Reproducible Research for OMNeT++ Based on Python and Pweave

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Abstract

As the amount and complexity of model implementation code, configuration files, and resulting data for simulation experiments are ever increasing, it becomes a real challenge to reliably and efficiently reproduce simulation data and their analysis results published in a scientific paper not only by its readers but also the authors themselves, which makes the claims and contributions made in the paper questionable. The idea of reproducible research comes as a solution to these problems and suggests that any scientific claims should be published together with relevant experimental data and software code for their analysis so that readers may verify the findings and build upon them; in case of computer simulation, the details of simulation implementation and its configurations are also should be provided. In this tutorial, we illustrate the practice of the reproducible research for OMNeT++ simulation based on Pweave and Python, where we show how to embed simulation configuration files and Python analysis code, import simulation data with automatic updating of simulation results, and analyze data and present their results in a LaTeXfile.

I. Introduction

We provide this file as a minimal template for a reproducible research document for OMNeT++ based on Python and Pweave. Documentation part is prepared for LaTeX and code between «» and @ is executed and results are included in the resulting document.

You can define various options for code chunks to control code execution and formatting (see Pweave docs).

II. Reproducible Research

Reproducible research is a key to any scientific method and ensures repeating an experiment and the results of its analysis in any place with any person.

A study can be truly reproducible when it satisfies at least the following three criteria.

- All methods are fully reported.
- All data and files used for the analysis are (publicly) available.
- The process of analyzing raw data is well reported and preserved.

This means
Same data + Same script = Same results

III. Python and Pweave

Fig. 1 shows an overview of weaving and tangling procedures provided by Pweave.

IV. Example: OMNeT++ FIFO Simulation

A. Simulation Configurations

```
import os

# set path to run Fifo simulation in DOS command prompt
omnetpp_root = os.environ['OMNETPP_ROOT']
path1 = '/'.join([omnetpp_root, 'bin'])
path2 = '/'.join([omnetpp_root, 'tools', 'win64', 'mingw64', 'bin'])
os.environ['Path'] = ';'.join([path1, path2, os.environ['Path']])

# run the simulation only if input files are newer than results
# - it can be extended to checking multiple NED, INI, and result files
ned = '/'.join(['.', 'fifo', 'Fifo.ned'])
ini = '/'.join(['.', 'fifo', 'omnetpp.ini'])
sca = '/'.join(['.', 'fifo', 'results', 'Fifo1-st=0.01-#0.sca'])
fifo = '/'.join(['.', 'fifo', 'fifo.exe'])
```

