TÉCNICO LISBOA

Serverless Dataflows: ...

Diogo Alexandre Ferreira de Jesus

Thesis to obtain the Master of Science Degree in

Computer Science and Engineering

Supervisor: Luis Manuel Antunes Veiga

Examination Committee

Chairperson: Prof. Name of the Chairperson
Supervisor: Luis Manuel Antunes Veiga
Member of the Committee: Prof. Name of First Committee Member

October 2025

Declaration
I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Acknowledgments

Abstract

Serverless computing has become a suitable cloud paradigm for many applications, prized for its operational ease, automatic scalability, and fine-grained pay-per-use pricing model. However, executing workflows, which are compositions of multiple tasks, in Function-as-a-Service (FaaS) environments remains inefficient. This inefficiency stems from the stateless nature of functions, and a heavy reliance on external services for intermediate data transfers and inter-function communication.

In this document, we introduce a decentralized DAG engine that leverages historical metadata to plan and influence task scheduling. Our solution encompasses metadata management, static workflow planning, and a worker-level scheduling strategy designed to drive workflow execution with minimal synchronization. We compare our scheduling approach against WUKONG, another decentralized serverless DAG engine. Our evaluation demonstrates that utilizing historical information significantly improves performance and reduces resource utilization for workflows running on serverless platforms.

Keywords

Maecenas tempus dictum libero; Donec non tortor in arcu mollis feugiat;Cras rutrum pulvinar tellus.

Resumo

A computação serverless tornou-se um paradigma de nuvem adequado para muitas aplicações, valorizado pela sua facilidade operacional, escalabilidade automática e modelo de preços granular baseado na utilização. Contudo, a execução de workflows, que são composições de múltiplas tarefas, em ambientes Function-as-a-Service (FaaS) permanece ineficiente. Esta ineficiência resulta da natureza *stateless* (sem estado) destas funções e de uma forte dependência de serviços externos para transferências de dados intermédios e comunicação entre funções.

Neste documento, apresentamos um motor de workflows serverless descentralizado que utiliza métricas recolhidas durante a execução para planear e influenciar o *scheduling* de tarefas. A nossa solução abrange a gestão de metadados, o planeamento estático de workflows e uma estratégia de *scheduling* ao nível dos workers concebida para conduzir a execução de workflows de uma forma descentralizada e com sincronização mínima. Comparamos a nossa abordagem com o WUKONG, outro motor de workflows serverless descentralizado. A nossa avaliação demonstra que a utilização de informação histórica melhora significativamente o desempenho e reduz a utilização de recursos para workflows executados em plataformas serverless.

Palavras Chave

Cloud Computing; Serverless; FaaS; Serverless Workflows; Serverless DAGs; Metadata; Workflow Prediction

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1

Introduction

Contents

Function-as-a-Service (FaaS) represents a serverless cloud computing paradigm that simplifies application deployment by abstracting away infrastructure management. It provides automatic, elastic scalability—potentially without limit—along with a fine-grained, pay-per-use pricing model. This has led to its widespread adoption for event-driven systems, microservices, and web services on platforms like AWS Lambda [1], Azure Functions [2], and Google Cloud Functions [3]. These applications typically benefit the most from FaaS because they are lightweight, stateless, and characterized by highly variable or unpredictable workloads, allowing them to leverage serverless platforms' on-demand scalability and cost-efficiency.

This paradigm is also increasingly used to execute complex scientific and data processing workflows, such as the Cybershake [4] seismic hazard analysis or Montage [5], an astronomy image mosaicking workflow. These applications are structured as workflows—formally represented as Directed Acyclic

Graphs (DAGs) of interdependent tasks. However, efficiently executing these complex workflows on serverless platforms remains a significant challenge.

