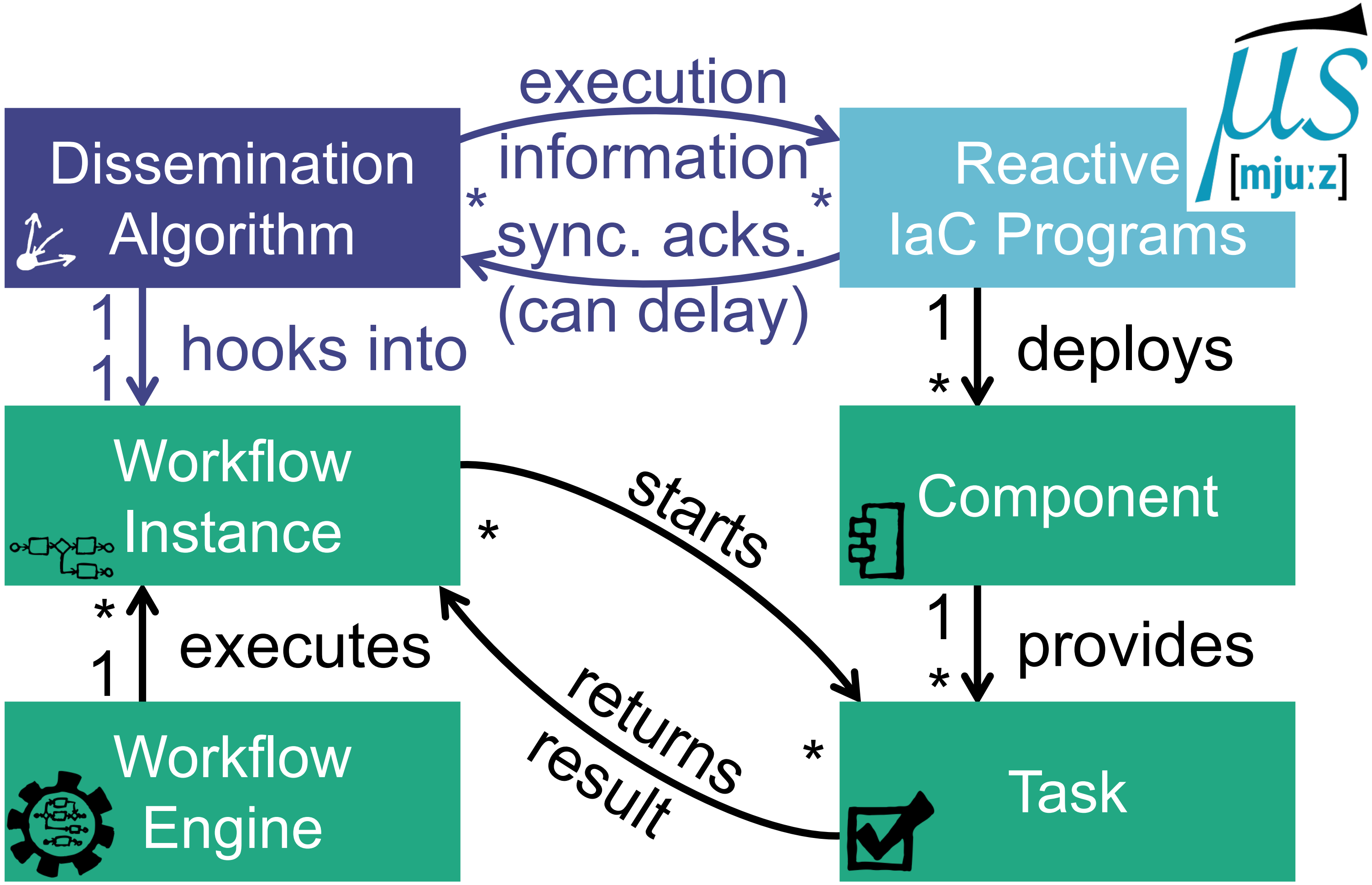
2. delay workflow instances.

Safe DSU for Workflows Setup



The dissemination algorithm mediates between workflow instance and the components' IaC programs.

It enables that IaC programs can:

1. identify safe update intervals.
2. delay workflow instances.

Decentralized Coordination for Reliable IaC Programs in Decentralized Organizations

Organizations need decentralized deployment coordination.

µs [mju:z] enables it through strong interfaces and decoupled operations.

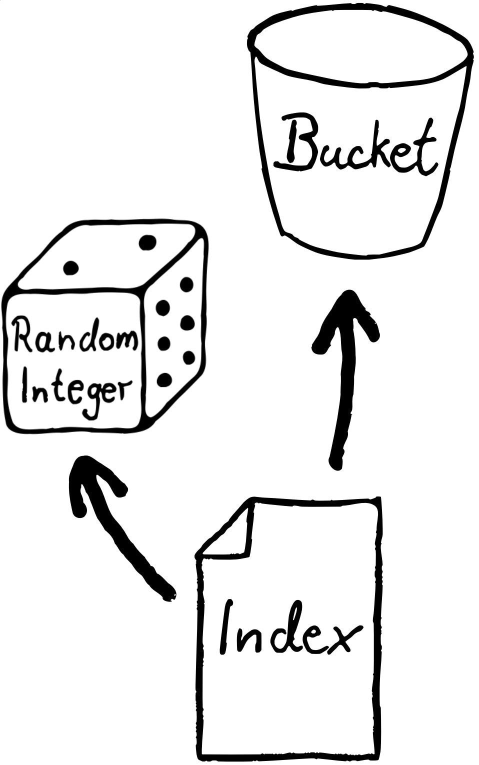
Beyond dependency availability: version consistency of workflows.

DALL·E 2023-12-10 14.15.39 - A distant view of a hiker, a small figure in the landscape, standing on a trail in the center of a vast valley. The hiker, in a purple jacket and carrying a backpack, is far away down the winding path, almost blending into the scenery. Surrounding the trail are expanses of lush green grass with bursts of red foliage. Towering mountains rise on both sides of the valley, and the sky is painted with a few soft clouds. The warm, golden sunlight bathes the valley, highlighting the serene and majestic atmosphere of the scene.

