Snafu: Function-as-a-Service (FaaS) Runtime Design and Implementation

Josef Spillner
Zurich University of Applied Sciences, School of Engineering
Service Prototyping Lab (blog.zhaw.ch/icclab/)
8401 Winterthur, Switzerland
josef.spillner@zhaw.ch
March 23, 2017

Abstract

Snafu, or Snake Functions, is a modular system to host, execute and manage language-level functions offered as stateless (micro-)services to diverse external triggers. The system interfaces resemble those of commercial FaaS providers but its implementation provides distinct features which make it overall useful to research on FaaS and prototyping of FaaS-based applications. This paper argues about the system motivation in the presence of already existing alternatives, its design and architecture, the open source implementation and collected metrics which characterise the system.

1 Introduction

The construction of software applications went through several historical trends. Early on, software programs were subdivided into functions, later into classes with methods, modules, higher-level components with well-defined interfaces and eventually into uniform service interfaces. As services grew and became monolithic, the trend was reversed, microservices became popular [1], and eventually fine-granular single functions are now again the unit of choice for encapsulating service functionality in many domains. This trend is leading to cloud applications with fine-grained billing and seemingly serverless hosting [2] and to improved computing abilities for mobile and connected devices [3] and scientific workflows [4].

Function-as-a-Service (FaaS) is therefore the technological concept to subdivide software applications into functions and to invoke these functions through network protocols with explicitly specified or externally triggered messages. The functions are deployed as FaaS units, encompassing the callable functions along with their dependencies, on dedicated FaaS runtimes. The runtimes are
platform-level host services whose tasks are the blazingly fast allocation of resources for the function execution and the precise accounting of the associated duration and processing load. Functions may be executed in-process or externally through interpreters, containers or other isolation layers. They are generally stateless, losing all local state after termination, and require bindings to external stateful services such as key-value stores, databases, file or blob storage for any persistence.

This paper positions Snafu as runtime system implementation to host in-process Python functions and external functions programmed in other languages within a FaaS environment. Snafu is flexible, low-effort and competitive with regards to similar runtimes and resolves the need for a FaaS runtime geared towards not only cloud providers but also cloud application engineers. The text is structured as follows. All of the next five sections start with a question which the section is answering to. The sections describe the motivation, design, architecture, implementation and experimental evaluation of Snafu. A last section concludes with an outlook on future work.

2 Motivation

Why spend time and effort on Snafu when there are already plenty of FaaS hosts for Python functions and multi-language functions available? Table 1 compares currently available open source and commercial FaaS runtimes which specifically target Python software engineers or application providers, most of which are recent additions to the market within the timeframe of 2015 to 2017. Only one service is commercially available on demand. Comparison tables for other languages would look similar with the notable exception of JavaScript (Node.js) which sees more wide-spread support.

| Runtime          | Classification                  |
|------------------|---------------------------------|
| AWS Lambda       | commercial service              |
| Docker-LambCI    | open source, reverse engineered  |
| OpenLambda [5]   | open source, research prototype  |
| PyWren [6]       | open source, AWS Lambda overlay |
| Fission          | open source                     |
| Kubeless         | open source, Kubernetes-integrated |
| IronFunctions    | open source, AWS Lambda compatible |

Many of these runtimes target infrastructure-level deployment and are not suitable for quick prototyping of applications or ad-hoc experiments. The main motivation for a different design is therefore flexibility coupled with a reduced effort when getting started with the system.

- Flexibility: AWS Lambda is known to have several operational limits of which only a subset can be configured or requested to be configured dif-
ferently [7]. In many scenarios, it is desirable to change limits or other details of the implementation which necessitates a fully controllable open source approach. The open source runtimes can be modified but often require code-level modifications for even basic extensions. The mapping from functions or methods in the programming scope to functions offered as a service in the FaaS scope is often incomplete.