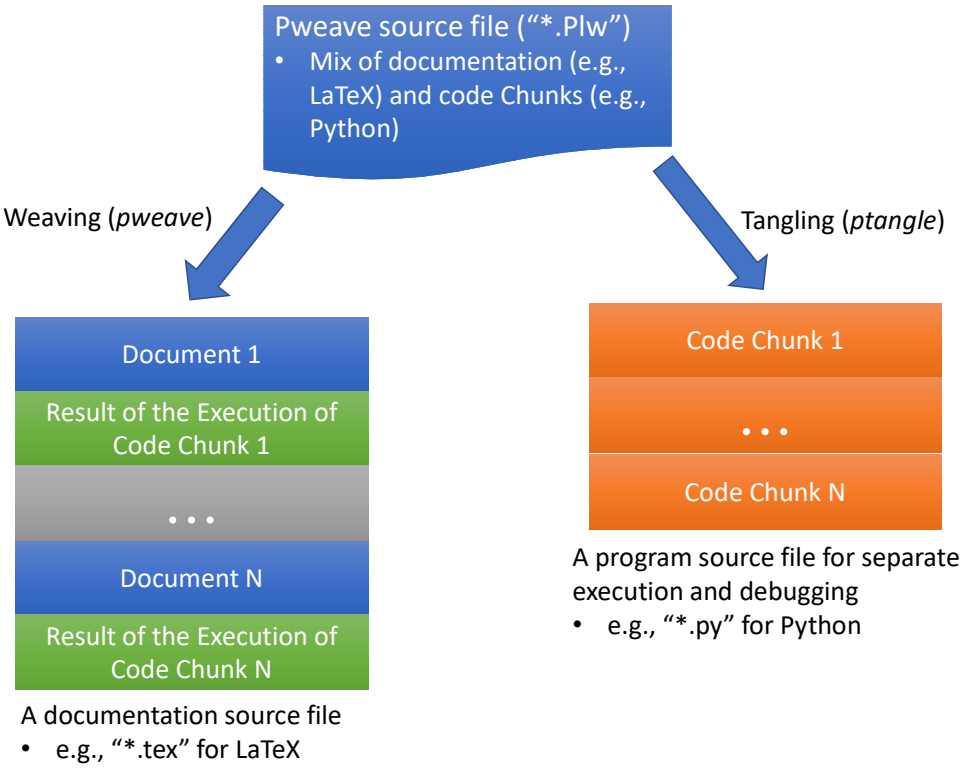

Fig. 1. Overview of weaving and tangling procedures.

```
//
// This file is part of an OMNeT++/OMNEST simulation example.
//
// Copyright (C) 1992-2015 Andras Varga
//
// This file is distributed WITHOUT ANY WARRANTY. See the file
// `license' for details on this and other legal matters.
//

//
// Simple queueing network: generator + FIFO + sink.
//
network FifoNet
{
    submodules:
        gen: Source {
            parameters:
                @display("p=89,100");
        }
        fifo: Fifo {
            parameters:
                @display("p=209,100");
        }
        sink: Sink {
            parameters:
                @display("p=329,100");
        }
    connections:
        gen.out --> fifo.in;
        fifo.out --> sink.in;
}
```

Listing 1: ’FifoNet.ned’ for FIFO sample model.

```
[General]
network = FifoNet
sim-time-limit = 5h
#cpu-time-limit = 300s
repeat = 5
**.vector-recording = false
#debug-on-errors = true
#record-eventlog = true

[Config Fifo1]
description = "low job arrival rate"
**.gen.sendIaTime = exponential(0.2s)
**.fifo.serviceTime = ${st=0.01..0.03 step 0.01}s

[Config Fifo2]
description = "high job arrival rate"
**.gen.sendIaTime = exponential(0.01s)
**.fifo.serviceTime = 0.01s
```

Listing 2: 'omnetpp.ini' for FIFO sample model.

B. *Importing Simulation Results*

Below is a python scrip that can run the OMNeT++ FIFO simulation only when simulation input files are newer than result files.

```
import subprocess

# run the simulation only if input files are newer than results
if (not os.path.isfile(sca)) or (os.path.getmtime(ini) >
os.path.getmtime(sca)):
    cwd = '/'.join(['.', 'fifo'])
    subprocess.call([fifo, '-u', 'Cmdenv', '-f', 'omnetpp.ini', '-c',
'Fifo1'], cwd=cwd)

# convert Fifo's scalar files to CSV
cwd = '/'.join(['.', 'fifo', 'results'])
subprocess.call(['scavetool', 'export', '-T', 's', '-o', 'fifo.csv',
'*.sca'], cwd=cwd)
```

```
0
```

```
import pandas as pd
fifo_df = pd.read_csv('/'.join([cwd, 'fifo.csv']))
```

The following Python code chunk can automatically generate a long table over multiple pages from a pandas dataframe[1]:

```
<<echo=False,results='raw'>> =
import numpy as np
df = fifo_df.filter(regex="^(?!(r|R)un).*$")  # exclude columns starting with run/Run
print(df.to_latex(longtable=True))
@
```

	File	Module	Name	Unnamed: 19
0	Fifo1-st=0.01-#0.sca	_runattrs_	st	0.010000
1	Fifo1-st=0.01-#0.sca	FifoNet.fifo	queueingTime:mean	0.000271
2	Fifo1-st=0.01-#0.sca	FifoNet.fifo	queueingTime:max	0.022790
3	Fifo1-st=0.01-#0.sca	FifoNet.fifo	busy:timeavg	0.050264
4	Fifo1-st=0.01-#0.sca	FifoNet.fifo	qlen:timeavg	0.001361
5	Fifo1-st=0.01-#0.sca	FifoNet.fifo	qlen:max	3.000000
6	Fifo1-st=0.01-#0.sca	FifoNet.sink	lifetime:mean	0.010271

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[1]Note that a space is inserted between '»' and '=' to prevent Pweave from weaving the code; it seems that there is no way to escape Pweave chunk code markers.