1.1 Problem/Motivation

Despite their advantages, serverless platforms present several limitations that complicate the execution of complex workflows. Since these platforms allow scaling down to zero resources to save costs, they can also introduce unpredictable latency, known as *cold starts* [6], particularly for short-lived functions, affecting overall workflow performance. The lack of *direct inter-function communication* [7] means that tasks often have to rely on external services, such as message brokers or databases to exchange intermediate data, which can increase overhead and reduce efficiency. Interoperability between platforms is further limited by the use of platform-specific workflow definition languages, which restricts the portability of workflows across different serverless environments. Additionally, while statelessness simplifies scaling and management, it can introduce overhead and complexity for applications that require continuity or coordination across multiple function invocations. Finally, developers have limited control over the underlying infrastructure, restricting the ability to optimize resource usage or tune performance for specific workloads.

Several solutions have emerged to address the limitations of serverless platforms. Stateful functions (e.g., AWS Step Functions [8], Azure Durable Functions [9], and Google Cloud Workflows [10]) expand the range of applications that can run on serverless platforms by maintaining state across multiple function invocations, coordinating complex workflows, and providing built-in fault tolerance. Other approaches tackle limitations at the runtime level, proposing extensions to FaaS platforms (e.g., Faa$T [11], Palette [12], Lambdata [13]) or entirely new serverless architectures (e.g., Apache OpenWhisk [14]).

Other research projects focus on improved orchestration and coordination mechanisms that work on top of FaaS platforms, such as Boxer [15], Pheromone [16], Triggerflow [17], FaDO [18], and FMI [19]. These solutions aim to overcome the inherent limitations of stateless functions through intelligent middleware layers that optimize function coordination, data placement, and workflow execution without requiring modifications to the underlying FaaS infrastructure.

Finally, some workflow-focused solutions (e.g., WUKONG [20], Unum [21], DEWEv3 [22]) employ scheduling strategies and workflow-level optimizations to enhance efficiency, primarily by improving data locality to bring computation closer to the data and minimize reliance on external services.

1.2 Gaps in prior work

These workflow-focused approaches, however, often use the *same resources for all tasks* in a workflow and rely on *"one-step scheduling"*, making decisions based solely on the immediate workflow stage without considering the broader context or the downstream effects of their decisions. This combination of homogeneous worker configurations and limited scheduling foresight can lead to inefficient use of resources when tasks have diverse requirements. Furthermore, the heuristic-based approaches used by other solutions can be inefficient in certain scenarios, as they lack mechanisms to adapt worker resource allocations to the specific needs of individual tasks. Moreover, we found no prior work that leverages metadata or historical metrics to inform scheduling decisions across an entire serverless workflow.

1.3 Proposed Solution

These research gaps motivated the central research question of this work: if we have knowledge of all DAG tasks, collect sufficient metrics on their behavior, and understand how they are composed to form the full workflow, can we leverage this information to make smarter scheduling decisions that minimize *makespan* (the total time taken to complete a workflow) and maximize resource efficiency in a FaaS environment?

To answer this research question, we propose a decentralized serverless workflow execution engine that leverages historical metadata from previous workflow runs to generate informed task allocation plans, which are then executed by FaaS workers in a choreographed manner, without needing a central scheduler. By relying on such planning, our approach aims to minimize the usage of external cloud storage services, which are often employed by similar solutions for intermediate data exchange and synchronization, while also avoiding the inefficiencies of homogeneous worker resource allocations.

1.4 Document Organization

The rest of this document is organized as follows: In Chapter 3 we do a background analysis on the serverless landscape, analyzing serverless platforms, offerings, open-source solutions and existing research work. In Chapter 4 we present our proposed solution, detailing its architecture and implementation of the core layers and components. In Chapter 5, we evaluate our proposed solution by comparing it with WUKONG's scheduling algorithm as well as with algorithms we have implemented. Finally, in Chapter 6 we conclude our work and discuss future directions for research.

