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

I would like to thank my parents for their friendship, encouragement and caring over all these years, for always being there for me through thick and thin and without whom this project would not be possible. I would also like to thank my grandparents, aunts, uncles and cousins for their understanding and support throughout all these years.

Quisque facilisis erat a dui. Nam malesuada ornare dolor. Cras gravida, diam sit amet rhoncus ornare, erat elit consectetuer erat, id egestas pede nibh eget odio. Proin tincidunt, velit vel porta elementum, magna diam molestie sapien, non aliquet massa pede eu diam. Aliquam iaculis.

Fusce et ipsum et nulla tristique facilisis. Donec eget sem sit amet ligula viverra gravida. Etiam vehicula urna vel turpis. Suspendisse sagittis ante a urna. Morbi a est quis orci consequat rutrum. Nullam egestas feugiat felis. Integer adipiscing semper ligula. Nunc molestie, nisl sit amet cursus convallis, sapien lectus pretium metus, vitae pretium enim wisi id lectus.

Donec vestibulum. Etiam vel nibh. Nulla facilisi. Mauris pharetra. Donec augue. Fusce ultrices, neque id dignissim ultrices, tellus mauris dictum elit, vel lacinia enim metus eu nunc.

I would also like to acknowledge my dissertation supervisors Prof. Some Name and Prof. Some Other Name for their insight, support and sharing of knowledge that has made this Thesis possible.

Last but not least, to all my friends and colleagues that helped me grow as a person and were always there for me during the good and bad times in my life. Thank you.

To each and every one of you – Thank you.

Abstract

Nulla facilisi. In vel sem. Morbi id urna in diam dignissim feugiat. Proin molestie tortor eu velit. Aliquam erat volutpat. Nullam ultrices, diam tempus vulputate egestas, eros pede varius leo, sed imperdiet lectus est ornare odio. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Proin consectetuer velit in dui. Phasellus wisi purus, interdum vitae, rutrum accumsan, viverra in, velit. Sed enim risus, congue non, tristique in, commodo eu, metus. Aenean tortor mi, imperdiet id, gravida eu, posuere eu, felis. Mauris sollicitudin, turpis in hendrerit sodales, lectus ipsum pellentesque ligula, sit amet scelerisque urna nibh ut arcu. Aliquam in lacus. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Nulla placerat aliquam wisi. Mauris viverra odio. Quisque fermentum pulvinar odio. Proin posuere est vitae ligula. Etiam euismod. Cras a eros.

Keywords

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

Resumo

Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Vestibulum tortor quam, feugiat vitae, ultricies eget, tempor sit amet, ante. Donec eu libero sit amet quam egestas semper. Aenean ultricies mi vitae est. Mauris placerat eleifend leo. Quisque sit amet est et sapien ullamcorper pharetra. Vestibulum erat wisi, condimentum sed, commodo vitae, ornare sit amet, wisi. Aenean fermentum, elit eget tincidunt condimentum, eros ipsum rutrum orci, sagittis tempus lacus enim ac dui. Donec non enim in turpis pulvinar facilisis. Ut felis. Aliquam aliquet, est a ullamcorper condimentum, tellus nulla fringilla elit, a iaculis nulla turpis sed wisi. Fusce volutpat. Etiam sodales ante id nunc. Proin ornare dignissim lacus. Nunc porttitor nunc a sem. Sed sollicitudin velit eu magna. Aliquam erat volutpat. Vivamus ornare est non wisi. Proin vel quam. Vivamus egestas. Nunc tempor diam vehicula mauris. Nullam sapien eros, facilisis vel, eleifend non, auctor dapibus, pede.

Palavras Chave

Colaborativo; Codificaçãoo; Conteúdo Multimédia; Comunicação;

Contents

List of Figures

List of Tables

List of Algorithms

Listings

Acronyms

1

Introduction

Contents

1.1 Problem/Motivation

1.2 Gaps in prior work

1.3 Proposed Solution

1.4 Document Organization

2

Related Work

Contents

2.1 Serverless Computing

2.1.1 Platforms

2.1.2 Use Cases

2.1.3 Limitations

2.2 Workflow Execution

2.3 Relevant Related Systems

2.3.1 Serverless Workflow Scheduling

2.4 Discussion/Analysis

3

Architecture

Contents

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

Contents

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Morbi commodo, ipsum sed pharetra gravida, orci magna rhoncus neque, id pulvinar odio lorem non turpis. Nullam sit amet enim. Suspendisse id velit vitae ligula volutpat condimentum. Aliquam erat volutpat. Sed quis velit. Nulla facilisi. Nulla libero. Vivamus pharetra posuere sapien. Nam consectetuer. Sed aliquam, nunc eget euismod ullamcorper, lectus nunc ullamcorper orci, fermentum bibendum enim nibh eget ipsum. Donec porttitor ligula eu dolor. Maecenas vitae nulla consequat libero cursus venenatis. Nam magna enim, accumsan eu, blandit sed, blandit a, eros.