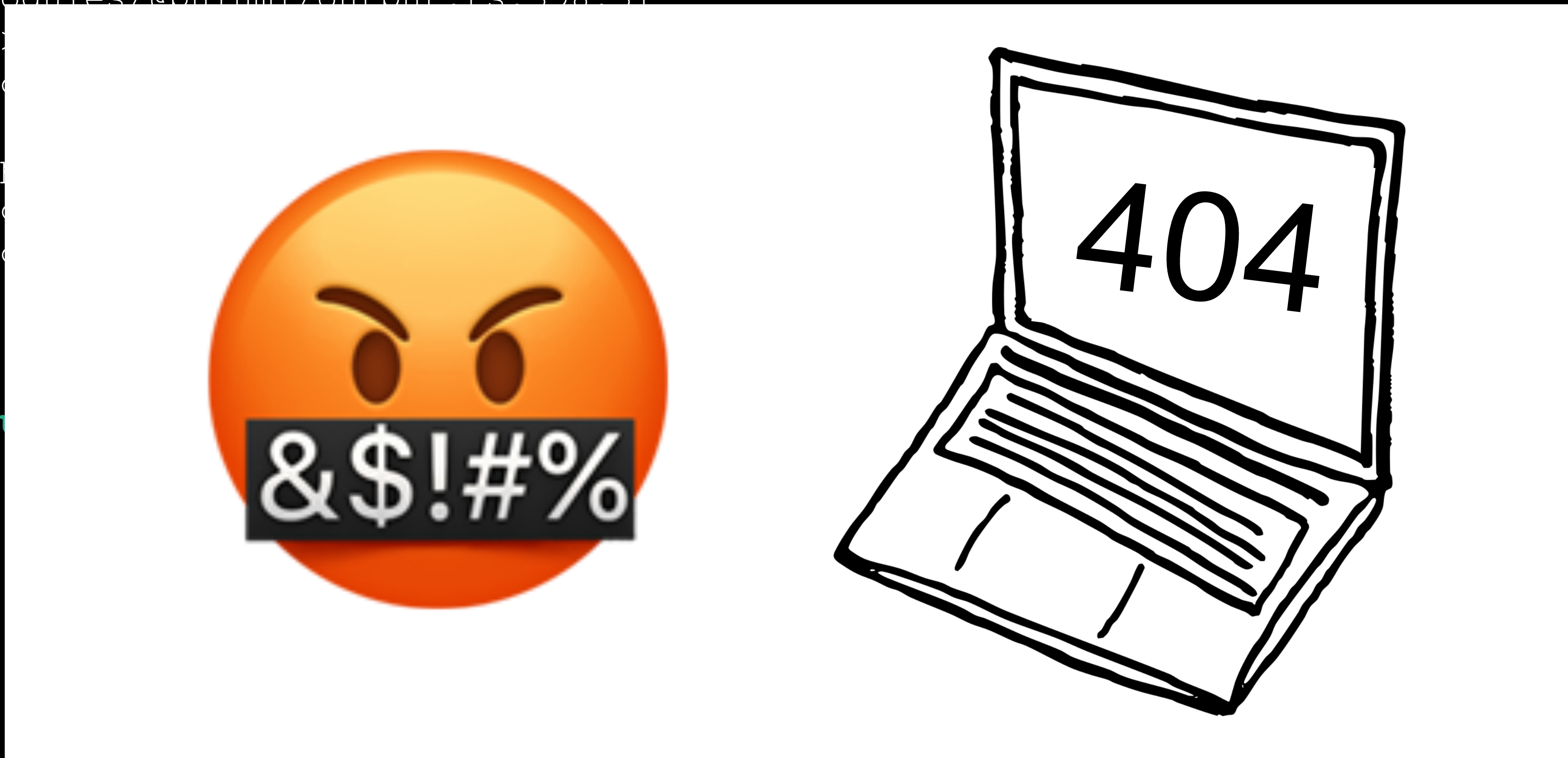
Testing IaC Programs

Example: Random Word Website

```
const words = ["software", "is", "great"]

const bucket = new s3.Bucket("website", { /* … */ });

const rng = new random.RandomInteger ("word-id", {
  min: 0, max: words.length
});

rng.result.apply((id) => {
  new s3.BucketObject("index", {
    bucket: bucket, /* … */
    content: /* … */ + words[id].toLowerCase()
  });
});

export const url = bucket.websiteEndpoint;
```



```
pulumi up -y --skip-preview
Updating (demo):
     Type                              Name                           Status                        Info
 +   pulumi:pulumi:Stack               random-word-webpage-demo
 +   ├─ aws:s3:Bucket                  website
 +   └─ random:index:RandomInteger     word-id

Diagnostics:
  pulumi:pulumi:Stack (random-word-webpage-demo):
    error: Running program 'random-word-webpage/index.ts' failed with an unhandled exception:
    TypeError: Cannot read properties of undefined (reading 'toLowerCase')
        at random-word-webpage/index.ts:12:52
        at random-word-webpage/node_modules/@pulumi/output.ts:398:31
        at Generator.next (<anonymous>
        at random-word-webpage/node_mo
        at new Promise (<anonymous>)
        at __awaiter (random-word-webp
        at applyHelperAsync (random-wo
        at random-word-webpage/node_mo
        at processTicksAndRejections

Outputs:
    url: "website-178809d.s3-website-

Resources:
    + 3 created

Duration: 7s
```



