



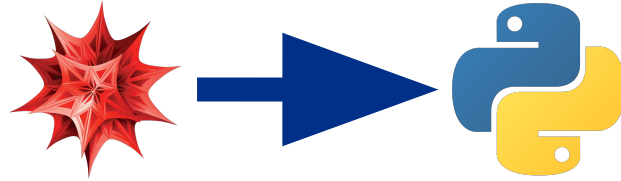
Case Study -- Python Implementation

Dylan J Temples

MAGIS-100 Simulation & Analysis Workshop

26 January 2022

Case Study -- Python Implementation



Goal: Port all functionality of the Mathematica case study notebook to Python 3

Motivation:

- Mathematica is proprietary software, licenses are expensive for non-Universities
- Python is open source, widely used, well documented, and powerful
- Utilizing high-performance computing resources for simulations (e.g. FNAL grid)

All methods available in the Mathematica notebook are duplicated in Python, mostly with identical names, arguments, and returned quantities.

Git Repository and Installation

Currently available on personal github (private), will migrate to the MAGIS Redmine

https://github.com/dtemp123/MAGIS_analysis

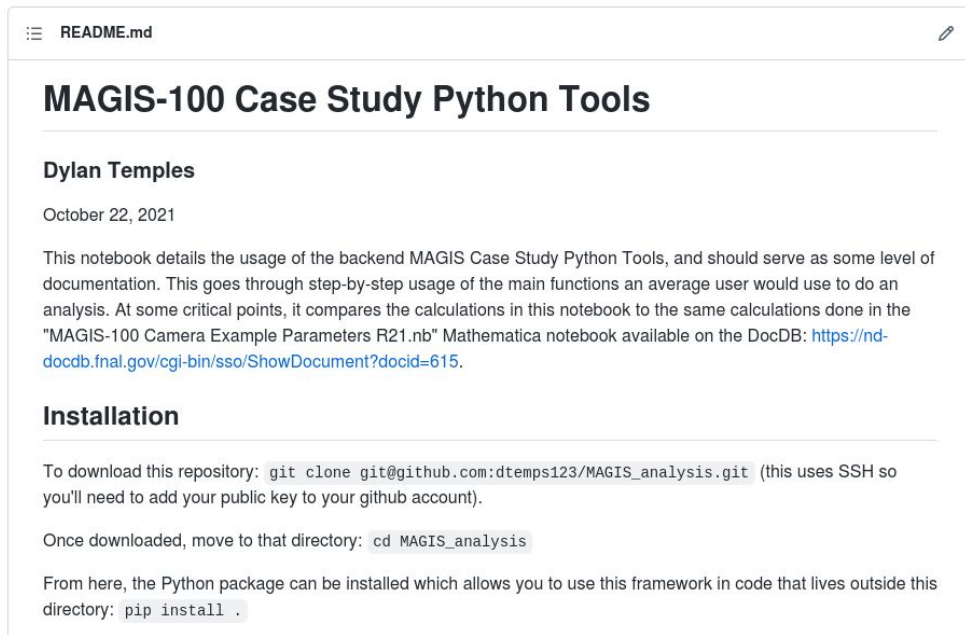
Clone with git

Install with pip

Fully documented in
the git Readme

Usage examples

- script-based
- interactive (Jupyter)



The screenshot shows a GitHub README file titled "MAGIS-100 Case Study Python Tools" by Dylan Temples, dated October 22, 2021. The text describes a notebook detailing the usage of the backend MAGIS Case Study Python Tools. It includes an "Installation" section with instructions on how to clone the repository and install the Python package.

```
git clone git@github.com:dtemp123/MAGIS_analysis.git
```

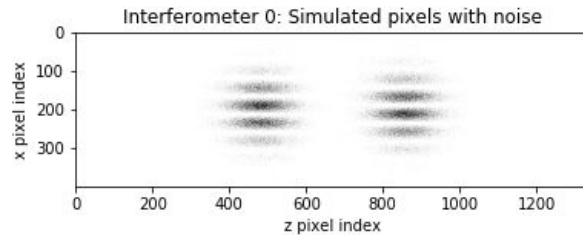
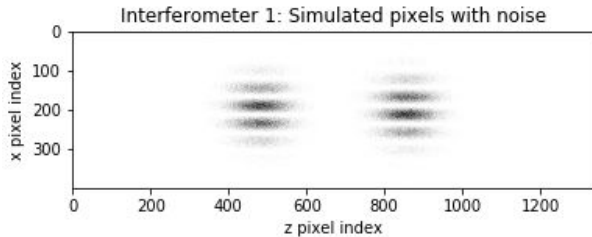
```
cd MAGIS_analysis
```

```
pip install .
```