	File	Module	Name	Unnamed: 19
7	Fifo1-st=0.01-#0.sca	FifoNet.sink	lifetime:max	0.032790
8	Fifo1-st=0.01-#1.sca	_runattrs_	st	0.010000
9	Fifo1-st=0.01-#1.sca	FifoNet.fifo	queueingTime:mean	0.000264
10	Fifo1-st=0.01-#1.sca	FifoNet.fifo	queueingTime:max	0.018800
11	Fifo1-st=0.01-#1.sca	FifoNet.fifo	busy:timeavg	0.050042
12	Fifo1-st=0.01-#1.sca	FifoNet.fifo	qlen:timeavg	0.001319
13	Fifo1-st=0.01-#1.sca	FifoNet.fifo	qlen:max	2.000000
14	Fifo1-st=0.01-#1.sca	FifoNet.sink	lifetime:mean	0.010264
15	Fifo1-st=0.01-#1.sca	FifoNet.sink	lifetime:max	0.028800
16	Fifo1-st=0.01-#2.sca	_runattrs_	st	0.010000
17	Fifo1-st=0.01-#2.sca	FifoNet.fifo	queueingTime:mean	0.000272
18	Fifo1-st=0.01-#2.sca	FifoNet.fifo	queueingTime:max	0.025558
19	Fifo1-st=0.01-#2.sca	FifoNet.fifo	busy:timeavg	0.050061
20	Fifo1-st=0.01-#2.sca	FifoNet.fifo	qlen:timeavg	0.001359
21	Fifo1-st=0.01-#2.sca	FifoNet.fifo	qlen:max	3.000000
22	Fifo1-st=0.01-#2.sca	FifoNet.sink	lifetime:mean	0.010272
23	Fifo1-st=0.01-#2.sca	FifoNet.sink	lifetime:max	0.035558
24	Fifo1-st=0.01-#3.sca	_runattrs_	st	0.010000
25	Fifo1-st=0.01-#3.sca	FifoNet.fifo	queueingTime:mean	0.000260
26	Fifo1-st=0.01-#3.sca	FifoNet.fifo	queueingTime:max	0.019135
27	Fifo1-st=0.01-#3.sca	FifoNet.fifo	busy:timeavg	0.049948
28	Fifo1-st=0.01-#3.sca	FifoNet.fifo	qlen:timeavg	0.001297
29	Fifo1-st=0.01-#3.sca	FifoNet.fifo	qlen:max	2.000000
30	Fifo1-st=0.01-#3.sca	FifoNet.sink	lifetime:mean	0.010260
31	Fifo1-st=0.01-#3.sca	FifoNet.sink	lifetime:max	0.029135
32	Fifo1-st=0.01-#4.sca	_runattrs_	st	0.010000
33	Fifo1-st=0.01-#4.sca	FifoNet.fifo	queueingTime:mean	0.000265
34	Fifo1-st=0.01-#4.sca	FifoNet.fifo	queueingTime:max	0.021754
35	Fifo1-st=0.01-#4.sca	FifoNet.fifo	busy:timeavg	0.049776
36	Fifo1-st=0.01-#4.sca	FifoNet.fifo	qlen:timeavg	0.001318
37	Fifo1-st=0.01-#4.sca	FifoNet.fifo	qlen:max	3.000000
38	Fifo1-st=0.01-#4.sca	FifoNet.sink	lifetime:mean	0.010265
39	Fifo1-st=0.01-#4.sca	FifoNet.sink	lifetime:max	0.031754
40	Fifo1-st=0.02-#0.sca	_runattrs_	st	0.020000
41	Fifo1-st=0.02-#0.sca	FifoNet.fifo	queueingTime:mean	0.001098
42	Fifo1-st=0.02-#0.sca	FifoNet.fifo	queueingTime:max	0.052863
43	Fifo1-st=0.02-#0.sca	FifoNet.fifo	busy:timeavg	0.099750
44	Fifo1-st=0.02-#0.sca	FifoNet.fifo	qlen:timeavg	0.005475
45	Fifo1-st=0.02-#0.sca	FifoNet.fifo	qlen:max	3.000000
46	Fifo1-st=0.02-#0.sca	FifoNet.sink	lifetime:mean	0.021098
47	Fifo1-st=0.02-#0.sca	FifoNet.sink	lifetime:max	0.072863
48	Fifo1-st=0.02-#1.sca	_runattrs_	st	0.020000
49	Fifo1-st=0.02-#1.sca	FifoNet.fifo	queueingTime:mean	0.001111
50	Fifo1-st=0.02-#1.sca	FifoNet.fifo	queueingTime:max	0.061320
51	Fifo1-st=0.02-#1.sca	FifoNet.fifo	busy:timeavg	0.100662
52	Fifo1-st=0.02-#1.sca	FifoNet.fifo	qlen:timeavg	0.005594
53	Fifo1-st=0.02-#1.sca	FifoNet.fifo	qlen:max	4.000000
54	Fifo1-st=0.02-#1.sca	FifoNet.sink	lifetime:mean	0.021111
55	Fifo1-st=0.02-#1.sca	FifoNet.sink	lifetime:max	0.081320
56	Fifo1-st=0.02-#2.sca	_runattrs_	st	0.020000
57	Fifo1-st=0.02-#2.sca	FifoNet.fifo	queueingTime:mean	0.001095
58	Fifo1-st=0.02-#2.sca	FifoNet.fifo	queueingTime:max	0.053629