- **Reduced effort:** Several of the open source FaaS runtimes, both AWS Lambda-compatible and incompatible ones, require a non-trivial setup and integration with other runtime components and frameworks. Reduced effort means that basic tasks should work without any configuration to achieve first results quickly, and more complex tasks should involve minimal configuration. Awareness for this requirement is increasing in cloud research [8].

From these explanation, concrete criteria are derived which allow for a comparative evaluation. Criteria thus encompass: Must be available as open source (C1), must be deployed and operational for simple tests within an attention span of ten minutes assuming the required basic setup and dependency installation has been performed (C2), and must work in some configuration without requiring other runtimes (C3). Furthermore, the runtime must consume source code and extract functions or methods found within (C4) to allow for quick conversion of legacy codebases. The motivation for a custom FaaS design is justified when it can be demonstrated that the existing runtimes do not fulfil these criteria. Table 2 roughly calculates how the existing runtimes score with one point given for each fulfilled criterion. The comparison shows that Docker-LambCI is mainly targeting Node.js whereas the Python part is not fully implemented, making it impossible to run Python scripts. OpenLambda and IronFunctions require Docker containers as isolation layer, and the former returns an empty string from the hello world function instead of the expected result, indicating a temporary bug. PyWren requires the creation of custom Lambda roles. Fission and Kubeless strictly require access to a running Kubernetes instance. Most runtimes require explicit function selection and configuration instead of dynamically exporting any function. This comparative feature calculation is not meant to be precise, but it gives an indication of the issues associated with current systems. Half points (0.5) are given for features which come close but do not fully fulfil the criteria.

None of the existing runtimes fulfil all criteria (sum = 4) which justifies either their improvement or a new design and implementation. Snafu follows a new design to evaluate the ease of prototypical engineering of an alternatively designed FaaS runtime.

3 Design

What are the design criteria to achieve a more flexible and effort-reduced FaaS host? Compared to the existing approaches, Snafu is designed to execute func-
Table 2: FaaS runtimes targeting Python functions.

| Runtime        | C1 | C2 | C3 | C4 | Sum |
|----------------|----|----|----|----|-----|
| AWS Lambda     | 0  | 1  | 1  | 0  | 2   |
| Docker-LambCI  | 1  | 0  | 0  | 0  | 1   |
| OpenLambda     | 1  | 1  | 0  | 0  | 2   |
| PyWren         | 1  | 0  | 0  | 1  | 2   |
| Fission        | 1  | 0  | 0  | 0  | 1   |
| Kubeless       | 1  | 1  | 0  | 0  | 2   |

...tions written in its implementation language Python in-process and functions in arbitrary languages through external processes. This design does therefore not preclude the addition of languages executed through an isolation layer such as spawned interpreters or containers. Furthermore, the design mandates a zero-configuration approach. The user experience after downloading the host should be instant by offering runnable sample functions and client functionality which works out of the box. To foster adoption, a migration path from commercial FaaS services, which for Python functions currently implies AWS Lambda, is integral to the design. Files which contain more than one function can be configured in a way that each function is exported so that code redundancy through multiple deployed function units is decreased. Triggers should be extensible and a suitable number of useful triggers is part of the software.

Fig. 1 shows the Snafu overall functional design. Functions consisting of implementation and configuration are either engineered from scratch or migrated from an existing FaaS. They are stored in a pool from which they can be executed with a host process which can be remote-controlled through a control plane with function management service interfaces.

![Figure 1: Snafu design](image)

4 Architecture

Which software architecture is appropriate for Snafu, given the design guidelines and constraints? As with the functions it supports, modularity and service-orientation are important architectural properties of the system itself.
The architecture follows the design. Flexibility is achieved by an extensible system whose functionality is partly contained in subsystems with pluggable components. Reduced effort is achieved by a zero-configuration default setup as well as flexible per-instance, per-tenant and per-function configuration options, in order of priority.