2

Related Work

Contents

In this section, we explore the serverless computing landscape, starting by exposing the architecture of a typical serverless computing platform, referencing the use cases for this new cloud computing model, and presenting both commercial and open-source offerings. We also delve into workflows, showing how they can be represented, how they are run and managed, and contrasting traditional frameworks for workflow management with more recent solutions that explore cloud technologies, including serverless. Then, we write about three extension proposals to the current serverless platforms design, aiming to improve data locality. We finish this section by presenting relevant workflow orchestrators and schedulers (serverful, serverless, and hybrid) for executing tasks, highlighting their advantages but also some

of their limitations and inefficiencies.

2.1 Serverless Computing

Serverless computing represents a paradigm shift in how applications are developed and deployed. At its core, it allows developers to focus on business logic without caring about the underlying infrastructure. This cloud computing model encompasses a range of cloud offerings that *abstract away infrastructure management*. At the storage and database layer, services such as serverless databases and object stores automatically scale with demand and charge based on actual usage. At the application level, **Backend-as-a-Service** (BaaS) platforms provide ready-to-use components like authentication, messaging, or data synchronization. Finally, at the compute layer, **Function-as-a-Service** (FaaS) represents the most flexible and fine-grained model, allowing developers to deploy individual functions that are executed on demand in response to events. In this document, we focus specifically on FaaS, as it is the model most relevant to our work.

The Function-as-a-Service (FaaS) model is now offered by major cloud providers, including Amazon (Lambda [1]), Google (Cloud Run Functions [3]), Microsoft (Azure Functions [2]), and Cloudflare (Workers [23]). In addition to these commercial offerings, several open-source runtimes such as OpenWhisk [14], OpenFaaS [24], and Knative [25] provide developers with alternatives for deploying FaaS in self-managed or hybrid environments.

2.1.1 Advantages

Recent industry reports [1] show that serverless computing has seen rapid adoption over the last few years. For example, in 2024 the global serverless computing market was estimated at USD 24.51 billion, and it is projected to more than double to USD 52.13 billion by 2030, with a compound annual growth rate (CAGR) of about 14.1%. Function-as-a-Service (FaaS) constitutes the majority service model, representing over 60% of serverless market share in 2024. This rapid growth highlights the increasing appeal of serverless architectures, which can be attributed to the following key benefits:

- **Operational Simplicity** means that developers are abstracted away from the underlying infrastructure management, without worrying about server maintenance, scaling, or provisioning. This enables faster development and deployment cycles;
- **Scalability** means the FaaS runtime handles increasing workloads by automatically provisioning additional computational capacity as demand grows, ensuring that applications remain respon-

[1] https://www.grandviewresearch.com/industry-analysis/serverless-computing-market-report

sive and performant. This makes the FaaS model ideal for applications with *highly variable* or *unpredictable* usage patterns, where we don't know *how many* or *when* requests will arrive;

- **Pay-per-use**: FaaS provides a pricing model where users are only charged for the resources used during the actual execution time over the memory used by their functions, rather than for pre-allocated resources (as in Infrastructure-as-a-Service).

Given these advantages, the serverless model is particularly attractive for applications with *highly variable* or *unpredictable* workloads, such as web services, event-driven pipelines, and real-time data processing. It also suits applications that benefit from rapid iteration and deployment, including microservices, and APIs, where minimizing operational overhead is crucial. Furthermore, serverless can be advantageous in cost-sensitive contexts, where pay-per-use pricing reduces expenses for workloads that do not require continuous execution.

2.1.2 Limitations

Li et al. [26] surveys the serverless computing landscape, highlighting its benefits, challenges and research opportunities. The challenges mentioned include:

- **Startup Latencies**: It's the time it takes for a function to start executing user code. Cold starts (explained further) can be critical, especially for functions with short execution times;
- **Isolation**: In serverless, multiple users share the same computational resources (often the same Kernel). This makes it crucial to properly isolate execution environments of multiple users;
- **Scheduling Policies**: Traditional cloud computing policies were not designed to operate in dynamic and ephemeral environments, such as FaaS's;
- **Resource Management**: Particularly storage and networking, needs to be optimized (by service providers) to handle the low latency and scalability requirements of serverless computing. The lack of direct inter-function networking is an example of a limitation that narrows down the variety of applications that can currently run on FaaS, as some may not support the overhead of using intermediaries (external storage) for data exchange;
- **Fault-Tolerance**: Cloud platforms impose restrictions on developers by encouraging the development of *idempotent functions*. This makes it easier for providers to implement fault-tolerance by retrying failed function executions.