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	File	Module	Name	Unnamed: 19
59	Fifo1-st=0.02-#2.sca	FifoNet.fifo	busy:timeavg	0.100041
60	Fifo1-st=0.02-#2.sca	FifoNet.fifo	qlen:timeavg	0.005476
61	Fifo1-st=0.02-#2.sca	FifoNet.fifo	qlen:max	3.000000
62	Fifo1-st=0.02-#2.sca	FifoNet.sink	lifetime:mean	0.021095
63	Fifo1-st=0.02-#2.sca	FifoNet.sink	lifetime:max	0.073629
64	Fifo1-st=0.02-#3.sca	_runattrs_	st	0.020000
65	Fifo1-st=0.02-#3.sca	FifoNet.fifo	queueingTime:mean	0.001149
66	Fifo1-st=0.02-#3.sca	FifoNet.fifo	queueingTime:max	0.060847
67	Fifo1-st=0.02-#3.sca	FifoNet.fifo	busy:timeavg	0.100764
68	Fifo1-st=0.02-#3.sca	FifoNet.fifo	qlen:timeavg	0.005787
69	Fifo1-st=0.02-#3.sca	FifoNet.fifo	qlen:max	4.000000
70	Fifo1-st=0.02-#3.sca	FifoNet.sink	lifetime:mean	0.021149
71	Fifo1-st=0.02-#3.sca	FifoNet.sink	lifetime:max	0.080847
72	Fifo1-st=0.02-#4.sca	_runattrs_	st	0.020000
73	Fifo1-st=0.02-#4.sca	FifoNet.fifo	queueingTime:mean	0.001126
74	Fifo1-st=0.02-#4.sca	FifoNet.fifo	queueingTime:max	0.054308
75	Fifo1-st=0.02-#4.sca	FifoNet.fifo	busy:timeavg	0.100372
76	Fifo1-st=0.02-#4.sca	FifoNet.fifo	qlen:timeavg	0.005653
77	Fifo1-st=0.02-#4.sca	FifoNet.fifo	qlen:max	3.000000
78	Fifo1-st=0.02-#4.sca	FifoNet.sink	lifetime:mean	0.021126
79	Fifo1-st=0.02-#4.sca	FifoNet.sink	lifetime:max	0.074308
80	Fifo1-st=0.03-#0.sca	_runattrs_	st	0.030000
81	Fifo1-st=0.03-#0.sca	FifoNet.fifo	queueingTime:mean	0.002684
82	Fifo1-st=0.03-#0.sca	FifoNet.fifo	queueingTime:max	0.101136
83	Fifo1-st=0.03-#0.sca	FifoNet.fifo	busy:timeavg	0.150412
84	Fifo1-st=0.03-#0.sca	FifoNet.fifo	qlen:timeavg	0.013455
85	Fifo1-st=0.03-#0.sca	FifoNet.fifo	qlen:max	4.000000
86	Fifo1-st=0.03-#0.sca	FifoNet.sink	lifetime:mean	0.032684
87	Fifo1-st=0.03-#0.sca	FifoNet.sink	lifetime:max	0.131136
88	Fifo1-st=0.03-#1.sca	_runattrs_	st	0.030000
89	Fifo1-st=0.03-#1.sca	FifoNet.fifo	queueingTime:mean	0.002658
90	Fifo1-st=0.03-#1.sca	FifoNet.fifo	queueingTime:max	0.112885
91	Fifo1-st=0.03-#1.sca	FifoNet.fifo	busy:timeavg	0.149972
92	Fifo1-st=0.03-#1.sca	FifoNet.fifo	qlen:timeavg	0.013286
93	Fifo1-st=0.03-#1.sca	FifoNet.fifo	qlen:max	4.000000
94	Fifo1-st=0.03-#1.sca	FifoNet.sink	lifetime:mean	0.032658
95	Fifo1-st=0.03-#1.sca	FifoNet.sink	lifetime:max	0.142885
96	Fifo1-st=0.03-#2.sca	_runattrs_	st	0.030000
97	Fifo1-st=0.03-#2.sca	FifoNet.fifo	queueingTime:mean	0.002623
98	Fifo1-st=0.03-#2.sca	FifoNet.fifo	queueingTime:max	0.100678
99	Fifo1-st=0.03-#2.sca	FifoNet.fifo	busy:timeavg	0.150370
100	Fifo1-st=0.03-#2.sca	FifoNet.fifo	qlen:timeavg	0.013148
101	Fifo1-st=0.03-#2.sca	FifoNet.fifo	qlen:max	4.000000
102	Fifo1-st=0.03-#2.sca	FifoNet.sink	lifetime:mean	0.032623
103	Fifo1-st=0.03-#2.sca	FifoNet.sink	lifetime:max	0.130678
104	Fifo1-st=0.03-#3.sca	_runattrs_	st	0.030000
105	Fifo1-st=0.03-#3.sca	FifoNet.fifo	queueingTime:mean	0.002661
106	Fifo1-st=0.03-#3.sca	FifoNet.fifo	queueingTime:max	0.091915
107	Fifo1-st=0.03-#3.sca	FifoNet.fifo	busy:timeavg	0.149858
108	Fifo1-st=0.03-#3.sca	FifoNet.fifo	qlen:timeavg	0.013292
109	Fifo1-st=0.03-#3.sca	FifoNet.fifo	qlen:max	4.000000
110	Fifo1-st=0.03-#3.sca	FifoNet.sink	lifetime:mean	0.032661

