Efficient Microservices
Using D

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Overview

- Microservice Concepts
- Unexpected Places for System-Level Languages
- Why D for Microservices?
- Putting it into Practice
  - A Practical Problem
  - System Architecture
  - Building in the Cloud
  - Deploying in the Cloud
- Concluding Remarks
Microservice Concepts
A brief bit of context.

**Microservices** refer to services that constitute a **microservice architecture**.

A microservice architecture is a variant of service-oriented architecture, which separates an application into loosely coupled software services.

These services communicate with each other via lightweight protocols:

- **Synchronous**: [REST](https://rest.com) using HTTP/JSON, [gRPC](https://grpc.io), etc,
- **Asynchronous**: [Apache Kafka](https://kafka.apache.org), RabbitMQ, [AWS SQS](https://aws.amazon.com/sqs/), etc.
Why bother?

- Allows different services to use different technologies
- De-couple work so that teams of people can work independently
- Define clear contracts that help system development and testing
- Isolate changes related to scaling/performance to where they are needed
- Make it easier to deploy more frequent and smaller changes

Such architectures are now the norm in many industries.
Microservices and Their Costs

Beyond the interfaces, scaling and deployment are important factors.

*Each m4.xlarge costs $0.20 per hour (on-demand), i.e. $144.00 per month.
Cutting Costs with Container Orchestration

Low efficiency deployments were enough for first-to-market services in the 2000's and 2010's. In the 2020's, competition and profitability are increasingly important.

Container orchestration systems like Kubernetes, AWS ECS, or OpenShift help configure and deploy multiple services per computer.
Microservices and Their Costs

Many types of costs per server:

- Hourly Pricing for CPU/RAM
- Hourly Disk Space per GB
- Network Bandwidth per GB
- Public IP Addresses
- Load Balancer Connections

Container orchestration can help with costs depending on pricing.
Savings exist for multiple mostly-idle services that need <1 CPU. However, savings for fully loaded servers is limited...

E.g. 2 smaller servers cost as much as 1 bigger server.

Even so, there are savings for:
- Load Balancers
- Public IPs
- Low-use services

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</table>
A Place for System-Level Languages
Get what you pay for, Pay for what you get

Cloud-computing platforms like AWS have become quite efficient.

Two 1-CPU computers cost roughly as much as one 2-CPU computer.

For big companies with 10-100K USD costs per month, resources needs are important.

For small companies with a small budget, resources needs are important.
Waste Not, Want Not

The most effective way to cut costs is to need less. Reducing needs by 50% can reduce costs by almost 50%.
Lower Resource Usage with System-Level Languages

Higher level programming languages are easy to work with, but aren't free:

- **Python, JavaScript, Ruby**: An interpreter must exist to execute the code, reducing performance and increasing memory usage.
- **Java, Scala, C#, Erlang**: Code is compiled for use by a virtual machine, which is more efficient than an interpreter, but still not free.

System-Level languages compile directly to machine code with little overhead:

- **D, C++, C, Rust, Go, Ada, Fortran**
## D vs. Java

A comparison between a **minimal web-server** using:

- **Java / Spring**
  - Binary Size: 16.8 MB
  - Resident Memory: 280 MB
  - Virtual Memory: 10,000 MB
  - Transactions/second: 5,200 trans/sec

- **D / Vibe.d**
  - Binary Size: 3.8 MB
  - Resident Memory: 11 MB
  - Virtual Memory: 510 MB
  - Transactions/second: 11,000 trans/sec

Sönke Ludwig has done fantastic work, check it out at [https://vibed.org](https://vibed.org)
Reasons Not to use System-Level Languages

Typical reasons to not use system-level languages include:

- Higher complexity and development costs.  
  (Still true, but powerful libraries reduce this barrier.)
- Lack of libraries for certain domains, e.g. AWS, Kafka, Web, ML, etc.  
  (As important as language selection is the libraries for that language.)
- Having to compile separately for multiple platforms.  
  (With cloud-infrastructure, this has become far less of an issue.)
- Long compilation times and slower development speeds.  
  (Varies considerably from language to language.)
Why D for Microservices?
Advantages of D for Web Services