4.1 Maecenas vitae nulla consequat

Aliquam aliquet, est a ullamcorper condimentum, tellus nulla fringilla elit, a iaculis nulla turpis sed wisi. Fusce volutpat. Etiam sodales ante id nunc. Proin ornare dignissim lacus. Nunc porttitor nunc a sem. Sed sollicitudin velit eu magna. Aliquam erat volutpat. Vivamus ornare est non wisi. Proin vel quam.

Vivamus egestas. Nunc tempor diam vehicula mauris. Nullam sapien eros 4.1, facilisis vel, eleifend non, auctor dapibus, pede.

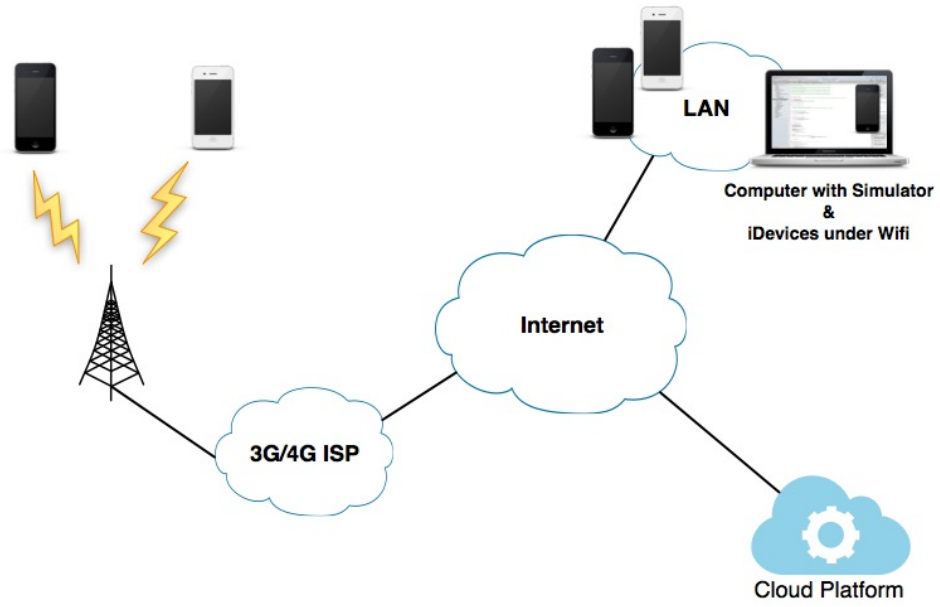


Figure 4.1: Test Environment

Aliquam aliquet, est a ullamcorper condimentum, tellus nulla fringilla elit, a iaculis nulla turpis sed wisi. Fusce volutpat. Etiam sodales ante id nunc. Proin ornare dignissim lacus. Nunc porttitor nunc a sem. Sed sollicitudin velit eu magna. Aliquam erat volutpat. Vivamus egestas. Nunc tempor diam vehicula mauris. Nullam sapien eros, facilisis vel, eleifend non, auctor dapibus, pede 4.1 used in the tests. The Network Link Conditioner allows to force/simulate fluctuations in fixed network segments.

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

Aliquam aliquet, est a ullamcorper condimentum, tellus nulla fringilla elit, a iaculis nulla turpis sed wisi. Fusce volutpat. Etiam sodales ante id nunc. Proin ornare dignissim lacus. Nunc porttitor nunc a sem. Sed sollicitudin velit eu magna. Aliquam erat volutpat. Vivamus ornare est non wisi. Proin vel quam. Vivamus egestas. Nunc tempor diam vehicula mauris. Nullam sapien eros, facilisis vel, eleifend non, auctor dapibus, pede.