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	File	Module	Name	Unnamed: 19
111	Fifo1-st=0.03-#3.sca	FifoNet.sink	lifetime:max	0.121915
112	Fifo1-st=0.03-#4.sca	_runattrs_	st	0.030000
113	Fifo1-st=0.03-#4.sca	FifoNet.fifo	queueingTime:mean	0.002642
114	Fifo1-st=0.03-#4.sca	FifoNet.fifo	queueingTime:max	0.094572
115	Fifo1-st=0.03-#4.sca	FifoNet.fifo	busy:timeavg	0.149782
116	Fifo1-st=0.03-#4.sca	FifoNet.fifo	qlen:timeavg	0.013189
117	Fifo1-st=0.03-#4.sca	FifoNet.fifo	qlen:max	4.000000
118	Fifo1-st=0.03-#4.sca	FifoNet.sink	lifetime:mean	0.032642
119	Fifo1-st=0.03-#4.sca	FifoNet.sink	lifetime:max	0.124572

This automatic generation of a table from a pandas dataframe is quite handy because we can quickly go through overall data and investigate important results in detail (i.e., actual numbers not just a trend provided by plots). The suggested solution of embedding a long table within a Pweave document, however, is not perfect yet as there is no option in *pandas.DataFrame.to_latex* API providing a caption and a label within a generated longtable environment. Note that surrounding the longtable with a tabular environment with its own caption and label does not work when the table spans over more than one pages.

C. Data Analysis and Presentation

Here we process the dataframe obtained in Sec. IV-B and create a bar plot with error bars showing mean queueing time against packet service time.

```
import matplotlib.pyplot as plt
import scipy as sp
import scipy.stats


def ci(x):                          # 99% confidence interval
    a = 1.0*np.array(x)
    n = len(a)
    m, se = np.mean(a), scipy.stats.sem(a)
    return (se * sp.stats.t._ppf((1+0.99)/2., n-1))


pivoted = fifo_df.pivot(index='Run', columns='Name', values='Unnamed: 19')
st_vs_qt = pivoted.pivot_table(index='st', values='queueingTime:mean')
errs = pivoted.pivot_table(index='st', values='queueingTime:mean', aggfunc=ci)
st_vs_qt.plot(kind='bar', legend=None, yerr=errs, color='red',
              error_kw=dict(ecolor='black', elinewidth=1, capsize=5))
plt.xlabel('Service Time')
plt.ylabel('Mean Queueing Time')
plt.show()
```

V. Summary

This short tutorial aims to demonstrate the power of Python and Pweave in making reproducible research for OMNeT++. Taking OMNeT++ FIFO simulation as an example, we explain how to embed simulation configuration files and Python analysis code, import simulation data with automatic updating of simulation results, and analyze data and present their results in a LaTeXfile. The source file of this tutorial has been prepared as a minimal template for future reproducible research for OMNeT++.