- **Lower Costs**: D's compiled high performance reduces hardware needs.
- **Quick Training**: D's C-family syntax speeds up onboarding for developers already familiar with C++, JavaScript, Python, Java, etc.
- **Incorporate Libraries**: Because D's multi-paradigm feature-rich approach, libraries from other programming languages can be mechanically converted.
- **Fast Development**: D, like Java, has garbage collection. The latency is acceptable and it simplifies development.
- **Error Detection**: D's integration of unit tests and pre/post-conditions makes it easier to write tests, encouraging better test coverage.
A quick note on other languages:

- **Rust**: ▲ High performance, ▼ unfamiliar syntax, ▼ must re-design libraries.
- **Go**: ▲ Good performance, ▼ unfamiliar syntax, ▼ limited features
- **C++**: ▲ High performance, ▼ difficult development
- **D**: ▲ High performance, ▲ familiar syntax, ▲ libraries convert mechanically
Challenges of Using D for Web Services (compared to Java)

● **Lack of IDE Integration:** Java has powerful IDE support ([IntelliJ IDEA](https://intellij IDEA)) and powerful debugging tools. (D [debuggers](https://debuggers) lack features like code execution.)

● **Lack of Profiling/Memory Tools:** Java has powerful inspection tools like [VisualVM](https://VisualVM). (D [profiling](https://profiling) is complex, tools often not maintained.)

● **Poor Library Coverage:** Frequently used libraries for Web Services are missing in D.
  - AWS SQS, SNS, Apache Kafka
  - Database ORM (e.g. PostgreSQL)
  - Rule Engines (e.g. Drools)
  - Security (e.g. Vault)
Overcoming Challenges: IDE Integration

IDE Integration:

- **VSCode**: General-use IDE.
  - **Extensions for D**: The user WebFreak has done a good job adding D support.
  - **Syntax Highlighting**: Looks great, responsive, welcoming.
  - **gdb, lldb**: Partial support
    - most expressions beyond primitives cannot be evaluated.
    - class members not displayed when debugging class function
```
setTimer(750.msecs,
{
    foreach (Name name; _schemaRegistry.getSchemaNames()) {
        // The data is now gone, make sure it gets sent.
        ubyte[] dataBytes;
        ushort count;
        _dataService.getAndClearData(name, count, dataBytes);
        auto bundle = new GenericDataBundle(name, count, dataBytes);
        logDebug("Writing to stem: GenericBundle\nname=%s, count=%d, dataBytes\nbundle name, bundle count, bundle data to string");
        continue;
        auto bundle = new GenericDataBundle(name, count, dataBytes);
        logDebug("Writing to stem: GenericBundle\nname=%s, count=%d, dataBytes\nbundle name, bundle count, bundle data to string");
    }
    if (dataBytes.length == 0)
        continue;
    auto bundle = new GenericDataBundle(name, count, dataBytes);
    logDebug("Writing to stem: GenericBundle\nname=%s, count=%d, dataBytes\nbundle name, bundle count, bundle data to string");
}
```

Debug and other configurations must be established by hand without auto-detection.

Despite existing configurations in dub, D IDE development is less "plug-and-play" than Java/Maven with IntelliJ or Eclipse.
Old Fashioned Tools Still Work

If speed and low resource usage are more important than good looks, classic tools still continue to work:
Emacs also works with the "gdb" command (here with "gdb-many-windows")
Overcoming Challenges: Profiling Tools

Profiling Tools: Valgrind

- Running through Valgrind (D Wiki: Other Dev Tools)
  - Run program through Valgrind, which has a smaller performance impact.
    
    $ \text{valgrind --tool=callgrind --collect-jumps=yes --callgrind-out-file=callgrind_out }$
    
    $\text{./mouth/target/funnel-mouth -- --avroSchemas=avro/user.avsc}$
  - Demangle D symbols to make them human readable:
    
    $\text{ddemangle callgrind_out > callgrind_out.demangle}$
  - View results using kcachegrind.
    