4.2 Proin ornare dignissim lacus

Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Vestibulum tortor quam, feugiat vitae, ultricies eget, tempor sit amet, ante. Donec eu libero sit amet quam egestas semper. Aenean ultricies mi vitae est. Mauris placerat eleifend leo. Quisque sit amet est et sapien ullamcorper pharetra. Vestibulum erat wisi, condimentum sed, commodo vitae, ornare sit amet, wisi. Aenean fermentum, elit eget tincidunt condimentum, eros ipsum rutrum orci, sagittis tempus lacus enim ac dui. Donec non enim in turpis pulvinar facilisis. Ut felis.

Et “optimistic” nulla dui purus, eleifend vel, consequat non, dictum porta, nulla. Duis ante mi, laoreet ut, commodo eleifend, cursus nec, lorem. Aenean eu est. Etiam imperdiet turpis. Praesent nec augue. Curabitur ligula quam, rutrum id, tempor sed, consequat ac, dui G_j, nec ligula et lorem consequat ullamcorper p ut mauris eu mi mollis luctus j, porttitor ut, 4.1, uctus posuere justo:

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., $C_{r(max)} = max(C_r)$.

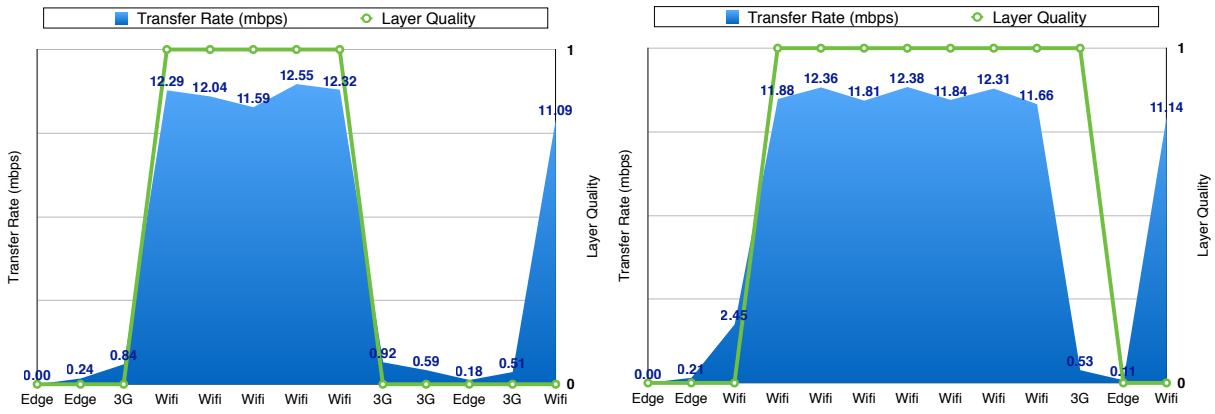
$$G_j = \begin{cases} \dfrac{n_j C_{r[j]}}{N_j} & \text{if } n_j > 0 \\ \dfrac{C_{r(max)}}{N_j + 1} & \text{if } n_j = 0 \end{cases} \tag{4.1}$$

Cursus $C_{r(max)}$ conubia nostra, per inceptos hymenaeos j gadipiscing mollis massa $N_j = 0$, unc ut dui eget nulla venenatis aliquet $G_j = C_{r(max)}$.

Vestibulum accumsan eros nec magna. Vestibulum vitae dui. Vestibulum nec ligula et lorem consequat ullamcorper. 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.

Both **??** Phasellus eget nisl ut elit porta “perfect” tincidunt. Class aptent taciti sociosqu ad litora torquent per conubia nostra.

Cras sed ante. Phasellus in massa. Curabitur dolor eros, gravida et, hendrerit ac, cursus non, massa. Aliquam lorem. In hac habitasse platea dictumst. Cras eu mauris. Quisque lacus. Donec ipsum. Nullam vitae sem at nunc pharetra ultricies. Vivamus elit eros, ullamcorper a, adipiscing sit amet, porttitor ut, nibh. Maecenas adipiscing mollis massa. Nunc ut dui eget nulla venenatis aliquet.



(a) Adaptation System Test 4

(b) Adaptation System Test 5

Figure 4.2: Adaptation System Behavior Test

Sed luctus posuere justo. Cras vehicula varius turpis. Vivamus eros metus, tristique sit amet, molestie dignissim, malesuada et, urna.

