SciSheets: Delivering the Power of Programming With The Simplicity of Spreadsheets

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Abstract—Short abstract.

Index Terms—software engineering

1. Introduction

Digital spreadsheets are the "killer app" that ushered in the PC revolution. This is largely because spreadsheets provide a conceptually simple way to do calculations that (a) closely associates data with the calculations that produce the data and (b) avoids the mental burdens of programming such as control flow, data dependencies, and data structures. Recent estimates suggest that over 800M professionals author spreadsheet formulas as part of their work [MODE2017], which is about 50 times the number of software developers world wide [Thib2013].

Our experience is that there are three types of spreadsheet users.

- **Calcers** want to evaluate equations. Spreadsheet formulas work well for Calcers since: (a) they can ignore data dependencies; (b) they can avoid flow control by using "copy" and "paste" for iteration; and (c) data structures are "visual" (e.g., rectangular blocks).
- **Scripters** feel comfortable with expressing calculations algorithmically using `for` and `if` statements; and they can use simple data structures such as lists and `pandas DataFrames` (which are like spreadsheets). However, they rarely encapsulate code into functions, preferring to copy code to get reuse.
- **Programmers** know about advanced data structures, modularization, reuse, and testing.

Our experience is primarily with scientists, especially biologists and chemists. Most commonly, we encounter Calcers and then Scripters. Only Programmers take advantage of spreadsheet macro capabilities (e.g., Visual Basic for Microsoft Excel or AppScript in Google Sheets).

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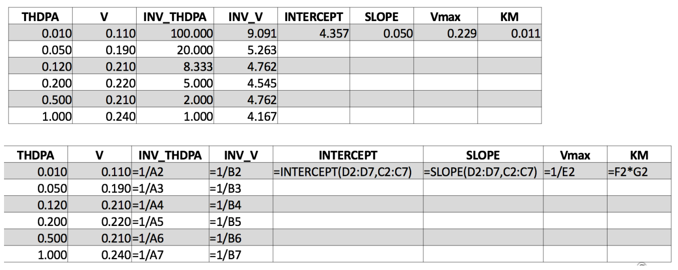
Based on this experience, we find that despite the appeal of spreadsheets, especially to Calcers and Scripters, existing spreadsheets lack several key requirements:

- **Expressivity**: The expressivity of formulas is limited because formulas are restricted to being expressions, not scripts, and so calculations cannot be written as algorithms.
- **Reuse**: It is impossible to reuse spreadsheet formulas in other formulas or in software systems.
- **Complex Data**: It remains burdensome to deal with complex data relationships in spreadsheets, such as hierarchically structured data.
- **Performance**: Very little has been done to address the performance problems that occur as spreadsheets scale.

Academic computer science has recognized the growing importance of end-user programming (EUP) [BURN2009]. Even though spreadsheets are likely the most pervasiveness example of EUP, there is a virtual absence of academic literature that attempts to remedy the shortcomings of spreadsheets. Outside of academia there has been significant interest in innovating spreadsheets. Google Fusion Tables [Gonz2010] and the "Tables" feature of Microsoft Excel ref?? use column formulas to avoid a common source of errors, the need to copy formulas as rows are added/deleted from a table. The Pyspread [PySpread] project uses Python as the formula language, which gives formulas access to thousands of Python packages. A more radical approach is taken by Stencila [Stencila], a document system that provides ways to execute code that updates tables (an approach that is in the same spirit as Jupyter Notebooks [Pere2015]). Stencila supports a variety of languages including JavaScript, Python, and SQL. However, Stencila lacks features that spreadsheet users expect: (a) closely associating data with the calculations that produce the data and and (b) avoiding considerations of data dependencies in calculations.

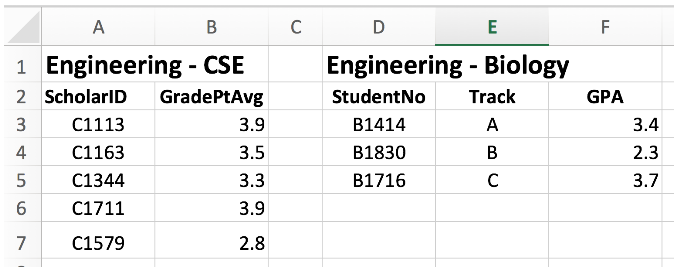
This paper introduces SciSheets [SciSheets], a new spreadsheet system with the goal of delivering the power of programming with the simplicity of spreadsheets. The name SciSheets is a contraction of the phrase "Scientific Spreadsheet", a nod to the users who motivated the requirements that we address. That said, our target users are more broadly technical professionals who do complex calculations on structured data. We note in passing that our focus is on calculations, not document processing features such as formatting and drawing