Hellerstein et al. [7] portrays FaaS as a *"Data-Shipping Architecture"*, where data is intensively moved to code, through external storage services like databases, bucket storage or queues, to circumvent

the limitation of inter-function direct communication. This can greatly degrade performance, while also incurring extra costs.

To overcome these limitations and explore the opportunities of serverless computing, *"Serverless Computing: State-of-the-Art, Challenges and Opportunities"* (Li et al.) gathered research being carried out on several fronts. Applying *machine learning* to resource management aims to optimize resource allocation and predict application needs, reducing costs and latencies. Although promising, the latency requirements and complexity of the settings of the machine learning approaches are not yet satisfactory. Integration with edge computing offers the opportunity to leverage the computing power of thousands of edge devices to provide low-latency services, making it a promising direction for serverless computing.

2.2 Workflow Execution

2.3 Relevant Related Systems

2.3.1 Serverless Workflow Scheduling

2.4 Discussion/Analysis

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Architecture

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3.1 Workflow Definition Language

3.2 Overview

3.3 Metadata Management

3.4 Static Workflow Planning

3.4.1 Simulation Layer

3.4.2 Planners

3.4.3 Optimizations

3.5 Decentralized Scheduling

Algorithm 1 Worker Assignment Algorithm

Require: $nodes$, $predictions$, $base\_rc$, SLA, $MAX\_CLUSTERING$

$assigned \leftarrow \emptyset$

▷ nodes are topologically sorted

for all $n \in nodes$ **do**
  if $n \in assigned$ **then**
    continue
  end if
  if $n.upstream = \emptyset$ **then** ▷ root nodes
    $roots \leftarrow \{r \in nodes \mid r.upstream = \emptyset \wedge r \notin assigned\}$
    AssignGroup(*null*, $roots$)
  else if $|n.upstream| = 1$ **then** ▷ 1→1 or 1→N
    $u \leftarrow n.upstream[0]$
    if $|u.downstream| = 1$ **then**
      AssignWorker($[n]$, $u.worker$) ▷ reuse worker
    else ▷ 1→N
      $fanout \leftarrow \{d \in u.downstream \mid d \notin assigned\}$
      AssignGroup($u.worker$, $fanout$)
    end if
  else ▷ N→1
    $outputs \leftarrow \{u.worker : predictions.output\_size(u) \mid u \in n.upstream\}$
    $best \leftarrow \arg\max_{w \in outputs} outputs[w]$
    AssignWorker($[n]$, $best$)
  end if
end for

function AssignGroup(up_worker, $tasks$)
  if $tasks = \emptyset$ **then return**
  end if
  $exec\_t \leftarrow \{t : predictions.exec\_time(t) \mid t \in tasks\}$
  $out\_sz \leftarrow \{t : predictions.output\_size(t) \mid t \in tasks\}$
  $median \leftarrow$ Median($exec\_t.values()$)
  $longs \leftarrow \{t \in tasks \mid exec\_t[t] > median\}$
  $shorts \leftarrow$ SortLargerOutputFirst($\{t \in tasks \mid exec\_t[t] \leq median\}$)

▷ 1) cluster short tasks with bigger outputs on upstream worker
  if $up\_worker \neq$ *null* $\wedge\ shorts \neq \emptyset$ **then**
    $cluster \leftarrow shorts[0 : MAX\_CLUSTERING]$
    AssignWorker($cluster$, up_worker)
    $shorts \leftarrow shorts[MAX\_CLUSTERING :]$
  end if