    $\text{kcache}grind \text{callgrind_out.demangle}$
Looks like validating JWT tokens is costly!
Overcoming Challenges: Memory Tools

Memory Profiling: Compiler option "-profile=gc"

- May also be enabled via dub through "dub build --build=profile-gc"
- Memory allocations are output to "profilegc.log"
- Output is reasonably formatted (albeit with long names), e.g.:

```
bytes allocated, allocations, type, function, file:line
4096000     500  ubyte[] vibe.internal.array.BatchBuffer!(ubyte, 0LU).BatchBuffer.capacity
../../../dub/packages/vibe-core-1.22.4/vibe-core/source/vibe/internal/array.d:580
662688      20709  std.array.Appender!(immutable(char)[]).Appender.Data
std.array.Appender!string.Appender.this /usr/include/dmd/phobos/std/array.d:3330
304000      1000  ubyte[] std.base64.Base64Impl!('-', '_', '\x00').decode!string.decode /usr/include/dmd/phobos/std/base64.d:1339
```
Overcoming Challenges: Memory Tools

Available tools still have gaps:
- No visual aid for tracking memory allocations.
- No ability to do memory sampling.

Languages like Java have such tools available =>
Overcoming Challenges: Profiling Tools to Avoid (for now)

Profiling Tools: dmd -profile

● Theoretically this is built in: Compile using "-profile"
  ○ Compile using the "-profile" switch or the dub build profile, e.g.
    $ dub build --build=profile

● Difficult to use in practice.
  ○ Compilation frequently fails, e.g.
    /usr/include/dmd/phobos/std/concurrency.d(2160,17): Warning: statement is not reachable
  ○ Compilation using "-profile" produces hard to read results.
  ○ Performance is impacted considerably.
  ○ The output format is undocumented and contains no labels.
Overcoming Challenges: Library Coverage

Library Coverage: Common Web Service libraries are missing in D... ...but D is an amazing language for importing libraries.

D's multi-paradigm approach makes it extremely compatible with most other programming languages.

<table>
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</table>
Porting Libraries to D

D's familiar syntax makes it easy to quickly convert libraries from other languages with much less effort than usual.

For converting large libraries, a common strategy is:

1. Understand the chain of dependencies in the library, build outward starting from the deepest dependencies (typically utils).
2. Convert the library as literally and mechanically as possible, alterations can have cascading impacts which are hard to track.
3. Be sure to migrate tests and validate work as it moves along.
4. Refactor a single feature at a time.
Typical range algorithms don't always work when converting libraries. Iterator-capable containers are often needed to port algorithms.

```cpp
// Position the iterator at the first cell that overlaps or follows
// "target", i.e. such that range_max() >= target.range_min().
void SeekTo(const RangeIterator& target) {
    it_.Seek(target.range_min());
    // If the current cell does not overlap "target", it is possible that the
    // previous cell is the one we are looking for. This can only happen when
    // the previous cell contains "target" but has a smaller S2CellId.
    if (it_.done() || it_.id().range_min() > target.range_max()) {
        if (it_.Prev() && it_.id().range_max() < target.id()) it_.Next();
    }
    Refresh();
}
```
Another example algorithm that requires iterators to be properly converted. In D, such containers are simply not part of the standard library, but can be implemented, e.g. `btree.d` and `btree_map.d`.

```d
// TODO(ericv): Use a single iterator (iter_) below and save position
// information using pair<S2CellId, const S2ShapeIndexCell*> type.
auto next = new S2ShapeIndex.Iterator(
    _index, S2ShapeIndex.InitialPosition.BEGIN);
auto last = new S2ShapeIndex.Iterator(
    _index, S2ShapeIndex.InitialPosition.END);
last.prev();
if (next.id() != last.id()) {
    // The index has at least two cells. Choose a level such that the entire
    // index can be spanned with at most 6 cells (if the index spans multiple
    // faces) or 4 cells (if the index spans a single face).
    int level = next.id().getCommonAncestorLevel(last.id()) + 1;
    // Visit each potential top-level cell except the last (handled below).
    S2CellId last_id = last.id().parent(level);
Putting it Into Practice
A Practical Problem

What do the following industries have in common?

- Ride Hailing
- Micro Mobility
- IoT and Sensor Monitoring
- Military/Security Situational Awareness
A Practical Problem

What do the following industries have in common?

- Ride Hailing
- Micro Mobility
- IoT and Sensor Monitoring
- Military/Security Situational Awareness

They all have very high volumes of data updates and queries in real-time.
By the Numbers

- 1,000 Taxis per City
- 50 Cities
- 1 position/status update per 10 seconds

**5,000 updates per second!**

- 10M people per city
- 5% of users look at the app per day
- each user session makes 5 queries

**1,500 queries per second!**

Numbers get big, fast.
Need for Speed

Customers need flexible queries... an RDS would fit.

Write performance needs to be extreme... a data-cache would fit.

Traditional solutions get VERY expensive as the system grows and grows, starting from a simple RDS, to multiple read-replicas, to sharding, to cache layers in Redis, etc.

Funnel-Labs.io was created to tackle this challenge with a ready-made solution.
A Brief Look

A simple JavaScript example client.

Data format with coordinates to query.

http://demo-query.funnel-labs.io/

Query results shown visually.
What does it look like to a user?

1. **Authenticate** and get a JWT token.
2. Upload a **schema**.
3. Upload your data as desired.
4. Execute queries on the data.