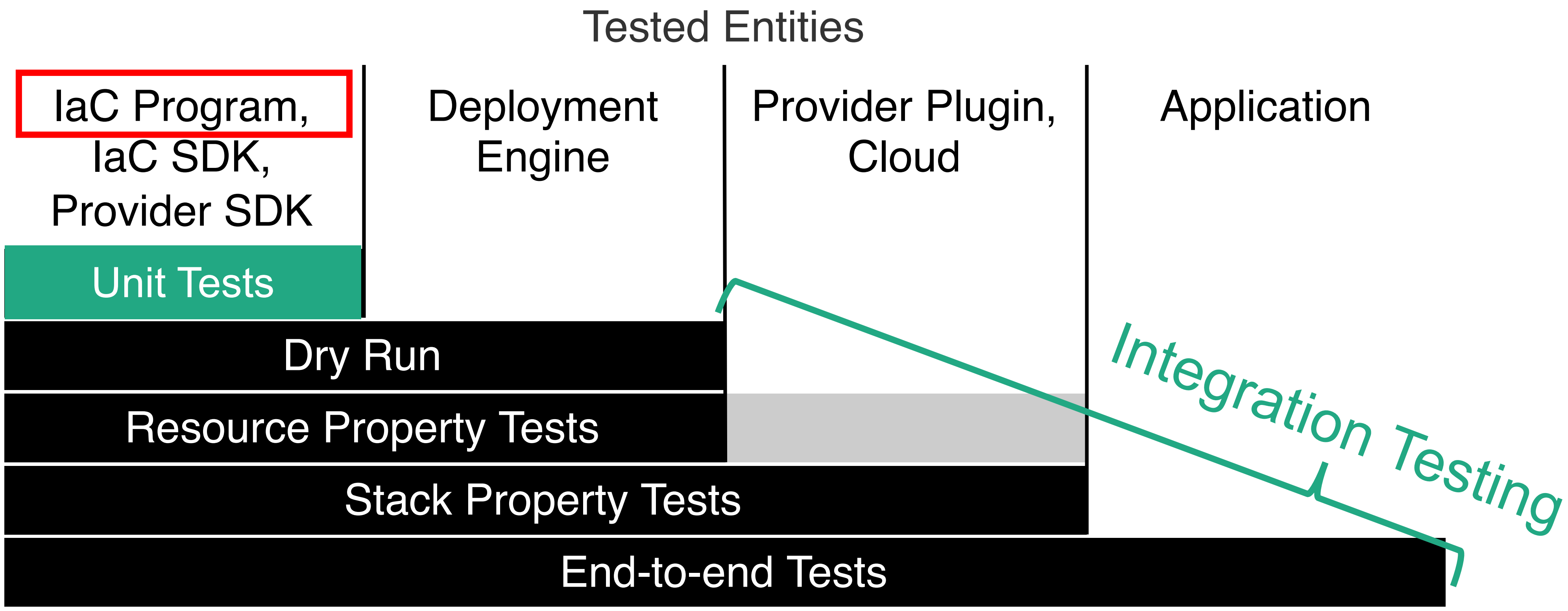
```
error: Running program 'random-word-webpage/index.ts' failed with an unhandle
TypeError: Cannot read properties of undefined (reading 'toLowerCase')
    at random-word-webpage/index.ts:12:52
```

```
1  const words = ["software", "is", "great"]
2
3  const bucket = new s3.Bucket("website", { /* ... */ });
4
5  const rng = new random.RandomInteger ("word-id", {
6    min: 0, max: words.length
7  });
8
9  rng.result.apply((id) => {
10   new s3.BucketObject("index", {
11     bucket: bucket, /* ... */
12     content: /* ... */ + words[id].toLowerCase()
13   });
14 });
15
16 export const url = bucket.websiteEndpoint;
```

```
error: Running program 'random-word-webpage/index.ts' failed with an unhandled
TypeError: Cannot read properties of undefined (reading 'toLowerCase')
    at random-word-webpage/index.ts:12:52
```

```
1  const words = ["software", "is", "great"]
2
3  const bucket = new s3.Bucket("website", { /* … */ });
4
5  const rng = new random.RandomInteger ("word-id", {
6    min: 0, max: words.length - 1
7  });
8
9  rng.result.apply((id) => {
10   new s3.BucketObject("index", {
11     bucket: bucket, /* … */
12     content: /* … */ + words[id].toLowerCase()
13   });
14 });
15
16 export const url = bucket.websiteEndpoint;
```

PL-IaC Testing Pyramid



IaC Programs on GitHub (August 2022)

Language	Pulumi
TypeScript	6 081
Python	2 927
C#	1 835
Go	1 834
JavaScript	35
Java	75
YAML	157
Haskell	1
Total	12 945

IaC Programs on GitHub: Unit Testing

Language	Pulumi	with Unit Testing	
TypeScript	6 081	51	(1%)
Python	2 927	27	(1%)
C#	1 835	22	(1%)
Go	1 834	15	(1%)
JavaScript	35	0	(0%)
Java	75	3	(4%)
YAML	157	0	(0%)
Haskell	1	0	(0%)
Total	12 945	118	(1%)

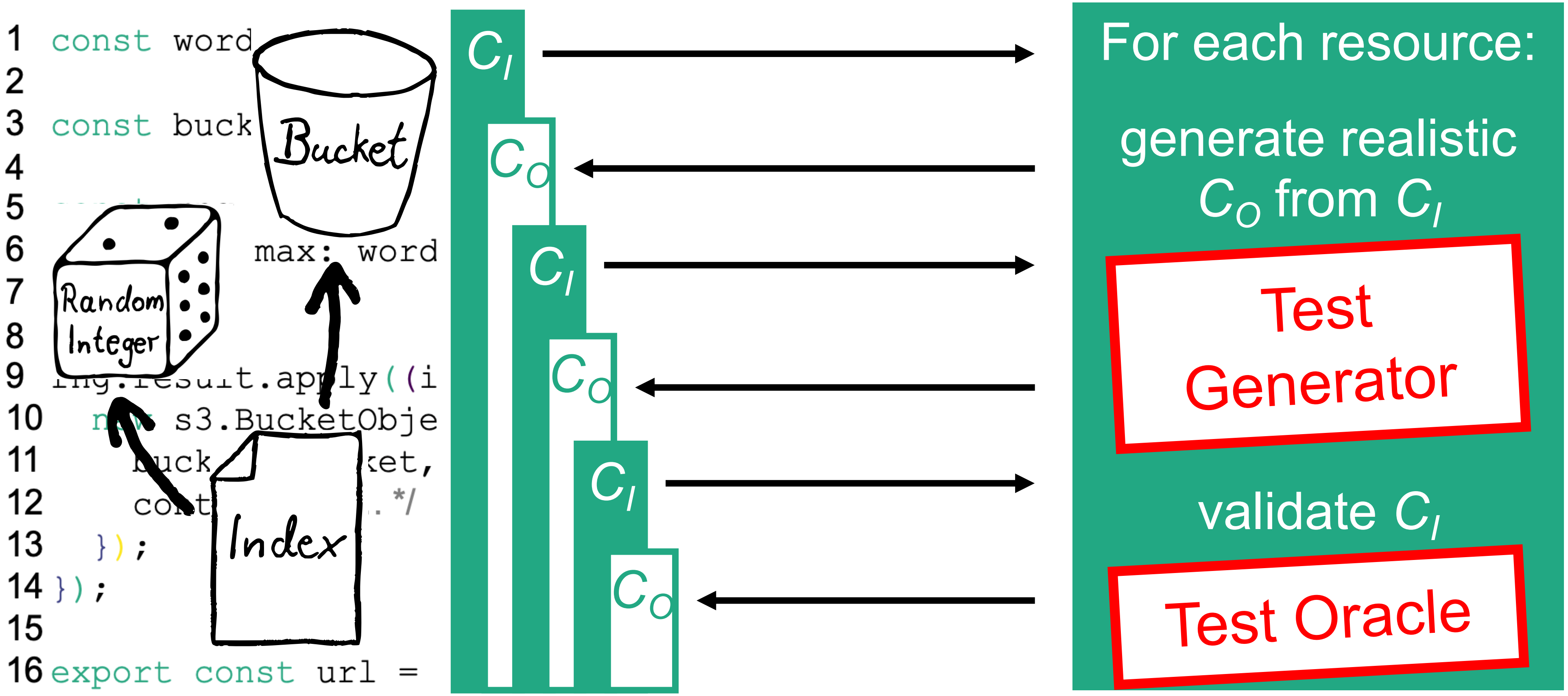
Mocks for PL-IaC Programs

C_I Input Configuration

C_O Output Configuration

IaC Program

Resource Mock



```
const word
const buck
                 max: word
rng.result.apply((i
  new s3.BucketObje
    buck         ket,
    cont         . */
  });
});
export const url =
```