5

Conclusion

Contents

Pellentesque vel dui sed orci faucibus iaculis. Suspendisse dictum magna id purus tincidunt rutrum. Nulla congue. Vivamus sit amet lorem posuere dui vulputate ornare. Phasellus mattis sollicitudin ligula. Duis dignissim felis et urna. Integer adipiscing congue metus.

Rui Cruz
You should always start a Chapter with an introductory text

5.1 Conclusions

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Morbi commodo, ipsum sed pharetra gravida, orci magna rhoncus neque, id pulvinar odio lorem non turpis. Nullam sit amet enim. Suspendisse id velit vitae ligula volutpat condimentum. Aliquam erat volutpat. Sed quis velit. Nulla facilisi. Nulla libero. Vivamus pharetra posuere sapien. Nam consectetuer. Sed aliquam, nunc eget euismod ullamcorper, lectus nunc ullamcorper orci, fermentum bibendum enim nibh eget ipsum. Donec porttitor ligula eu dolor. Maecenas vitae nulla consequat libero cursus venenatis. Nam magna enim, accumsan eu, blandit sed, blandit a, eros.

Quisque facilisis erat a dui. Nam malesuada ornare dolor. Cras gravida, diam sit amet rhoncus ornare, erat elit consectetuer erat, id egestas pede nibh eget odio. Proin tincidunt, velit vel porta elementum, magna diam molestie sapien, non aliquet massa pede eu diam. Aliquam iaculis. Fusce et ipsum et nulla tristique facilisis. Donec eget sem sit amet ligula viverra gravida. Etiam vehicula urna vel turpis. Suspendisse sagittis ante a urna. Morbi a est quis orci consequat rutrum. Nullam egestas feugiat felis. Integer adipiscing semper ligula. Nunc molestie, nisl sit amet cursus convallis, sapien lectus pretium metus, vitae pretium enim wisi id lectus. Donec vestibulum. Etiam vel nibh. Nulla facilisi. Mauris pharetra. Donec augue. Fusce ultrices, neque id dignissim ultrices, tellus mauris dictum elit, vel lacinia enim metus eu nunc.

Proin at eros non eros adipiscing mollis. Donec semper turpis sed diam. Sed consequat ligula nec tortor. Integer eget sem. Ut vitae enim eu est vehicula gravida. Morbi ipsum ipsum, porta nec, tempor id, auctor vitae, purus. Pellentesque neque. Nulla luctus erat vitae libero. Integer nec enim. Phasellus aliquam enim et tortor. Quisque aliquet, quam elementum condimentum feugiat, tellus odio consectetuer wisi, vel nonummy sem neque in elit. Curabitur eleifend wisi iaculis ipsum. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. In non velit non ligula laoreet ultrices. Praesent ultricies facilisis nisl. Vivamus luctus elit sit amet mi. Phasellus pellentesque, erat eget elementum volutpat, dolor nisl porta neque, vitae sodales ipsum nibh in ligula. Maecenas mattis pulvinar diam. Curabitur sed leo.

Nulla facilisi. In vel sem. Morbi id urna in diam dignissim feugiat. Proin molestie tortor eu velit. Aliquam erat volutpat. Nullam ultrices, diam tempus vulputate egestas, eros pede varius leo, sed imperdiet lectus est ornare odio. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Proin consectetuer velit in dui. Phasellus wisi purus, interdum vitae, rutrum accumsan, viverra in, velit. Sed enim risus, congue non, tristique in, commodo eu, metus. Aenean tortor mi, imperdiet id, gravida eu, posuere eu, felis. Mauris sollicitudin, turpis in hendrerit sodales, lectus ipsum pellentesque ligula, sit amet scelerisque urna nibh ut arcu. Aliquam in lacus. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Nulla placerat aliquam wisi. Mauris viverra odio. Quisque fermentum pulvinar odio. Proin posuere est vitae ligula. Etiam euismod. Cras a eros.

Nunc auctor bibendum eros. Maecenas porta accumsan mauris. Etiam enim enim, elementum sed, bibendum quis, rhoncus non, metus. Fusce neque dolor, adipiscing sed, consectetuer et, lacinia sit amet, quam.

5.2 System Limitations and Future Work

Aliquam aliquet, est a ullamcorper condimentum, tellus nulla fringilla elit, a iaculis nulla turpis sed wisi. Fusce volutpat. Etiam sodales ante id nunc. Proin ornare dignissim lacus. Nunc porttitor nunc a sem.