▷ 2) pair long tasks with remaining short tasks (1 long per group)
  while $longs \neq \emptyset \wedge shorts \neq \emptyset$ **do**
    $cluster \leftarrow [longs[0]] + shorts[0 : MAX\_CLUSTERING - 1]$
    $worker\_id \leftarrow$ NewWorkerId
    AssignWorker($cluster$, $worker\_id$)
    $longs \leftarrow longs[1 :]$
    $shorts \leftarrow shorts[MAX\_CLUSTERING - 1 :]$
  end while

▷ 3) group remaining short tasks
  while $shorts \neq \emptyset$ **do**
    $worker\_id \leftarrow$ NewWorkerId
    AssignWorker($shorts[0 : MAX\_CLUSTERING]$, $worker\_id$)
    $shorts \leftarrow shorts[MAX\_CLUSTERING :]$
  end while

▷ 4) group remaining longs (half-size)
  $half \leftarrow \max(1, \lfloor MAX\_CLUSTERING/2 \rfloor)$
  while $longs \neq \emptyset$ **do**
    $worker\_id \leftarrow$ NewWorkerId
    AssignWorker($longs[0 : half]$, $worker\_id$)
    $longs \leftarrow longs[half :]$
  end while
end function

Algorithm 2 Resource Downgrading Algorithm

Require: dag, $nodes$, $critical\_path\_ids$, $original\_cp\_time$, $configs$, $predictions$

$workers\_outside \leftarrow \emptyset$

▷ 1) Identify workers outside the critical path

for all $n \in nodes$ **do** ▷ nodes are topologically sorted

  $wid \leftarrow n.worker\_id$

  if $n.id \notin critical\_path\_ids \wedge \forall cp \in dag.critical\_path\_nodes : wid \neq cp.worker\_id$ **then**

    $workers\_outside \leftarrow workers\_outside \cup \{wid\}$

  end if

end for

$nodes\_outside\_cp \leftarrow \{n \in nodes \mid n.id \notin critical\_path\_ids\}$

▷ 2) Attempt downgrade for each worker outside critical path

for all $wid \in workers\_outside$ **do**

  $last\_good\_rc \leftarrow \{n.id : n.config \mid n \in nodes\_outside\_cp \wedge n.worker\_id = wid\}$

▷ Iterate through weaker configurations (skip strongest at index 0)