For each resource:

generate realistic C_O from C_I

Test Generator

validate C_I

Test Oracle

Unit Testing the Random Word Website

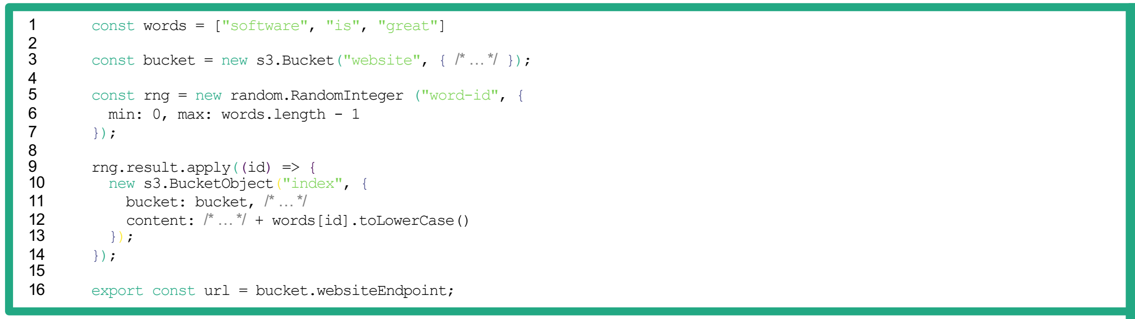
```
const words = ["software", "is", "gr

const bucket = new s3.Bucket("website

const rng = new random.RandomInteger
  min: 0, max: words.length - 1
});

rng.result.apply((id) => {
  new s3.BucketObject("index", {
    bucket: bucket, /* … */
    content: /* … */ + words[id].toLowe
  });
});

export const url = bucket.websiteEnd
```

IaC Program

```
test("random-word-website", async() => {
  pulumi.runtime.setMocks({
    newResource: function(args: pulumi.run
      return {
        id: "",
        state: {},
      };
    },
    call: function(args: pulumi.runtime.Mo
      return {};
    },
  });

  await import("./index");
  await new Promise(setImmediate);
});
```

Unit Test

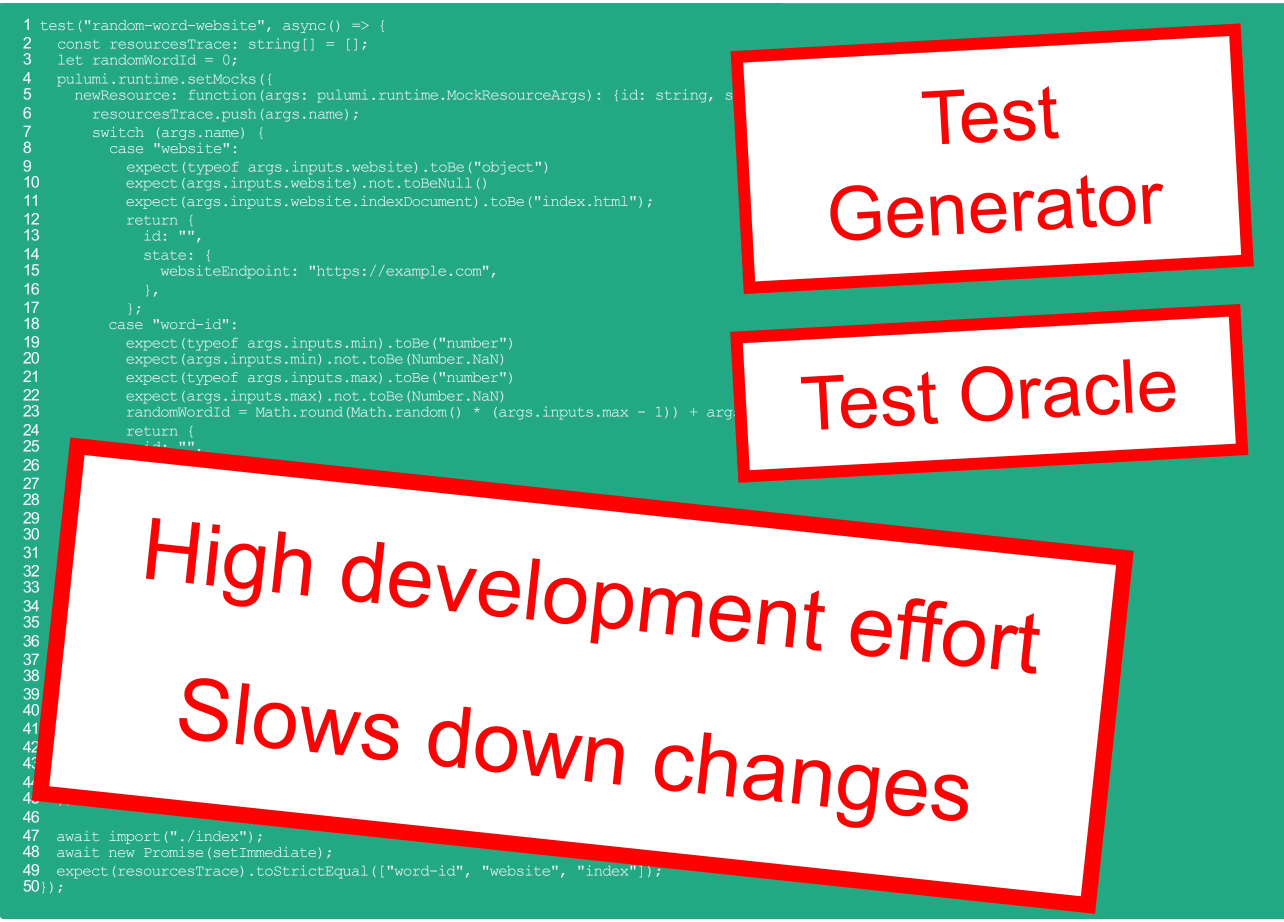
Unit Testing the Random Word Website



```
const words = ["software", "is", "great"]

const bucket = new s3.Bucket("website", { /* ... */ });

const rng = new random.RandomInteger ("word-id", {
  min: 0, max: words.length - 1
});

rng.result.apply((id) => {
  new s3.BucketObject("index", {
    bucket: bucket, /* ... */
    content: /* ... */ + words[id].toLowerCase()
  });
});

export const url = bucket.websiteEndpoint;
```