THDPA	V	INV_THDPA	INV_V	INTERCEPT	SLOPE	Vmax	KM
0.010	0.110	100.000	9.091	4.357	0.050	0.229	0.011
0.050	0.190	20.000	5.263				
0.120	0.210	8.333	4.762				
0.200	0.220	5.000	4.545				
0.500	0.210	2.000	4.762				
1.000	0.240	1.000	4.167				

THDPA	V	INV_THDPA	INV_V	INTERCEPT	SLOPE	Vmax	KM
0.010	0.110	=1/A2	=1/B2	=INTERCEPT(D2:D7,C2:C7)	=SLOPE(D2:D7,C2:C7)	=1/E2	=F2*G2
0.050	0.190	=1/A3	=1/B3				
0.120	0.210	=1/A4	=1/B4				
0.200	0.220	=1/A5	=1/B5				
0.500	0.210	=1/A6	=1/B6				
1.000	0.240	=1/A7	=1/B7				

Fig. 1: *Data view (top) and formulas view (bottom) for an Excel spreadsheet that calculates Michaelis-Menten Parameters.*



	A	B	C	D	E	F
1	Engineering - CSE			Engineering - Biology		
2	ScholarID	GradePtAvg		StudentNo	Track	GPA
3	C1113	3.9		B1414	A	3.4
4	C1163	3.5		B1830	B	2.3
5	C1344	3.3		B1716	C	3.7
6	C1711	3.9				
7	C1579	2.8				

Fig. 2: *Student grade data from two departments in the school of engineering.*

figures.

SciSheets addresses the above requirements by introducing several novel features.

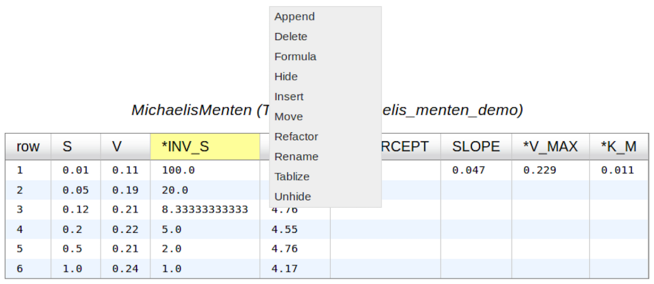
- *SciSheets formulas can be Python scripts, not just expressions.* This addresses the expressivity requirement since spreadsheet calculations can be expressed as algorithms.
- *SciSheets spreadsheets can be exported as standalone Python programs.* This addresses the reuse requirement since exported spreadsheets can be used in SciSheets formulas and/or by python programs. Further, performance is improved by this export feaure since calculations can execute without the overheads of the spreadsheet environment.
- *Tables can have nested columns (columns within columns).* This addresses the complex data requirement, such as representing n-to-m relationships.

The remainder of the paper is organized as follows. Section 2 describes the requirements that we consider, and section 3 details the SciSheets features that address these requirements. The design of SciSheets is discussed in Section 4, and section 5 discusses features planned for SciSheets. Our conclusions are presented in Section 6.

2. Requirements

This section motivates the requirements of expressivity, reuse, and complex data by present examples of spreadsheets.

1. Expressivity and Reuse
   a. Background. Common processing of biochemical assays to compute key characteristics of enzymes
   b. Requirements
      a.) *Expressivity*: limited ability specify calculations as expressions b.) *Reuse*: Cannot reuse (robustly) formulas in other spreadsheets or in software systems
2. Complex Data
   a. Background. Multiple departments in the school of engineering, keeping records in slightly different ways.
   b. Requirements
      a) *Complex data*: Cannot easily manipulate complex data, such as nested tables. Examples include of manipulations: View data side-by-side, but still manage as separate tables in terms of insert/delete.

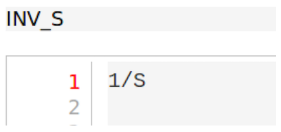


row	S	V	*INV_S		RCEPT	SLOPE	*V_MAX	*K_M
1	0.01	0.11	100.0			0.047	0.229	0.011
2	0.05	0.19	20.0					
3	0.12	0.21	8.33333333333	4.76				
4	0.2	0.22	5.0	4.55				
5	0.5	0.21	2.0	4.76				
6	1.0	0.24	1.0	4.17				

Fig. 3: *Column popup menu in a scisheet for the Michaelis-Menten calculation.*

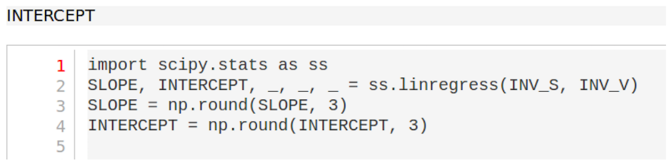
3. Features

1. SciSheets UI structure
   a. Elements - sheet, tables, columns, rows, cells (Fig)
   b. Popup menus
   c. Execution model: prologue, formula evaluations, epilogue. (Dependency checking is not possible because users can employ "eval" statement.)
   d. Column names are python variables of type pandas.array; this means that vector calculations are supported directly, including the han-



```
1/S
```