```json
{
  "namespace": "com.example",
  "name": "Staff",
  "type": "record",
  "fields": [
    {
      "name": "loc",
      "type": {
        "type": "record",
        "name": "Location",
        "fields": [
          {"name": "latitude", "type": "double"},
          {"name": "longitude", "type": "double"}
        ]
      },
      "idx_type": "spatial"
    }
  ]
}
```

```
HTTP POST
https://auth.funnel-labs.io/auth/realms/funnel/protocol/openid-connect/token

client_id=service
&grant_type=password
&username=ExampleInc
&password=abcd1234
```

```
$ curl
https://api.funnel-labs.io/users/ExampleInc/data/com.example/Staff \\
-X POST -d \\
'{"id": 3, 
"job": "WAITER", 
"loc": {"latitude": 1.0, "longitude": 2.0}, 
"rating": 1.3, 
"name": "Bob"}' \\
-H 'Content-Type: application/json' \\
-H "Authorization: Bearer $ACCESS_TOKEN"
```

OK

loc WITHIN 2km of (13.34, 43.21)

rating > 2.5 AND type = ECONOMY
Basic Structure of Funnel System

The Funnel System was built to solve this problem as cheaply as possible.

Data collected into batches to reduce network load.

Data replicated to spouts using pub/sub in batches.

Data indexed in RAM for queries.

Arbitrary queries pour in.
**Dependencies**

- **Vibe.d**: Sönke Ludwig - Web Server and concurrency
- **Pegged**: Philippe Sigaud - Grammar based parser generator

- **S2 Geometry**: Converted to D from C++ as `s2geometry-d`
  - A team of 1 converted this 70K loc library more completely than Go, Rust, Java, etc.
- **Avro**: Converted to D from Java as `avro-d`
  - Converted in only a few weeks of work.

**Using D, small teams can match the productivity of bigger organizations.**
Build Pipeline
# Create an Alpine Linux image w/ docker & ldg2.
FROM docker:dind
RUN apk update

# Add tools and dependencies.
RUN apk add --no-cache gcc
RUN apk add --no-cache ldc

# The dub build tool is used to build a D repository.
RUN apk add --no-cache -X https://dl-cdn.alpinelinux.org/alpine/edge/testing dub

# Add any C dependencies needed.
RUN apk add --no-cache openssl-dev
RUN apk add --no-cache musl-dev
RUN apk add --no-cache zlib-dev

# Install AWS CLI tools for use with ECR
RUN apk add --no-cache aws-cli
RUN aws --version

# Create a build user with reduced privileges.
ARG USER=default
ENV HOME /home/$USER
RUN apk add --update sudo
RUN adduser -D $USER 
   && echo "$USER ALL=(ALL) NOPASSWD: ALL" > /etc/sudoers.d/$USER 
   && chmod 0440 /etc/sudoers.d/$USER

USER $USER
WORKDIR $HOME
Many options exist, but minimizing engineering cost, server setup, maintenance, etc. can pay off in spades.

A classic Jenkins server can be set up, but has costs whether in use or not.

Alternatively, cloud-services like AWS CodePipeline only charge for build-time.

Add a buildspec.yml file to your project which runs in your build docker container, and you're off to the races.
Dockerized Build/Deploy Environments

When building using cloud-based resources like AWS CodePipeline, they do not know what kind of environment you need to build and run your application.

Generally, you will need 3 different types of docker containers:

- **Build Environment**: Has build tools like a compiler, library headers, and can upload built images to Docker.
- **Runtime Base**: A common environment for running D programs, with D runtime libraries.
- **Project Runtime**: The container for a specific project, with the compiled program and any additional files.
Build Pipeline: buildspec.yml

With AWS CodeBuild, the buildspec.yml runs in your build environment, and builds a deployable image.