As shown in Fig. 2, the two main building blocks are the FaaS host core and the control plane. Both blocks are complemented by six extensible subsystems for triggering, authenticating, logging, debugging, forwarding and finally execution of functions. Support for Lambda functions is offered through a dedicated import path which imports all functions from an AWS region in a batch process, as well as through the compatible control plane which apart from Lambda also implements the necessary service interfaces of AWS S3 and STS.

Figure 2: Snafu architecture

Functions may be invoked locally through the Snafu tool which interacts with humans through a command-line interface. Requests are also received by the control plane which, depending on the configuration, authenticates the request, decides about routing it to a pre-configured static or dynamically launched secondary instance of Snafu (e.g. for per-tenant isolation or load balancing) or processing it internally. In the latter case, the request, execution and response of the function are properly logged and amended with debugging information. The execution is performed in-process or out-of-process. A third channel for invocation are the connectors which make functions available through triggers such as web services, message queue subscriptions and timers.
5 Implementation

How is Snafu implemented in order to maintain the design criteria of flexibility and reduced effort? The implementation consists of a set of Python 3 executables and library modules as well as parts implemented in other languages which cover the entire functionality shown in the architecture (Fig. 2). The executables are the `snafu` command-line tool as function host process, `snafu-import` to import already deployed functions in AWS Lambda, and `snafu-control` to run a Lambda-compatible control plane. The executables interact with the filesystem to read and write function files, and with various triggers to receive events. Five triggers are implemented: web (HTTP invocations), messaging (AMQP messages), filesystem (file change notifications through inotify), cli (interactive command-line input), and cron (scheduled regular invocations).

The implementation possesses both in-process and out-of-process executors. The former group is limited to Python 3 functions which matches the implementation language. The choice of Python 3 as implementation language renders Snafu in-process function execution initially incompatible with AWS Lambda which only supports Python 2.7. To mitigate any friction, Snafu can be instructed to automatically upgrade all Python 2 code to Python 3 either upon explicit import or upon the creation of new functions, using Python’s 2to3 utility. Furthermore, among the implemented external executors one supports Python 2 for increased compatibility due to the effective but still heuristic 2to3 conversion algorithm. Another external executor runs Java methods as functions which is otherwise a unique feature of AWS Lambda among the commercial FaaS providers. In total, five executors with different language and isolation capabilities are available.

For scalability and multi-tenancy, forwarders are available which redirect requests to other instances of Snafu which are static or created dynamically per tenant. Tenants are authenticated against an accounts list by any number of authenticators. Compatibility with AWS Lambda is achieved by the availability of an AWS4 signature verification among the authenticators.

The complete implementation architecture is shown in Fig. 3. All subsystems can be extended by placing additional Python files adhering to their function signature constraints into the respective subsystem directories. The parts marked in grey belong to existing commercial FaaS providers and are not required for operation.

Multi-threading is used on three occasions. Each remote request received by the control plane creates a processing thread to ensure parallel processing of multiple requests. Furthermore, if requested, one static thread monitors the sockets of all incoming connections (reaper thread) and another one monitors the filesystem for hot-deployed functions (hot deployer thread).

The entire codebase of Snafu consists of around 1300 lines of Python 3 code and smaller footprints for Python 2 and Java 8 parsing and execution. To give an impression of how the tool is used in versatile ways: `snafu -x helloworld hello.py` would execute the function `helloworld` from the specified source file. Any function argument not already known is queried interactively from the user.
Figure 3: Snafu implementation

if possible. Depending on the connector and calling convention, the parameters event and context may be preset per convention among commercial FaaS implementations. The invocation of `snafu-control -e docker -a aws` would run each function after authentication within a per-tenant Docker container.

## 6 Metrics

How does Snafu perform and scale? This section reports about an experimental evaluation of the software implementation according to various configurations. The configuration space for the internal (in-process) Python function execution is shown in Fig. 4. The light grey-highlighted measured configurations are complemented with external (out-of-process) executors and forwarders, and the
In the experiments, $O$ is represented by debug messages written to the process standard output. $L$ is represented by CSV logs, $A$ by the AWS4 digital signature verification and $I$ by the stateless function isolation.