Fig. 4: *Formula for computing the inverse of the input value S.*



```
import scipy.stats as ss
SLOPE, INTERCEPT, _, _, _ = ss.linregress(INV_S, INV_V)
SLOPE = np.round(SLOPE, 3)
INTERCEPT = np.round(INTERCEPT, 3)
```

Fig. 5: *Formula for computing the slope and intercept of a regression line for the Michaelis-Menten calculation. Note that the formula is a script. Also, note that the INTERCEPT column assigns a value to the SLOPE column.*

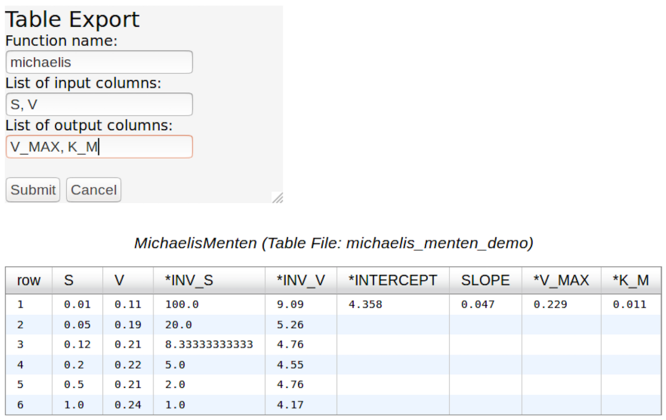
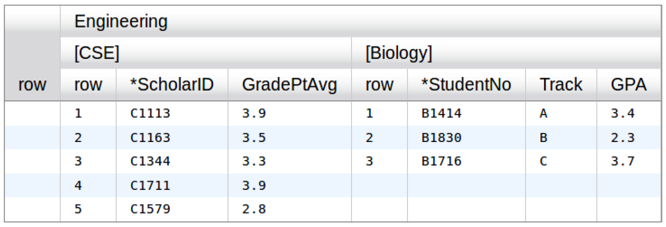


Table Export
Function name: michaelis
List of input columns: S, V
List of output columns: V_MAX, K_M

MichaelisMenten (Table File: michaelis_menten_demo)

row	S	V	*INV_S	*INV_V	*INTERCEPT	SLOPE	*V_MAX	*K_M
1	0.01	0.11	100.0	9.09	4.358	0.047	0.229	0.011
2	0.05	0.19	20.0	5.26				
3	0.12	0.21	8.33333333333	4.76				
4	0.2	0.22	5.0	4.55				
5	0.5	0.21	2.0	4.76				
6	1.0	0.24	1.0	4.17				

Fig. 6: *Menu to export a table as a standalone python program.*



	Engineering						
	[CSE]			[Biology]			
row	row	*ScholarID	GradePtAvg	row	*StudentNo	Track	GPA
	1	C1113	3.9	1	B1414	A	3.4
	2	C1163	3.5	2	B1830	B	2.3
	3	C1344	3.3	3	B1716	C	3.7
	4	C1711	3.9				
	5	C1579	2.8				

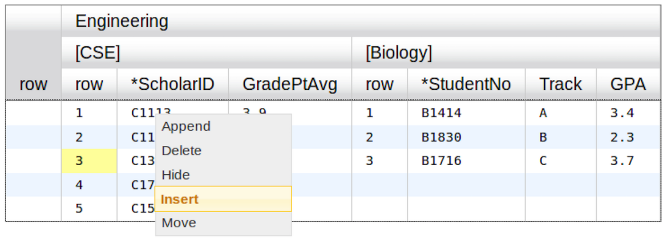
Fig. 7: *A table with two subtables.*

dling of missing data for floating point using np.nan.