```yaml
version: 0.2
env:
  variables:
    # Multiple threads is only supported in ldc2.
    DFLAGS: "--threads=4"
phases:
  install:
    commands:
      - nohup /usr/local/bin/dockerd --host=unix:///var/run/docker.sock --host=tcp://127.0.0.1:2375 &
      - timeout 15 sh -c "until docker info; do echo .; sleep 1; done"
  pre_build:
    commands:
      # Log into docker and the container registry.
      - AWS_ACCOUNT_ID=$(echo $CODEBUILD_BUILD_ARN | cut -d ':' -f5)
      - COMMIT_HASH=$(echo $CODEBUILD_RESOLVED_SOURCE_VERSION | cut -c 1-7)
      - IMAGE_NAME=funnel-mouth
      - IMAGE_TAG=${COMMIT_HASH:=latest}
      - ECR_REPO=$AWS_ACCOUNT_ID.dkr.ecr.$AWS_DEFAULT_REGION.amazonaws.com
      - aws ecr get-login-password --region $AWS_DEFAULT_REGION | docker login --username AWS --password-stdin
  build:
    commands:
      - echo Build started on `date`
      - cd mouth
      - dub build -b release
      - dub test -b release
      - echo Creating docker image...
      - docker build --build-arg IMAGE_BASE=$ECR_REPO/runtime:latest -t $IMAGE_NAME:$IMAGE_TAG
      - docker tag $IMAGE_NAME:$IMAGE_TAG $ECR_REPO/$IMAGE_NAME:$IMAGE_TAG
      - docker tag $IMAGE_NAME:$IMAGE_TAG $ECR_REPO/$IMAGE_NAME:latest
  post_build:
    commands:
      - echo Build completed on `date`
      - echo Pushing the Docker image...
      - docker push $ECR_REPO/$IMAGE_NAME:$IMAGE_TAG
      - docker push $ECR_REPO/$IMAGE_NAME:latest
```

Docker Containers: Example Project Container

Projects have their own Dockerfile, defining what files and arguments are needed.

```
# Container definition for the funnel-mouth project.
ARG IMAGE_BASE=runtime:latest
FROM $IMAGE_BASE

## Environment Variables
# LISTEN_PORT - The port where HTTP requests are received.
# STEM_SUB_HOST - The hostname of a mouth-stem server.

ENV LISTEN_PORT=8080
ENV STEM_SUB_HOST=127.0.0.1

RUN mkdir service

WORKDIR service
COPY target/funnel-mouth .
RUN sudo chown -R $USER .