Sed sollicitudin velit eu magna. Aliquam erat volutpat. Vivamus ornare est non wisi. Proin vel quam. Vivamus egestas. Nunc tempor diam vehicula mauris. Nullam sapien eros, facilisis vel, eleifend non, auctor dapibus, pede.

Bibliography

A

Code of Project

Nulla dui purus, eleifend vel, consequat non, dictum porta, nulla. Duis ante mi, laoreet ut, commodo eleifend, cursus nec, lorem. Aenean eu est. Etiam imperdiet turpis. Praesent nec augue. Curabitur ligula quam, rutrum id, tempor sed, consequat ac, dui. Vestibulum accumsan eros nec magna. Vestibulum vitae dui. Vestibulum nec ligula et lorem consequat ullamcorper.

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>
```

Etiam imperdiet turpis. Praesent nec augue. Curabitur ligula quam, rutrum id, tempor sed, consequat ac, dui. 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.

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.

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

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.

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>
```

Nulla dui purus, eleifend vel, consequat non, dictum porta, nulla. Duis ante mi, laoreet ut, commodo eleifend, cursus nec, lorem. Aenean eu est. Etiam imperdiet turpis. Praesent nec augue. Curabitur ligula quam, rutrum id, tempor sed, consequat ac, dui. Vestibulum accumsan eros nec magna. Vestibulum vitae dui. Vestibulum nec ligula et lorem consequat ullamcorper.

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   }
```

Nulla dui purus, eleifend vel, consequat non, dictum porta, nulla. Duis ante mi, laoreet ut, commodo eleifend, cursus nec, lorem. Aenean eu est. Etiam imperdiet turpis. Praesent nec augue. Curabitur ligula quam, rutrum id, tempor sed, consequat ac, dui. Vestibulum accumsan eros nec magna. Vestibulum vitae dui. Vestibulum nec ligula et lorem consequat ullamcorper.

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

Aliquam et nisl vel ligula consectetuer suscipit. Morbi euismod enim eget neque. Donec sagittis massa. Vestibulum quis augue sit amet ipsum laoreet pretium. Nulla facilisi. Duis tincidunt, felis et luctus placerat, ipsum libero vestibulum sem, vitae elementum wisi ipsum a metus. Nulla a enim sed dui hendrerit lobortis. Donec lacinia vulputate magna. Vivamus suscipit lectus at quam. In lectus est, viverra a, ultricies ut, pulvinar vitae, tellus. Donec et lectus et sem rutrum sodales. Morbi cursus. Aliquam a odio. Sed tortor velit, convallis eget, porta interdum, convallis sed, tortor. Phasellus ac libero a lorem auctor mattis. Lorem ipsum dolor sit amet, consectetuer adipiscing elit.

Nunc auctor bibendum eros. Maecenas porta accumsan mauris. Etiam enim enim, elementum sed, bibendum quis, rhoncus non, metus. Fusce neque dolor, adipiscing sed, consectetuer et, lacinia sit amet, quam. Suspendisse wisi quam, consectetuer in, blandit sed, suscipit eu, eros. Etiam ligula enim, tempor ut, blandit nec, mollis eu, lectus. Nam cursus. Vivamus iaculis. Aenean risus purus, pharetra in, blandit quis, gravida a, turpis. Donec nisl. Aenean eget mi. Fusce mattis est id diam. Phasellus faucibus interdum sapien. Duis quis nunc. Sed enim. Nunc auctor bibendum eros. Maecenas porta accumsan mauris. Etiam enim enim, elementum sed, bibendum quis, rhoncus non, metus. Fusce neque dolor, adipiscing sed, consectetuer et, lacinia sit amet, quam.

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.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Morbi commodo, ipsum sed pharetra gravida, orci magna rhoncus neque, id pulvinar odio lorem non turpis. Nullam sit amet enim. Suspendisse id velit vitae ligula volutpat condimentum. Aliquam erat volutpat. Sed quis velit. Nulla facilisi. Nulla libero. Vivamus pharetra posuere sapien. Nam consectetuer. Sed aliquam, nunc eget euismod ullamcorper, lectus nunc ullamcorper orci, fermentum bibendum enim nibh eget ipsum. Donec porttitor ligula eu dolor. Maecenas vitae nulla consequat libero cursus venenatis. Nam magna enim, accumsan eu, blandit sed, blandit a, eros.

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