Problems

- A lot of test code, grows fast
- Replicates the program (coupled)
- Replicates provider logic



```
test("random-word-website", async() => {
  const resourcesTrace: string[] = [];
  let randomWordId = 0;
  pulumi.runtime.setMocks({
    newResource: function(args: pulumi.runtime.MockResourceArgs): {id: string, s
      resourcesTrace.push(args.name);
      switch (args.name) {
        case "website":
          expect(typeof args.inputs.website).toBe("object")
          expect(args.inputs.website).not.toBeNull()
          expect(args.inputs.website.indexDocument).toBe("index.html");
          return {
            id: "",
            state: {
              websiteEndpoint: "https://example.com",
            },
          };
        case "word-id":
          expect(typeof args.inputs.min).toBe("number")
          expect(args.inputs.min).not.toBe(Number.NaN)
          expect(typeof args.inputs.max).toBe("number")
          expect(args.inputs.max).not.toBe(Number.NaN)
          randomWordId = Math.round(Math.random() * (args.inputs.max - 1)) + arg
          return {
            id: "",



  await import("./index");
  await new Promise(setImmediate);
  expect(resourcesTrace).toStrictEqual(["word-id", "website", "index"]);
});
```

Test Generator

Test Oracle

High development effort

Slows down changes

ProTI

Automated Configuration Testing

Framework:
Automated Configuration Testing

C_I Input Configuration

C_O Output Configuration

IaC Program

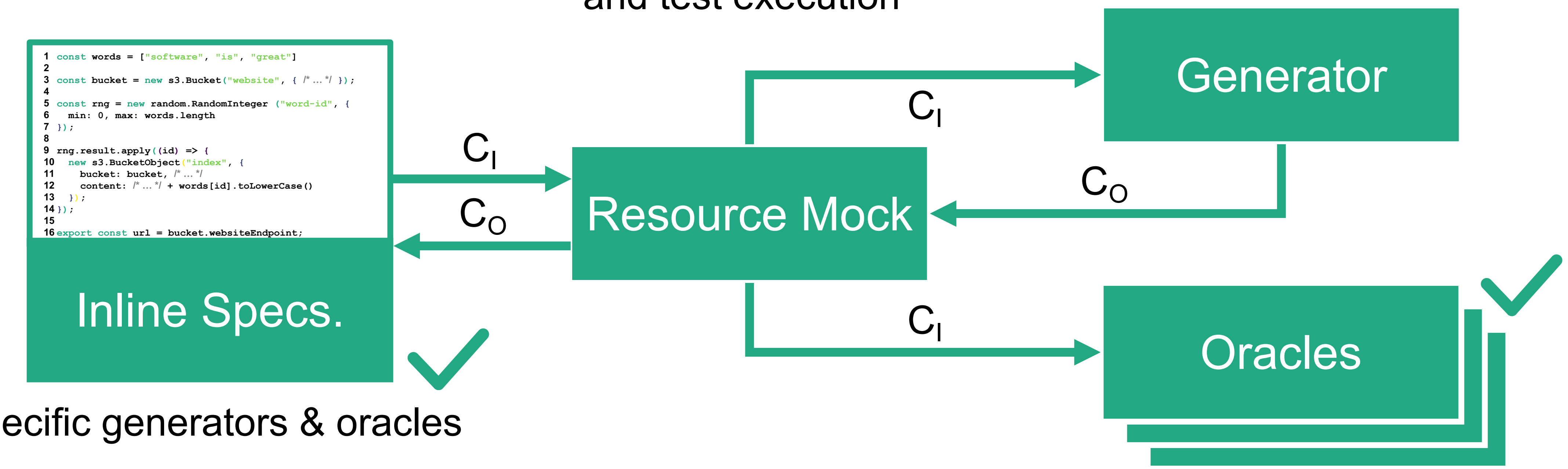
Core

automates mocking

and test execution

Plugins

generalized & reusable



```
const words = ["software", "is", "great"]

const bucket = new s3.Bucket("website", { /* ... */ });

const rng = new random.RandomInteger ("word-id", {
  min: 0, max: words.length
});

rng.result.apply((id) => {
  new s3.BucketObject("index", {
    bucket: bucket, /* ... */
    content: /* ... */ + words[id].toLowerCase()
  });
});

export const url = bucket.websiteEndpoint;
```

specific generators & oracles

ACT for Pulumi TypeScript: ProTI

Test Runner

- @proti-iac/runner
- @proti-iac/test-runner
- @proti-iac/reporter

Jest

Core

- @proti-iac/spec
- @proti-iac/core

fast-check

Plugins

- @proti-iac/pulumi-packages-schema

Pulumi

Provider Package Schemas

Evaluation

□ 1. Can ProTI find bugs reliably?

□ 2. Can ProTI be run on real-world code?

□ 3. Is ProTI fast enough?

□ 4. Can existing testing tools be integrated?

Evaluation
1. Can ProTI find bugs reliably?

□ 1.