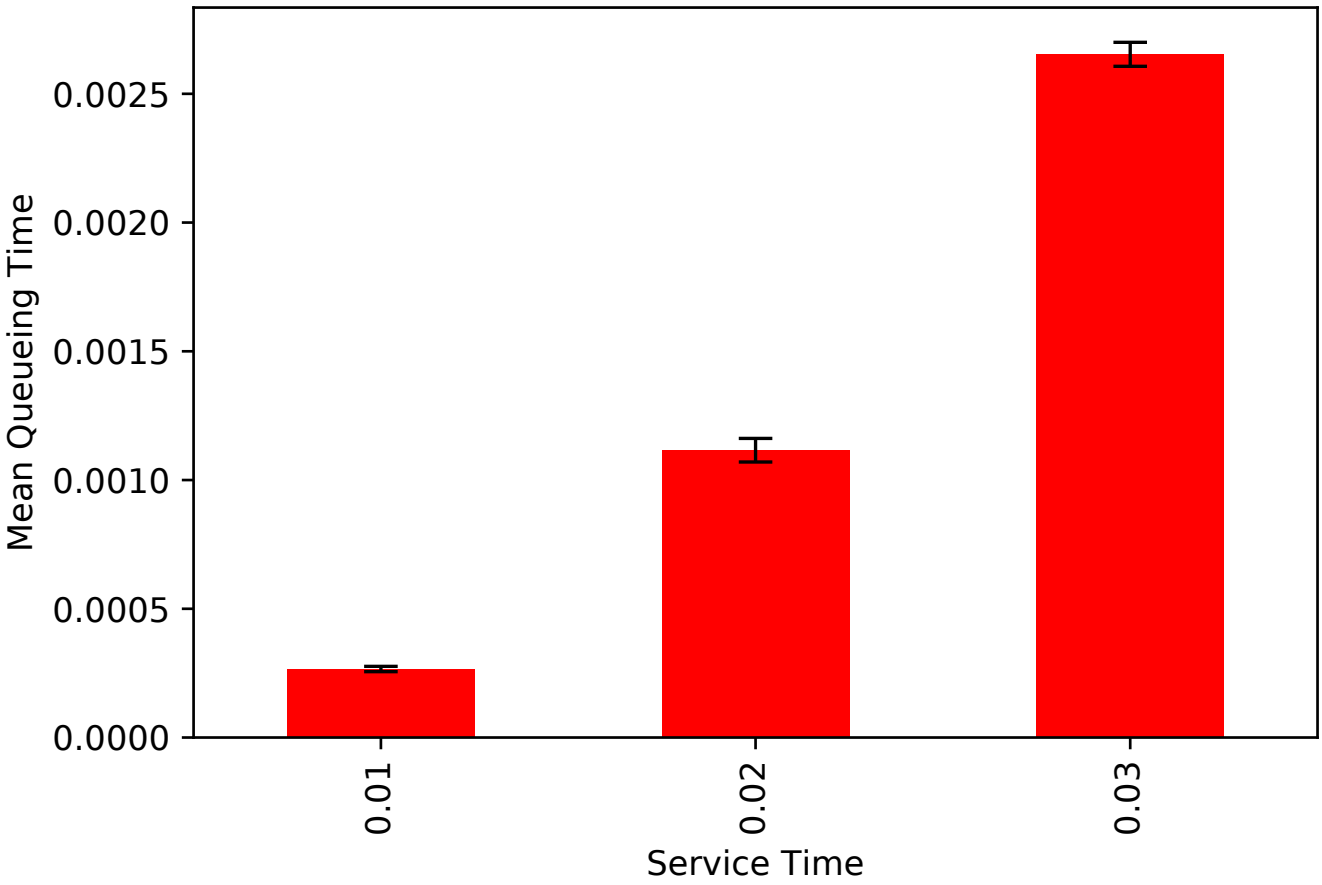

Fig. 2. Mean queueing time vs. service time (with 99 percent confidence intervals).