Current Functionality

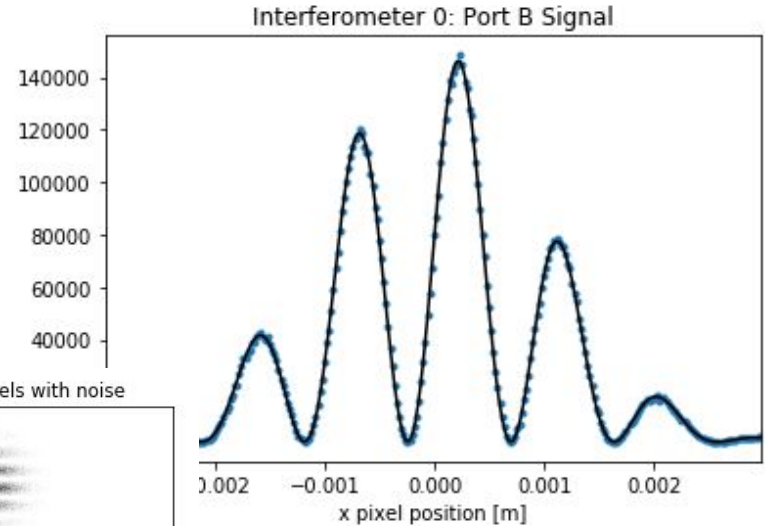
What does it do?

- Statistically generate atom positions from wavefunction
- Discretizes photon counts w/ noise across pixels to generate image using parameterized optics settings
- Simultaneous fits of up to 4x interference patterns to determine phase shift
- Automated reporting of simulation



What doesn't it do?

- Optical simulations (ray tracing)
- Quadratic wavefunction/fitting



Performance vs Mathematica

Example code to generate one image per interferometer and extract the phase



Metric	Mathematica	Python
Time to simulate & fit images 100 times [sec]	5550	1487*
Mean $\Delta\phi$ [rad]	-0.000204	-0.003312
Mean $\Delta\phi$ error [rad]	0.000358	0.001577
Mean fit χ^2/N_{dof}	16.6462 / 14	16.4153 / 14

* Most time is spent creating marginalized position distributions (only needs to be done once). Image generation and fitting is very fast.

```
1 import matplotlib.pyplot as plt
2
3 from MAGIS_analysis import Parameters as sp
4 from MAGIS_analysis import Interferometer as ic
5 from MAGIS_analysis import Wavefunctions as wf
6 from MAGIS_analysis import SimTools as st
7 from MAGIS_analysis import FitTools as ft
8
9 ## Show the fundamental constants
10 print(sp.hbar)
11 print(sp.m)
12 print(sp.in_to_m)
13 print(sp.Gamma)
14 print(sp.pi)
15
16 ## Show the user options
17 sp.PrintUsrOpts()
18 sp.PrintImgParams()
19 sp.PrintSnrParams()
20
21 ## Load up the wavefunctions
22 wf.PrintParams()
23
24 ## Create the interferometer objects
25 int0 = ic.Interferometer()
26 int0.PrintParams()
27
28 int1 = ic.Interferometer()
29 int1.SetParam("atomsPerCloud", 1.1e6)
30 int1.SetParam("cloudRadius" , 0.0018)
31 int1.PrintParams()
32
33 ## Calculate the marginal distributions of atom positions
34 ## in both interferometers
35 st.CalculateMarginalDistributions(int0)
36 st.CalculateMarginalDistributions(int1)
37
38 ## Generate a single image from each interferometer
39 img0, x_marg0, z_marg0 = st.GenerateImage(int0, recalculate_pdf=False)
40 img1, x_marg1, z_marg1 = st.GenerateImage(int1, recalculate_pdf=False)
41
42 ## Extract the images from each port on both interferometers
43 xvalsbox0, portAArray0, portBArray0, nzsummedA0, nzsummedB0 = ft.Extract2Ports(img0, x_marg0, z_marg0, 3, 3, int0)
44 xvalsbox1, portAArray1, portBArray1, nzsummedA1, nzsummedB1 = ft.Extract2Ports(img1, x_marg1, z_marg1, 3, 3, int1)
45
46 ## Fit the image distributions
47 fr = ft.SimFits_2Port2Int(xvalsbox0, portAArray0, portBArray0, nzsummedA0, nzsummedB0,
48                          xvalsbox1, portAArray1, portBArray1, nzsummedA1, nzsummedB1,
49                          int0 , int1)
50 fr.show()
51
52 plt.show()
```

Next Steps & Interfaces

To do:

- Improve fitting to reduce uncertainty
- Implement quadratic wavefunction and fitting
- Implement single interferometer and single port fits
- Improve automated reporting
- Test all combinations of user options
- Optimization and parallelization