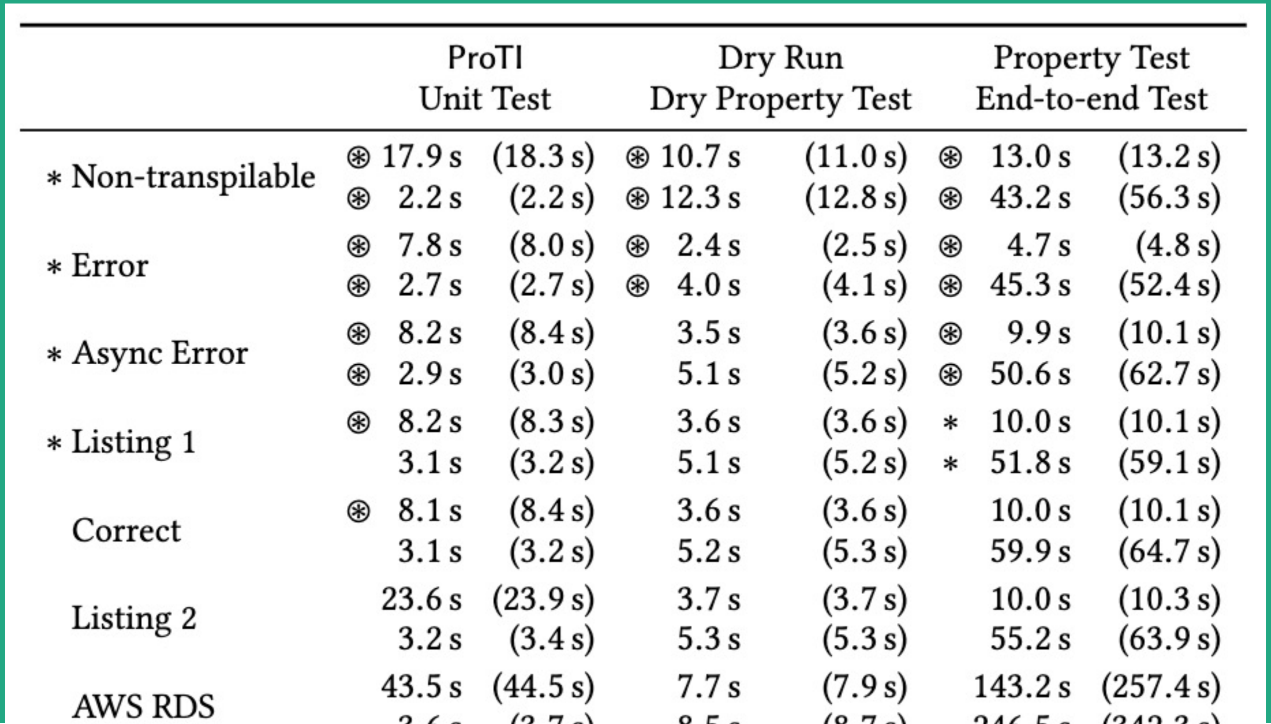
□ 2.

□ 3.

□ 4.