The configurations were measured with concrete Snafu subsystem configurations. All local experiments were performed on a contemporary notebook with a quad-core i7-5600U CPU clocked at 2.60GHz and 16 GB RAM.

6.1 Performance

The performance of a FaaS host depends not only on the function execution speed but also at the system topology determined by scalability, isolation and authentication requirements. Fig. 5 combines four possible setups for operating Snafu in the cloud. Setup «a» is the default configuration in which Python functions are executed in-process. The master-slave setup «b» forwards all function requests to a containerised slave. All requests from functions to other functions, including recursive requests, remain contained. Setup «c» forwards these requests back to the master instance which may decide to forward it back again or to other container instances for load balancing. Setup «d» is the most complex one in which a load balancer distributes load among multiple master instances. This paper reports on the setups «a»–«c».

Table 3 summarises the measured execution times of the recursive Fibonacci function $fib$ implemented in Python according to setup «a». The function references a global counter variable which tracks the number of function calls. On each invocation, the function calculates this number times the sine of the number, leading to increasing execution times across calls for the non-isolated executor. Each value is averaged over five calls with clean restarts after each measurement sequence.
Figure 5: Four benchmark setups to determine the performance of Snafu

Table 3: Snafu performance comparison in calls per second.

| Configuration                                      | fib(7)  | fib(12) | fib(15) |
|---------------------------------------------------|---------|---------|---------|
| Stateful in-process (IP)                          | 81.91   | 298.90  | 327.28  |
| IP + debug output + CSV log                       | 81.38   | 278.05  | 316.80  |
| IP + debug output + AWS4 authenticator            | 76.22   | 240.25  | 263.14  |
| Isolating in-process (IIP)                        | 66.17   | 155.14  | 183.11  |
| IIP + AWS4 + debug + CSV log                      | 62.78   | 146.56  | 162.96  |
| External Python2 isolating executor               | 45.85   | 119.54  | 139.33  |
| External Python2 non-shared executor              | 7.22    | 7.77    | 7.79    |
| External Docker shared executor                   | 34.10   | 173.69  | 246.95  |
| Comparison: AWS Lambda                            | 15.25   | 59.64   | 86.64   |

The measurements clearly show that the performance is impaired by any configuration option desirable for production use. However, not only the best, but also the worst in-process performance are still competitive compared to execution of the same function in AWS Lambda with 377.75% and 188.09% relative speed for \(f_{ib}(15)\), respectively. Furthermore, the most closely matching configuration of isolated execution through containers per tenant yield 223–285% of Lambda’s call performance.

Another result is the highly degraded performance when spawning external processes to execute functions. The degradation is much smaller (57.42% compared to 97.62%) when re-using external interpreter instances; the difference between isolated and stateful external execution is a lot higher than between their stateful and stateless internal counterparts (50.21%). It should be noted that the entire implementation is single-threaded apart from incoming request threads and future versions can thus be expected to perform better when making use of automated parallelisation optimisation.
Fig. 6 picks up the configuration space from Fig. 4 again and relates all configuration performance values based on the execution of $fib(15)$.

![Diagram of configuration space]

Figure 6: Measured configuration space with the internal execution compared against external and AWS Lambda

### 6.2 Connection handling

A useful feature of Snafu is the socket reaper which works around inadequacies in the default invocation tool configuration provided by AWS and used by many application engineers. These tools, both the AWS CLI and the Boto library for Python which is used for calling other functions or for recursive calls from a function implemented in Python, have default socket read timeouts of 60 seconds each. Requests are repeated when the timeout happens which implies that previous function instances keep running while new ones are added. Fig. 7 compares the effect of the different configurations on the number of open sockets in Snafu, in particular sockets in `CLOSE_WAIT` state whose execution results are not read anymore by clients. The function semantics are opaque, thus terminating function instances is not an option, but closing the lingering sockets is helpful to avoid a resource exhaustion as most systems allow for only 1024 open file descriptors (including sockets) by default as determined by `ulimit -n`.