Potential interfaces:

- Optical simulation tool: use simulated atom positions to generate images
- Integration into data pipeline for quick online analysis / performance monitoring
- Integration with signal model choice: phase shift vs time



Thank You

Case Study -- Python Implementation

https://github.com/dtemp123/MAGIS_analysis

Dylan J Temples
dtemples@fnal.gov

Package Contents

folder	MAGIS_analysis	file	FitTools.py	Fit result class & fitting algs.
folder	docs	file	Interferometer.py	Interferometer class: parameterized
folder	examples	file	Parameters.py	Constants & sim params
file	.gitignore	file	Reporting.py	Saving plots and values (pdf/html)
file	LICENSE.txt	file	SimTools.py	General image generation methods
file	README.md	file	Wavefunctions.py	Linear + test wavefunctions
file	setup.py	file	__init__.py	Startup configuration

Package Contents

FitTools.py

```
12 class FitResult():
13
14     def __init__(self, n_param):
15
16
17
18
19
20
21
22
23
24
25     def show(self):
26
27
28
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30
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33
34     def show_cov_mat(self):
35
36
37
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41
42     def show_cor_mat(self):
43
44
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50     def params_to_dict(self):
51
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54     def p_errs_to_dict(self):
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116 def Z2Ports1Int_FitFunc(z, ampA,
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135 def FitZ2Ports1Int(z_dist_hpts, z
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551
552 def SimFits_2Port2Int(int0_x, int
```

Interferometer.py

```
7  Create an instantiable class for In
8  class Interferometer:
9      id_n = 0
10
11  Define Default Interferometer Par
12  phiphi = sp.pi / 2.
13  atomsPerCloud = 1e6
14  cloudRadius = 0.002  ## [ m ]
15  xCenter = 0.000  ## [ m ]
16  zCenter = -0.0075  ## [ m ]
17
18  Derived Parameters
19  acceptedPhotons = atomsPerCloud * sp
20  signalPerCloud = acceptedPhotons *
21  pixelAcceptance = (sp.snsr_params["d
22  signalPerPixel = pixelAcceptance*si
23
24  Initialization Method
25 def __init__(self, id_n):
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```

Wavefunctions.py

```
7  Wavefunction Parameters
8  tFinalBS = 3.0  ## [ s ]
9  tExtra = 0.1  ## [ s ] time be
10 portBvz = 0.15  ## [ m/s ] diffe
11 zsep = portBvz * tExtra  ##
12 kFringe = 1/0.0003
13 yFringe = 2.0 * sp.pi / kFringe
14 aQuad = 1e-12
15
16  Dictionary for Sensor Paramete
17 params = {
18
19
20
21
22
23
24
25
26
27 def CalculateDerivedParams():
28
29
30
31
32 def SetParam(key, val):
33
34
35
36
37 def GetParam(key):
38
39
40
41
42
43
44 def PrintParams():
45
46
47
48
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51
52  Define the actual wavefunctio
53 def testfunction(x, z, xA, zA, p
54
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66 def wavefunction(x, z, xA, zA, p
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118 def EvaluateWavefunction(wf_obj,
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139 def Evaluate(intfr, x_array, z_e
```

Package Contents

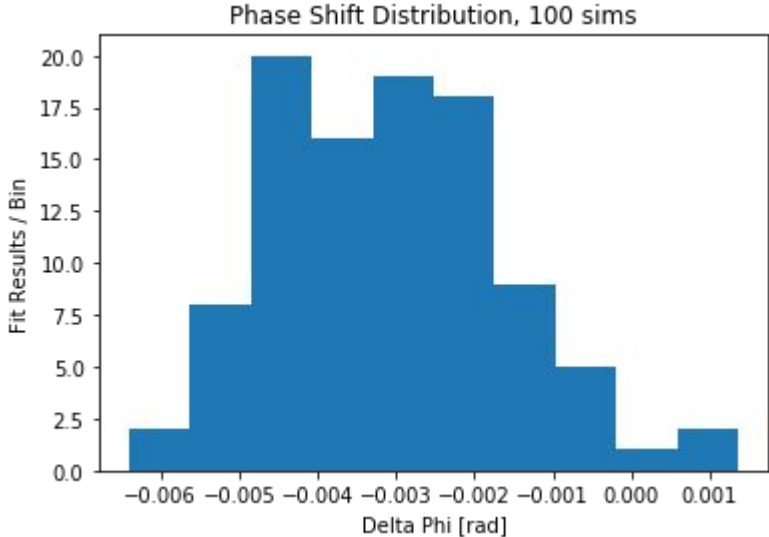
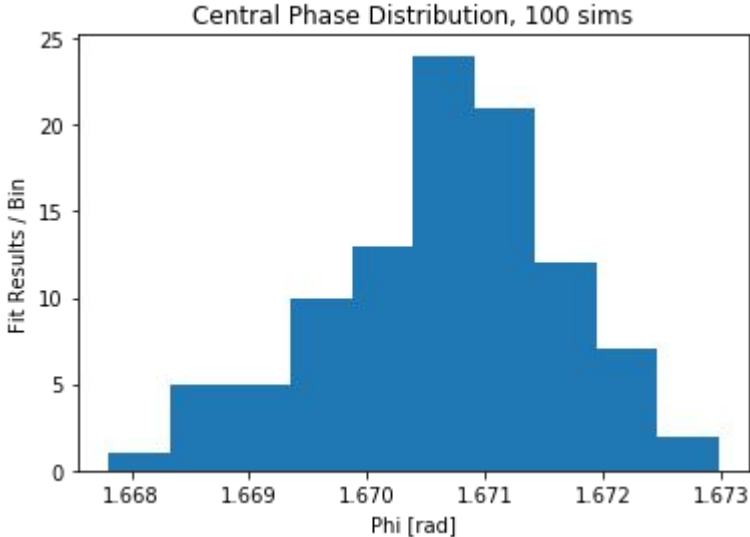
SimTools.py