Compared on variants of the random word website

ProTI find bugs reliably, even in edge cases

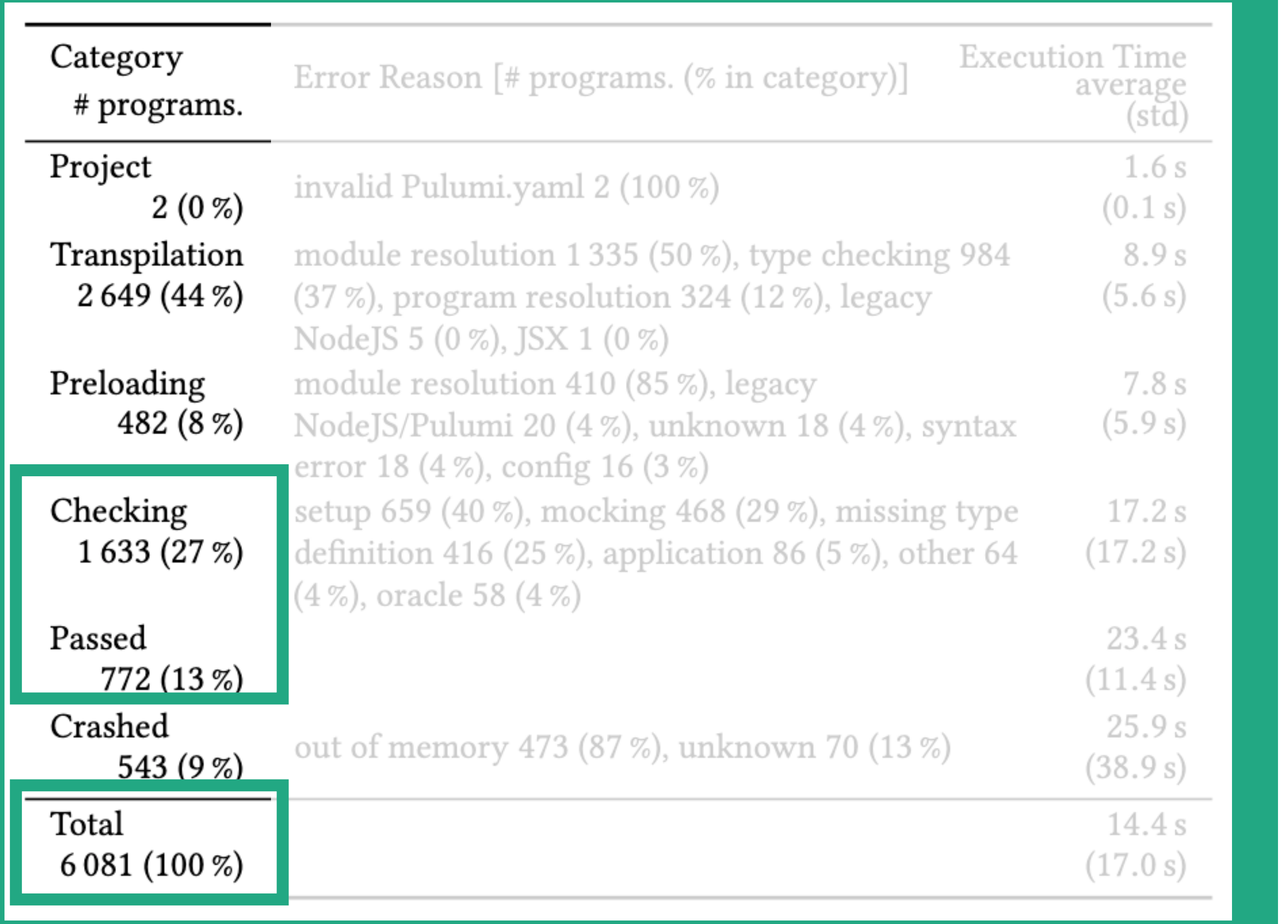


	ProTI		Dry Run		Property Test	
	Unit Test		Dry Property Test		End-to-end Test	
∗ Non-transpilable	⊛ 17.9 s	(18.3 s)	⊛ 10.7 s	(11.0 s)	⊛ 13.0 s	(13.2 s)
	⊛ 2.2 s	(2.2 s)	⊛ 12.3 s	(12.8 s)	⊛ 43.2 s	(56.3 s)
∗ Error	⊛ 7.8 s	(8.0 s)	⊛ 2.4 s	(2.5 s)	⊛ 4.7 s	(4.8 s)
	⊛ 2.7 s	(2.7 s)	⊛ 4.0 s	(4.1 s)	⊛ 45.3 s	(52.4 s)
∗ Async Error	⊛ 8.2 s	(8.4 s)	3.5 s	(3.6 s)	⊛ 9.9 s	(10.1 s)
	⊛ 2.9 s	(3.0 s)	5.1 s	(5.2 s)	⊛ 50.6 s	(62.7 s)
∗ Listing 1	⊛ 8.2 s	(8.3 s)	3.6 s	(3.6 s)	∗ 10.0 s	(10.1 s)
	3.1 s	(3.2 s)	5.1 s	(5.2 s)	∗ 51.8 s	(59.1 s)
Correct	⊛ 8.1 s	(8.4 s)	3.6 s	(3.6 s)	10.0 s	(10.1 s)
	3.1 s	(3.2 s)	5.2 s	(5.3 s)	59.9 s	(64.7 s)
Listing 2	23.6 s	(23.9 s)	3.7 s	(3.7 s)	10.0 s	(10.3 s)
	3.2 s	(3.4 s)	5.3 s	(5.3 s)	55.2 s	(63.9 s)
AWS RDS	43.5 s	(44.5 s)	7.7 s	(7.9 s)	143.2 s	(257.4 s)
	3.6 s	(3.7 s)	8.5 s	(8.7 s)	246.5 s	(342.3 s)

Evaluation
2. Can ProTI be run on real-world code?

- ✅ 1.
- ☐ 2.
- ☐ 3.
- ☐ 4.

Ran ProTI on 6081 Pulumi TypeScript projects from GitHub



Category # programs.	Error Reason [# programs. (% in category)]	Execution Time average (std)
Project 2 (0 %)	invalid Pulumi.yaml 2 (100 %)	1.6 s (0.1 s)
Transpilation 2 649 (44 %)	module resolution 1 335 (50 %), type checking 984 (37 %), program resolution 324 (12 %), legacy NodeJS 5 (0 %), JSX 1 (0 %)	8.9 s (5.6 s)
Preloading 482 (8 %)	module resolution 410 (85 %), legacy NodeJS/Pulumi 20 (4 %), unknown 18 (4 %), syntax error 18 (4 %), config 16 (3 %)	7.8 s (5.9 s)
Checking 1 633 (27 %)	setup 659 (40 %), mocking 468 (29 %), missing type definition 416 (25 %), application 86 (5 %), other 64 (4 %), oracle 58 (4 %)	17.2 s (17.2 s)
Passed 772 (13 %)		23.4 s (11.4 s)
Crashed 543 (9 %)	out of memory 473 (87 %), unknown 70 (13 %)	25.9 s (38.9 s)
Total 6 081 (100 %)		14.4 s (17.0 s)

Evaluation
3. Is ProTI fast enough?

☑ 1.

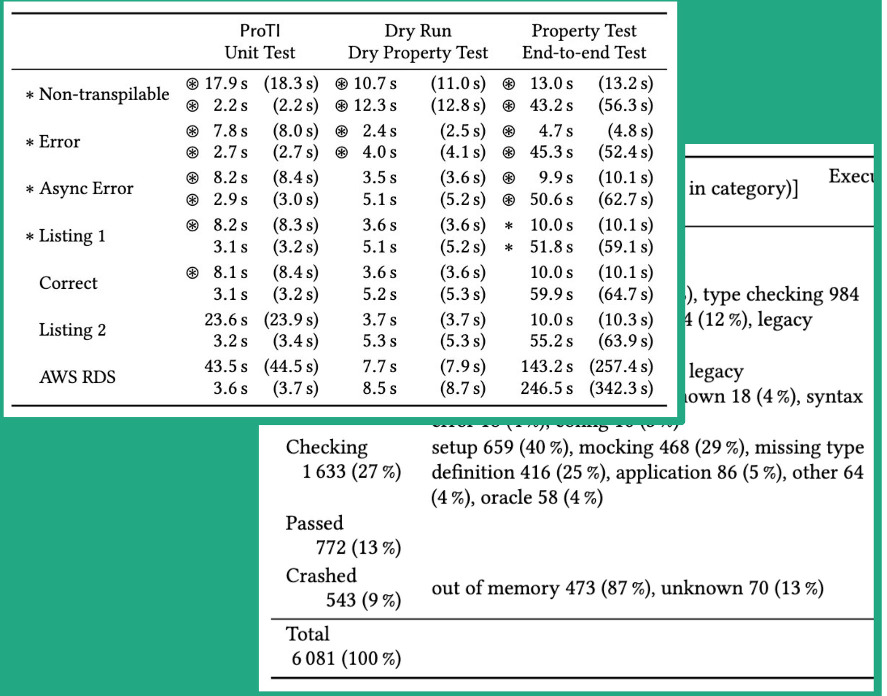
☑ 2.

□ 3.

□ 4.

Single test is typically 100s of ms

Increases linearly with number of resources (not type)



	ProTI		Dry Run		Property Test	
	Unit Test		Dry Property Test		End-to-end Test	
∗ Non-transpilable	⊛ 17.9 s	(18.3 s)	⊛ 10.7 s	(11.0 s)	⊛ 13.0 s	(13.2 s)
	⊛ 2.2 s	(2.2 s)	⊛ 12.3 s	(12.8 s)	⊛ 43.2 s	(56.3 s)
∗ Error	⊛ 7.8 s	(8.0 s)	⊛ 2.4 s	(2.5 s)	⊛ 4.7 s	(4.8 s)
	⊛ 2.7 s	(2.7 s)	⊛ 4.0 s	(4.1 s)	⊛ 45.3 s	(52.4 s)
∗ Async Error	⊛ 8.2 s	(8.4 s)	3.5 s	(3.6 s)	⊛ 9.9 s	(10.1 s)
	⊛ 2.9 s	(3.0 s)	5.1 s	(5.2 s)	⊛ 50.6 s	(62.7 s)
∗ Listing 1	⊛ 8.2 s	(8.3 s)	3.6 s	(3.6 s)	∗ 10.0 s	(10.1 s)
	3.1 s	(3.2 s)	5.1 s	(5.2 s)	∗ 51.8 s	(59.1 s)
Correct	⊛ 8.1 s	(8.4 s)	3.6 s	(3.6 s)	10.0 s	(10.1 s)
	3.1 s	(3.2 s)	5.2 s	(5.3 s)	59.9 s	(64.7 s)
Listing 2	23.6 s	(23.9 s)	3.7 s	(3.7 s)	10.0 s	(10.3 s)
	3.2 s	(3.4 s)	5.3 s	(5.3 s)	55.2 s	(63.9 s)
AWS RDS	43.5 s	(44.5 s)	7.7 s	(7.9 s)	143.2 s	(257.4 s)
	3.6 s	(3.7 s)	8.5 s	(8.7 s)	246.5 s	(342.3 s)

in category)]