Fig. 8 shows the effect of using the reaper while keeping the AWS CLI and Boto default configuration. The executed $fib$ function has been modified to wait a constant time of 0.1s in each invocation instead of performing the sine calculation. This modified function can still be considered an edge case with worst processing to I/O ratio whereas other functions would give the reaper more time to perform. Using the reaper saves opening around 60 sockets, or
Figure 7: Snafu open sockets over time while executing fib(25): all timeouts deactivated (upper left); AWS CLI timeouts deactivated (upper right); Boto timeouts deactivated (lower left); default timeouts (lower right) – y scales not normalised

one third, in the peak time, and shortens the process execution considerably by around 120 seconds, or one fifth.

### 6.3 Economics

For a fair comparison of the cost of function invocations, Snafu needs to be operated in a setting comparable to commercial FaaS providers. As AWS Lambda is currently the only provider supporting Python functions, the experiments are conducted using the provider’s Elastic Compute Cloud (EC2) which offers virtual machines on demand. The initial cost comparison experiment for setups «a»–«c» is conducted with an on-demand EC2 t2.small instance which albeit being a bursty instance type is still expected to have a usable performance, and a small Lambda instance with 128 MB of memory and a free tier of 1 million requests. The calls per second (cps) are determined with a fib(20) invocation which leads to 13529 recursive invocations. Interpolating from the cps metric, the upper bound for the calls per month (cpm) is determined with $cpm = \frac{365}{12} \times 24 \times 60^2 \times cps$. Similarly, the price per month (ppm) is calculated from the provider-specified price per hour (pph) with $ppm = \frac{365}{12} \times 24 \times pph$ or from the price per million calls (ppmc).

A utility index is defined to determine the performance in relation to the cost, calculated per the utility function $\frac{cpm}{ppm \times \text{1 million}}$. Table 4 contains all results. It becomes clear that the utility is highest for the unauthenticated in-process ex-
In practice, the choice of instance type needs to be clear before offering the service due to the inability of most commercial cloud providers to scale instances vertically in fine-grained steps. Fig. 9 explains which EC2 instance type is required depending on the setup («b» or «c») and the expected calls per month. Due to the actual pay-per-use pricing model of AWS Lambda, it outperforms Snafu for the benchmarked \( fib(20) \) method for low use. For more frequent use (> 260 mio cpm), the Snafu deployments perform better and are still more economical. For even heavier use (> 580 mio cpm), Snafu still performs with larger instance types but quickly becomes prohibitively expensive. At some point (> 600 mio cpm), the internal scalability constraints of either the FaaS host or the function implementation let the performance stuck while the price still climbs.

Recent research on microservice-based application architectures and cloud-native applications has focused similarly on economical arguments. The authors
of [9] claim infrastructure cost reduction of 70% compared to an equivalent monolithic software when using AWS Lambda’s Node.js executor for a very specific call frequency. With Snafu, there is now the possibility to leave the application on EC2 but modularise it on a fine-grained level and receive shared revenue from functions offered on cloud marketplaces. The authors of [10] propose the CostHat model to determine the overall cost of both monolithic and microservice-based applications for instance deployed on FaaS. Such cost models will evolve to cover more flexible and requirements-driven deployments of functions whose pricing changes according to per-tenant and per-function multipliers for scalability, isolation and authentication, among other factors.