EXPOSE ${LISTEN_PORT}

ENTRYPOINT ./funnel-mouth --port=${LISTEN_PORT} --stemSubUrl=tcp://${STEM_SUB_HOST}:5000 --vverbose
```
A small tidy runtime environment enables faster deployments.

# Light-weight runtime environment.
FROM alpine:3.15

# Numerous shared libraries needed in the environment.
RUN apk add ldc-runtime
RUN apk add openssl
RUN apk add musl
RUN apk add zlib

# Install AWS CLI tools for use with ECR
RUN apk add --no-cache aws-cli
RUN aws --version

# Create a build user with reduced privileges.
ARG USER=default
ENV HOME /home/$USER

RUN apk add --update sudo
RUN adduser -D $USER \
    && echo "$USER ALL=(ALL) NOPASSWD: ALL" > \
    /etc/sudoers.d/$USER \
    && chmod 0440 /etc/sudoers.d/$USER

USER $USER
WORKDIR $HOME
Deployment
Example Deployment Flow

GitHub

Repository

AWS CodePipeline

Amazon Elastic Container Registry (Amazon ECR)

Registry

Amazon Elastic Container Service (Amazon ECS)

Service
Infrastructure and Deployment

If your goal is to lower costs, keep costs in mind when choosing how to deploy!

For example, should an AWS setup use AWS Elastic Kubernetes Service (EKS) or AWS Elastic Container Service (ECS)?

In terms of price:

- EKS has a base-price of $0.10 per hour, i.e. $72 per month, plus EC2/Fargate.
- ECS has no such base price, only the cost of EC2/Fargate resources.
Right Tools for the Job

If you plan on deploying a project, the tools being used should match the skills of the people doing the work.

Kubernetes has excellent, albeit lengthy and complicated documentation. Deployment is done via YAML files, which are constructed very carefully.

If you are short on people and do not have dedicated DevOps staff, consider something like AWS Cloud Development Kit (CDK).

CDK consists of programming APIs that generate config files for Kubernetes, ECS, Terraform, etc.

Program your deployment in a familiar environment with development tools.
Create Reuseable Functions for Standard Configurations

// Constructs a service that follows all the standard rules described in {@link StdServiceSettings}.
public FargateService constructStdService(Cluster cluster, ApplicationListener applicationListener, StdServiceSettings settings) {
    // A FargateService is a load-balanced set of Tasks, each of which are defined by a TaskDefinition.
    FargateTaskDefinition taskDefinition = FargateTaskDefinition.Builder.create(this, settings.name + "-td")
        .cpu(settings.cpu)
        .memoryLimitMiB(settings.memoryLimitMiB)
        .build();

    // Define and add a project container and to the TaskDefinition.
    ContainerDefinition stdContainerDefinition = taskDefinition.addContainer(settings.name, ContainerDefinitionOptions.builder()
        .image(ContainerImage.fromEcrRepository(Repoitory.fromRepositoryName(this, settings.name + "-ci", settings.name), "latest"))
        .portMappings(List.of(
            PortMapping.builder()
                .hostPort(8080)
                .containerPort(8080)
                .build()))
        .build());

    FargateService fargateService = FargateService.Builder.create(this, settings.name + "-service")
        .serviceName(settings.name)
        .cluster(cluster) // Required
        .securityGroups(settings.securityGroup != null ? List.of(settings.securityGroup) : null)
        .desiredCount(settings.desiredCount) // Default is 1
        .taskDefinition(taskDefinition)}
Example Deployment Config in Java

```java
FargateService mouthService =
    constructStdService(
        networkStack.getEcsCluster(), loadBalancerStack.getHttpsListener(),
        StdServiceSettings.builder()
            .name("funnel-mouth")
            .securityGroup(networkStack.getSecurityGroup())
            .hostname(hostname)
            .urlPrefixes(List.of("/users/*/data/*"))
            .httpRequestMethods(List.of("POST"))
            .environment(Map.of(
                "JWT_PUBLIC_KEY_URL", "https://auth.funnel-labs.io/auth/realms/funnel",
                "ADMIN_REST_URL", "http://funnel-admin.local:8080")
            .cpu(512)
            .memoryLimitMiB(1024)
            .desiredCount(2)
            .build());
```

The important point is: code-completion, documentation, functions, and other programming features can lower the cost of setting up infrastructure.
Concluding Remarks

- D can deliver significantly higher performance and lower costs than higher-level languages like Java, Python, JavaScript, Ruby, etc.
- D is very feature rich, making it especially suitable for bringing in libraries from other programming languages.
- D has a good balance of feature to help speed up programming (like garbage collection) without sacrificing much for performance.
- However, D suffers from a smaller community and tooling needs some love.
Thank you!
Questions?
Feedback?