  for $i \leftarrow 1$ **to** $|configs| - 1$ **do**

    $trial \leftarrow configs[i].\textsc{Clone}(wid)$

▷ Apply trial configuration to all nodes of this worker

    for all $n \in nodes\_outside\_cp$ **do**

      if $n.worker\_id = wid$ **then**

        $n.config \leftarrow trial$

      end if

    end for

▷ Recompute workflow timing with predictions

    $cp\_time \leftarrow \textsc{SimulateCriticalPathTime}(dag)$

    if $cp\_time = original\_cp\_time$ **then**

▷ Downgrade acceptable, record as last good state

      for all $n \in nodes\_outside\_cp$ **do**

        if $n.worker\_id = wid$ **then**

          $last\_good\_rc[n.id] \leftarrow n.config$

        end if

      end for

    else

▷ Downgrade increases critical path, revert and move on to the next worker

      for all $n \in nodes\_outside\_cp$ **do**

        if $n.worker\_id = wid$ **then**

          $n.config \leftarrow last\_good\_rc[n.id]$

        end if

      end for

      break ▷ move to next worker

    end if

  end for

end for

4

Evaluation

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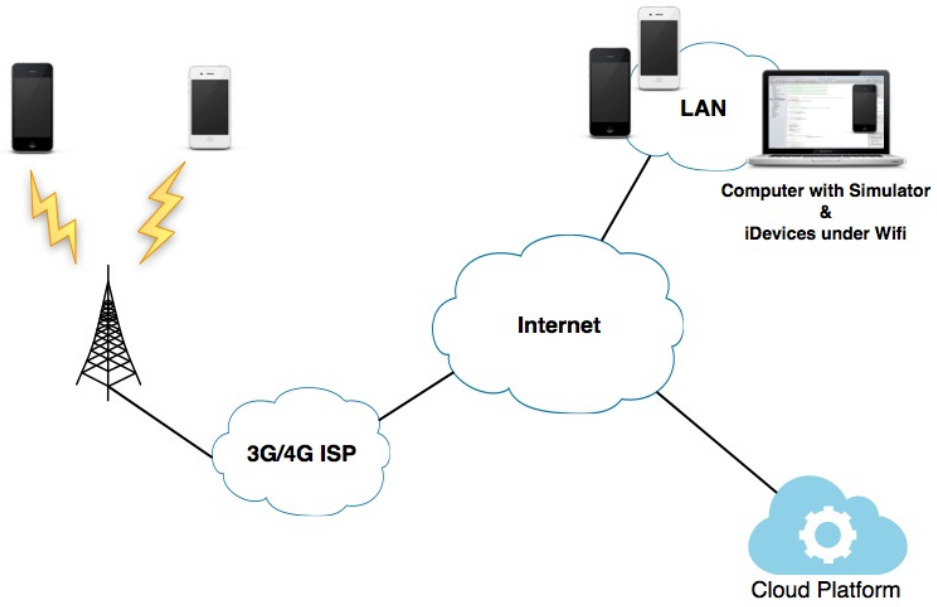

Figure 4.1: Test Environment

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Table 4.1: Network Link Conditioner Profiles

Network Profile	Bandwidth	Packets Droped	Delay
Wifi	40 mbps	0%	1 ms
3G	780 kbps	0%	100 ms
Edge	240 kbps	0%	400 ms

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N_j Is the number of times peer j has been optimistically unchoked.

n_j Among the N_j unchokes, the number of times that peer j responded with unchoke or supplied segments to peer p.

$C_{r[j]}$ The cooperation ratio of peer j. If peer j never supplied peer p, the information of $C_{r[j]}$ may not be available.

$C_{r(max)}$ The maximum cooperation ratio of peer p’s neighbors, i.e., $C_{r(max)} = max(C_r)$.

$$G_j = \begin{cases} \dfrac{n_j C_{r[j]}}{N_j} & \text{if } n_j > 0 \\ \dfrac{C_{r(max)}}{N_j + 1} & \text{if } n_j = 0 \end{cases} \tag{4.1}$$

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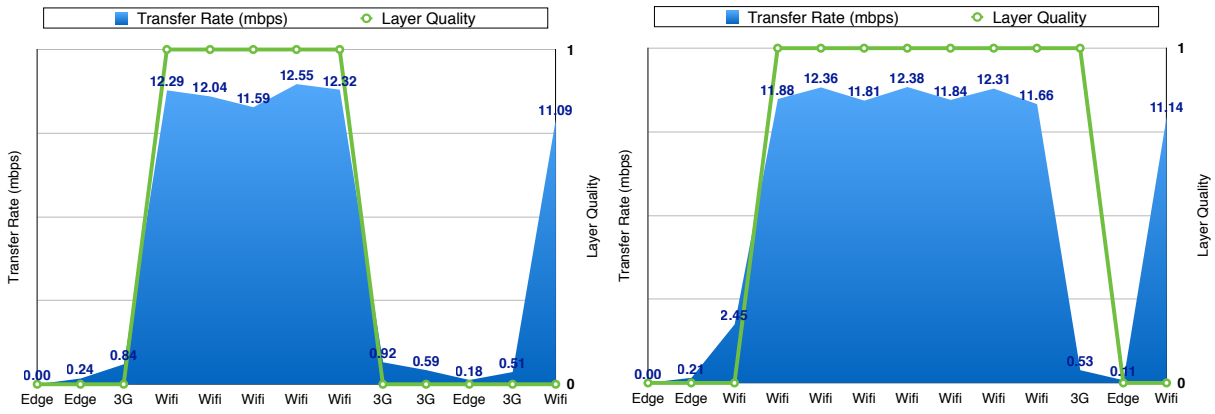