7 Conclusion

The design space for FaaS hosts is still largely empty despite an increasing number of proposed and implemented systems. Snafu contributes a distinct design which does not overlap with any of the existing hosts. Its architecture is modular and extensible, and its implementation is competitive with existing commercial and open source FaaS runtimes. In particular, the flexible design makes it possible to balance isolation and authentication with raw performance speed which sets it apart from comparable systems. Snafu thus contributes to the broad availability of usable FaaS tools and therefore to the feasibility of engineering applications on top of this service class. Cloud platform providers benefit from operating Snafu in multi-tenant mode, cloud application engineers avail themselves of a low-effort tooling to test locally without incurring cost, and academics get a modular system to study and extend. Limitations to overcome in the future include the lack of an asynchronous function model and a performance prediction and tuning component.
Repeatability

Snafu is publicly available at https://github.com/serviceprototypinglab/snafu. Implementations of all referenced functions as well as invocation instructions are provided for reproducing the stated results in the project wiki https://github.com/serviceprototypinglab/snafu/wiki which serves as continuous scientific open notebook.

Acknowledgements

This research has been supported by an AWS in Education Research Grant which helped us to run our experiments on AWS Lambda as representative public commercial FaaS.

References

[1] Nicola Dragoni, Ivan Lanese, Stephan Thordal Larsen, Manuel Mazzara, Ruslan Mustafin, and Larisa Safina. Microservices: How To Make Your Application Scale. CoRR abs/1702.07149, February 2017.

[2] Mengting Yan, Paul C. Castro, Perry Cheng, and Vatche Ishakian. Building a Chatbot with Serverless Computing. In 1st International Workshop on Mashups of Things and APIs, MOTA@Middleware, pages 5:1–5:4, Trento, Italy, December 2016.

[3] Ikuo Nakagawa, Masahiro Hiji, and Hiroshi Esaki. Dripcast - Architecture and Implementation of Server-less Java Programming Framework for Billions of IoT Devices. Journal of Information Processing (JIP), 23(4):458–464, 2015.

[4] Maciej Malawski. Towards Serverless Execution of Scientific Workflows – HyperFlow Case Study. In 11th Workshop on Workflows in Support of Large-Scale Science (WORKS@SC), volume CEUR-WS 1800 of CEUR Workshop Proceedings, pages 25–33, Salt Lake City, Utah, USA, November 2016.

[5] Scott Hendrickson, Stephen Sturdevant, Tyler Harter, Venkateshwaran Venkataramani, Andrea C. Arpaci-Dusseau, and Remzi H. Arpaci-Dusseau. Serverless Computation with OpenLambda. In 8th USENIX Workshop on Hot Topics in Cloud Computing (HotCloud), Denver, Colorado, USA, June 2016.

[6] Eric Jonas, Shivaram Venkataraman, Ion Stoica, and Benjamin Recht. Occupy the Cloud: Distributed Computing for the 99%. preprint at arXiv:1702.04024, February 2017.
[7] Josef Spillner. Exploiting the Cloud Control Plane for Fun and Profit. preprint at arXiv:1701.05945, January 2017.

[8] Michel Catan, Roberto Di Cosmo, Antoine Eiche, Tudor A. Lascu, Michael Lienhardt, Jacopo Mauro, Ralf Treinen, Stefano Zacchiroli, Gianluigi Zavattaro, and Jakub Zwolakowski. Aeolus: Mastering the Complexity of Cloud Application Deployment. In Service-Oriented and Cloud Computing – Second European Conference (ESOCC), pages 1–3, Málaga, Spain, September 2013.

[9] Mario Villamizar, Oscar Garces, Lina Ochoa, Harold E. Castro, Lorena Salamanca, Mauricio Verano, Rubby Casallas, Santiago Gil, Carlos Valencia, Angee Zambrano, and Mery Lang. Infrastructure Cost Comparison of Running Web Applications in the Cloud Using AWS Lambda and Monolithic and Microservice Architectures. In 16th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGrid), pages 179–182, 2016.

[10] Philipp Leitner, Jürgen Cito, and Emanuel Stöckli. Modelling and Managing Deployment Costs of Microservice-Based Cloud Applications. In 9th IEEE/ACM International Conference on Utility and Cloud Computing (UCC), Shanghai, China, December 2016.