Execu

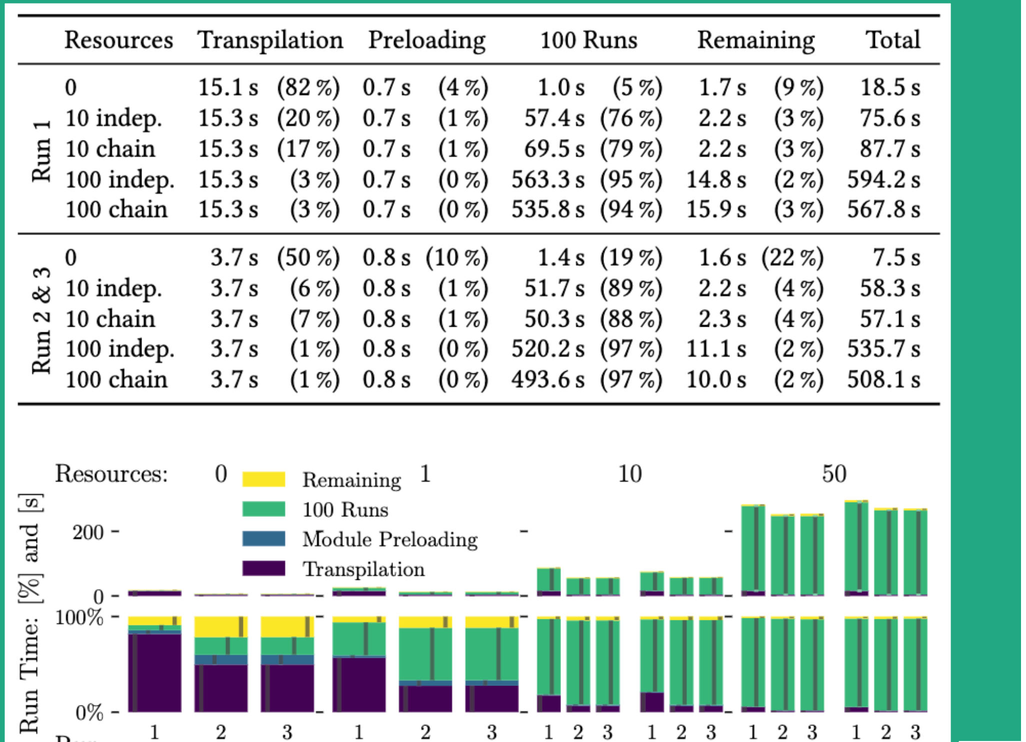
), type checking 984

4 (12 %), legacy

legacy

own 18 (4 %), syntax

Checking 1 633 (27 %)	setup 659 (40 %), mocking 468 (29 %), missing type definition 416 (25 %), application 86 (5 %), other 64 (4 %), oracle 58 (4 %)
Passed 772 (13 %)	
Crashed 543 (9 %)	out of memory 473 (87 %), unknown 70 (13 %)
Total 6 081 (100 %)	



	Resources	Transpilation		Preloading		100 Runs		Remaining		Total
Run 1	0	15.1 s	(82 %)	0.7 s	(4 %)	1.0 s	(5 %)	1.7 s	(9 %)	18.5 s
	10 indep.	15.3 s	(20 %)	0.7 s	(1 %)	57.4 s	(76 %)	2.2 s	(3 %)	75.6 s
	10 chain	15.3 s	(17 %)	0.7 s	(1 %)	69.5 s	(79 %)	2.2 s	(3 %)	87.7 s
	100 indep.	15.3 s	(3 %)	0.7 s	(0 %)	563.3 s	(95 %)	14.8 s	(2 %)	594.2 s
	100 chain	15.3 s	(3 %)	0.7 s	(0 %)	535.8 s	(94 %)	15.9 s	(3 %)	567.8 s
Run 2 & 3	0	3.7 s	(50 %)	0.8 s	(10 %)	1.4 s	(19 %)	1.6 s	(22 %)	7.5 s
	10 indep.	3.7 s	(6 %)	0.8 s	(1 %)	51.7 s	(89 %)	2.2 s	(4 %)	58.3 s
	10 chain	3.7 s	(7 %)	0.8 s	(1 %)	50.3 s	(88 %)	2.3 s	(4 %)	57.1 s
	100 indep.	3.7 s	(1 %)	0.8 s	(0 %)	520.2 s	(97 %)	11.1 s	(2 %)	535.7 s
	100 chain	3.7 s	(1 %)	0.8 s	(0 %)	493.6 s	(97 %)	10.0 s	(2 %)	508.1 s

Evaluation
4. Can existing testing tools be integrated?

✅ 1.

✅ 2.

✅ 3.

⬜ 4.

Demonstrated ProTI plugins using

- Radamsa fuzzer
- Daikon invariant detector

Evaluation

✅ 1. Can ProTI find bugs reliably?

✅ 2. Can ProTI be run on real-world code?

✅ 3. Is ProTI fast enough?

✅ 4. Can existing testing tools be integrated?

Decentralized Coordination for Reliable IaC Programs in Decentralized Organizations

Organizations need decentralized deployment coordination.

µs [mju:z] enables it through strong interfaces and decoupled operations.

Beyond dependency availability: version consistency of workflows.

DALL·E 2023-12-10 14.15.44 - An image of a hiker, with a purple jacket and backpack, arriving at a cozy mountain cabin at sunset. The hiker is standing at the entrance of the home, which is nestled at the edge of a lush green forest with mountains in the background. The cabin is made of wood with smoke gently rising from the chimney. The sky is ablaze with the warm hues of the setting sun, and the surrounding scenery is peaceful, with hints of wildflowers near the path leading to the cabin.

Decentralized Coordination and Automated Testing for Reliable IaC Programs in Decentralized Organizations

Organizations need decentralized deployment coordination.

µs [mju:z] enables it through strong interfaces and decoupled operations.

Beyond dependency availability: version consistency of workflows.

IaC program developers don't test because it is either slow or much development effort.

ACT automates mocking with test generator and oracle plugins.

ProTI implements ACT for Pulumi TypeScript.

University of St.Gallen

p.g Programming Group

https://mjuz.rocks

https://proti-iac.github.io

https://programming-group.com

Daniel Sokolowski

https://dsoko.de

X Soko2D

in dsoko