(a) Adaptation System Test 4

(b) Adaptation System Test 5

Figure 4.2: Adaptation System Behavior Test

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5

Conclusion

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Rui Cruz
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5.1 Conclusions

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5.2 System Limitations and Future Work

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A

Code of Project

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Listing A.1: Example of a XML file.

```
<?xml version="1.0" encoding="UTF-8"?>
<StreamInfo version="2.0">
    <Clip duration="PT01M0.00S">
        <BaseURL>videos/</BaseURL>
        <Description>svc_1</Description>
        <Representation mimeType="video/SVC" codecs="svc" frameRate="30.00" bandwidth="401.90"
            width="176" height="144" id="L0">
            <BaseURL>svc_1/</BaseURL>
            <SegmentInfo from="0" to="11" duration="PT5.00S">
                <BaseURL>svc_1-L0-</BaseURL>
            </SegmentInfo>
        </Representation>
```

```
13          <Representation mimeType="video/SVC" codecs="svc" frameRate="30.00" bandwidth="1322.60"
14              width="352" height="288" id="L1">
15              <BaseURL>svc_1/</BaseURL>
16              <SegmentInfo from="0" to="11" duration="PT5.00S">
17                  <BaseURL>svc_1-L1-</BaseURL>
18              </SegmentInfo>
19          </Representation>
20      </Clip>
21  </StreamInfo>
```

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This inline MATLAB code `for i=1:3, disp('cool'); end;` uses the `\mcode{}` command.[1]

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Listing A.2: `Matlab Function`

```
1  for i = 1:3
2      if i >= 5 && a ~= b        % literate programming replacement
3          disp('cool');          % comment with some LaTeXin it:  πx^2
4      end
5      [:,ind] = max(vec);
6      x_last = x(1,end) - 1;
7      v(end);
8      ylabel('Voltage (μV)');
9  end
```

Nullam ut mauris eu mi mollis luctus. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Sed cursus cursus velit. Sed a massa. Duis dignissim euismod quam. Nullam euismod metus ut orci.

[1] MATLAB Works also in footnotes: `for i=1:3, disp('cool'); end;`

Listing A.3: `function.m`

```
%   Copyright 2010 The MathWorks, Inc.
function ObjTrack(position)
% #codegen
% First, setup the figure
numPts = 300;              % Process and plot 300 samples
figure;hold;grid;          % Prepare plot window
% Main loop
for idx = 1: numPts
    z = position(:,idx);   % Get the input data
    y = kalmanfilter(z);   % Call Kalman filter to estimate the position
    plot_trajectory(z,y);  % Plot the results
end
hold;
end   % of the function
```

Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Phasellus eget nisl ut elit porta ullamcorper. Maecenas tincidunt velit quis orci. Sed in dui. Nullam ut mauris eu mi mollis luctus. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Sed cursus cursus velit. Sed a massa. Duis dignissim euismod quam. Nullam euismod metus ut orci. Vestibulum erat libero, scelerisque et, porttitor et, varius a, leo.

Listing A.4: HTML with CSS Code

```
<!DOCTYPE html>
<html>
  <head>
    <title>Listings Style Test</title>
    <meta charset="UTF-8">
    <style>
      /* CSS Test */
      * {
        padding: 0;
        border: 0;
        margin: 0;
      }
    </style>
    <link rel="stylesheet" href="css/style.css" />
  </head>
```

```
  <header> hey </header>
  <article> this is a article </article>
  <body>
    <!-- Paragraphs are fine -->
    <div id="box">
      <p>
        Hello World
      </p>
      <p>Hello World</p>
      <p id="test">Hello World</p>
      <p></p>
    </div>
    <div>Test</div>
    <!-- HTML script is not consistent -->
    <script src="js/benchmark.js"></script>
    <script>
      function createSquare(x, y) {
        // This is a comment.
        var square = document.createElement('div');
        square.style.width = square.style.height = '50px';
        square.style.backgroundColor = 'blue';

        /*
         * This is another comment.
         */
        square.style.position = 'absolute';
        square.style.left = x + 'px';
        square.style.top = y + 'px';

        var body = document.getElementsByTagName('body')[0];
        body.appendChild(square);
      };

      // Please take a look at +=
      window.addEventListener('mousedown', function(event) {
        // German umlaut test: Berührungspunkt ermitteln
        var x = event.touches[0].pageX;
        var y = event.touches[0].pageY;
```

```
54          var lookAtThis += 1;
55        });
56      </script>
57    </body>
58  </html>
```