```
12 ▶ def PrintDerivedParameters(intfr0,intfr1): ☐
27
28 ▶ def CalculateMarginalDistributions(intfr, n_samps=2000): ☐
78
79 ▶ def SampleFromInvertedCDF(rvars, pvals, n_samps): ☐
96
97 ▶ def WaveFunctionPixelation(intfr): ☐
113
114 ▶ def PhotonPixelation(phtn_array): ☐
134
135 ▶ def DiffusedAtomPositions(N_atoms): ☐
160
161 ▶ def RandomSampleAtomPositions(intfr, port="A"): ☐
179
180 ▶ def ProjectToPixels(portA_atoms_x, portA_atoms_z, portB_ato
209
210 ▶ def GenerateImage(intfr, recalculate_pdfs=False): ☐
```

Reporting.py

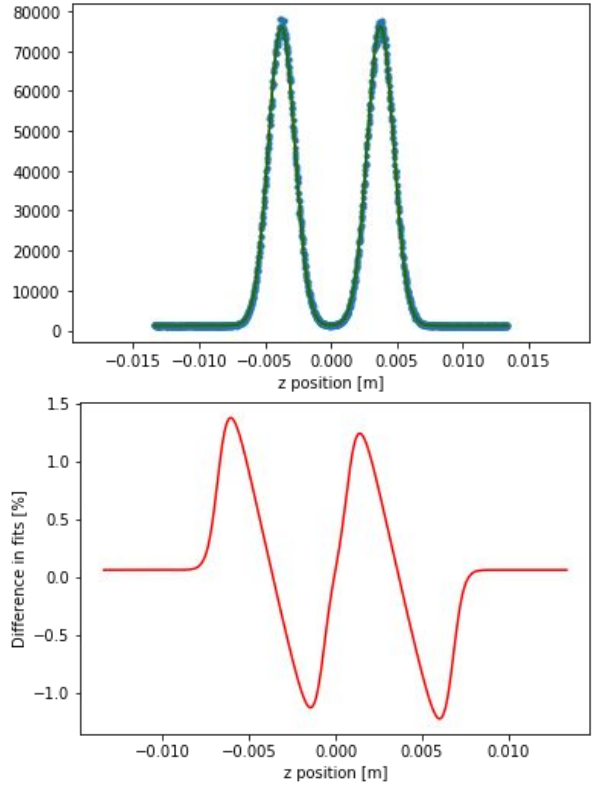
```
7 data_path = "./"          ## Path where this
8 series_id = "2222-9999_0000"  ## The uni
9
10 smry_prefix = "log"         ## Appended to t
11 smry_suffix = ".md"        ## Appended to t
12
13 enable = False             ## Do you
14
15 ▶ options = { ☐
23 }
24
25 ▶ def SetOpt(key, val): ☐
28
29 ▶ def GetOpt(key): ☐
35
36 ▶ def PrintOpts(): ☐
43
44 ▶ def Initialize(path_str=".", series=None):
92
93 ▶ def LogTextLine(*message): ☐
117
118 ▶ def LogOutputLine(*output_msg): ☐
142
143 ▶ def LogCodeBlock(*code): ☐
163
164 ▶ def LogImage(img_file_name, fig_obj): ☐
185
186 ▶ def LogMarkdownDump(mkdn_str): ☐
```

Phase Shift Statistics



1D Fit Result: Python vs Mathematica

Z-position distribution (1 interferometer, integrated over both ports)



X-position distribution (1 interferometer, integrated over both ports)