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Listing A.5: HTML CSS Javascript Code

```
1
2  @media only screen and (min-width: 768px) and (max-width: 991px) {
3
4    #main {
5      width: 712px;
6      padding: 100px 28px 120px;
7    }
8
9    /* .mono {
10     font-size: 90%;
11   } */
12
13   .cssbtn a {
14     margin-top: 10px;
15     margin-bottom: 10px;
16     width: 60px;
17     height: 60px;
18     font-size: 28px;
19     line-height: 62px;
20   }
```

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Listing A.6: PYTHON Code

```
class TelgramRequestHandler(object):
    def handle(self):
        addr = self.client_address[0]          # Client IP-adress
        telgram = self.request.recv(1024)      # Recieve telgram
        print "From: %s, Received: %s" % (addr, telgram)
        return
```

B

A Large Table

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As B.1 shows, the data can be inserted from a file, in the case of a somehow complex structure. Notice the Table footnotes.

Table B.1: Example table

Benchmark: ANN	**#Layers** (1)	**#Nets** (2)	#Nodes* (3) = 8 · (1) · (2)	Critical path (4) = 4 · (1)	**Latency (T_{iter})** (5)
A1	**3–1501**	1	**24–12008**	**12–6004**	4
A2	501	1	4008	2004	**2–2000**
A3	10	**2–1024**	**160–81920**	40	60†
A4	10	50	4000	40	**80–1200**
Benchmark: FFT	**FFT size‡** (1)	*#Inputs* (2) = $2^{(1)}$	*#Nodes** (3) = 10 · (1) · (2)	*Critical path* (4) = 4 · (1)	**Latency (T_{iter})** (5)
F1	**1–10**	2–1024	**20–102400**	4–40	6–60†
F2	**5**	32	1600	20	**40 – 1500**
Benchmark: Random networks	**#Types** (1)	**#Nodes** (2)	*#Networks* (3)	*Critical path* (4)	**Latency (T_{iter})** (5)
R1	3	10–2000	500	*variable*	(4)
R2	3	50	500	*variable*	(4) × [1; · · · ; 20]

* *Excluding constant nodes.*
† *Value kept proportional to the critical path:* $(5) = (4) * 1.5$.
‡ *A size of* x *corresponds to a* 2^x *point FFT.*
Values in bold indicate the parameter being varied.

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And now an example (**??**) of a table that extends to more than one page. Notice the repetition of the Caption (with indication that is continued) and of the Header, as well as the continuation text at the bottom.

An example of a large Table that autofits the size to the page margins is illustrated in B.2. Please notice the text size that is shrunken in order fot the table to adjust to the page:

Table B.2: Sample Table.

URL	First Time Visit	Last Time Visit	URL Counts	Value	Reference
https://web.facebook.com/	1521241972	1522351859	177	56640	[facebook-2021]
http://localhost/phpmyadmin/	1518413861	1522075694	24	39312	database-management
https://mail.google.com/mail/u/	1516596003	1522352010	36	33264	Google-Gmail-2021
https://github.com/shawon100	1517215489	1522352266	37	27528	Code-Repository
https://www.youtube.com/	1517229227	1521978502	24	14792	Youtube-video-2021