2. Expressivity: Formulas can be scripts
3. Reuse: Code re-use through export
4. Complex data: managing multiple tables

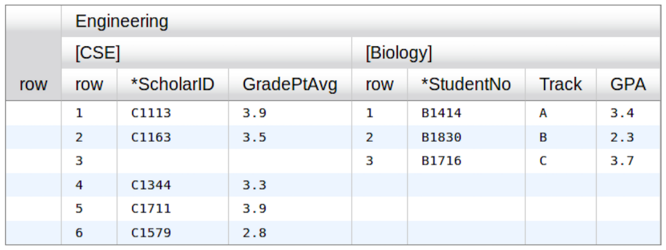
4. Design

To enable a zero-install deployment and leverage the rapid pace of UI innovation happening with web technologies,



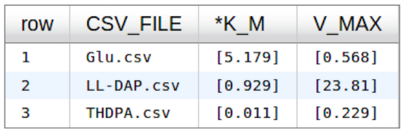
	Engineering						
	[CSE]			[Biology]			
row	row	*ScholarID	GradePtAvg	row	*StudentNo	Track	GPA
	1	C1113	3.9	1	B1414	A	3.4
	2	C11		2	B1830	B	2.3
	3	C13		3	B1716	C	3.7
	4	C17					
	5	C15					

Fig. 8: *Menu to insert a row in one subtable.*



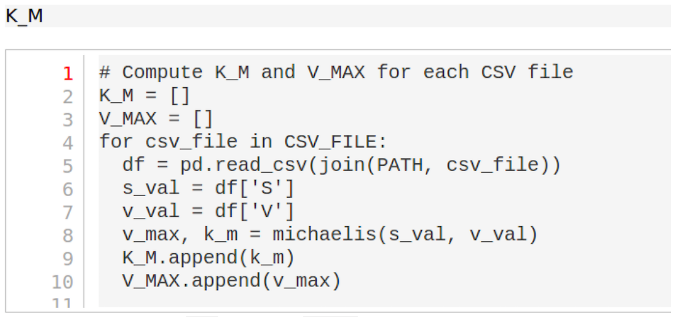
	Engineering						
	[CSE]			[Biology]			
row	row	*ScholarID	GradePtAvg	row	*StudentNo	Track	GPA
	1	C1113	3.9	1	B1414	A	3.4
	2	C1163	3.5	2	B1830	B	2.3
	3			3	B1716	C	3.7
	4	C1344	3.3				
	5	C1711	3.9				
	6	C1579	2.8				

Fig. 9: *Result of inserting a row in one subtable.*



row	CSV_FILE	*K_M	V_MAX
1	Glu.csv	[5.179]	[0.568]
2	LL-DAP.csv	[0.929]	[23.81]
3	THDPA.csv	[0.011]	[0.229]

Fig. 10: *A scisheet that processes many CSV files.*



K_M

```
# Compute K_M and V_MAX for each CSV file
K_M = []
V_MAX = []
for csv_file in CSV_FILE:
  df = pd.read_csv(join(PATH, csv_file))
  s_val = df['S']
  v_val = df['V']
  v_max, k_m = michaelis(s_val, v_val)
  K_M.append(k_m)
  V_MAX.append(v_max)
```

Fig. 11: *Column formula that is a script to process CSV files.*

SciSheets is a client-server application in which the front end uses HTML and Javascript; tables are rendered using YUI DataTables ref??. The backend handles the bulk of the computing tasks (e.g., formula evaluation). We connect the frontend and backend using Django ref??.

Fig 12 displays the relationships between core classes used in the SciSheets backend.

The use cases create the following requirements: (a) SciSheets must perform calculations without prior knowledge of data dependencies between columns; and (b) column formulas may be arbitrary Python scripts. The latter means that *SciSheets cannot use a static analysis to discover data dependencies between columns* (as is possible in a traditional spreadsheet). To see the issue here, note that a formula may contain an *eval* statement on a string variable whose value cannot be determined until runtime. Another example is that a formula may call an external function that changes values in columns.

A second implication follows from (b); this relates to debuggability. Specifically, since a formula may be a script consisting of many lines, syntax errors and exceptions must localize the problem to a line within the script. We refer to this as the *Script Debuggability Requirement*.

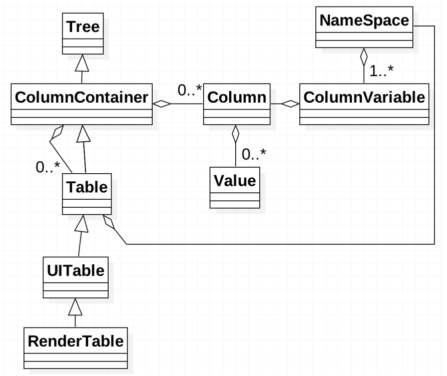


Fig. 12: *SciSheets core classes.*

We begin with our approach to handling data dependencies. Our solution is ...

- Use term "formula evaluation loop"
- Calculation workflow

Concern (2), localizing errors, seques into a broader discussion of how spreadsheets are executed. This must be done in a way so that the column formulas run in a standalone program.

```
# Function definition
def michaelis(S, V):
  from scisheets.core import api as api
  s = api.APIPlugin('michaelis.scish')
  s.initialize()
  _table = s.getTable()
```

Prologue

```
#
  s.controller.startBlock('Prologue')
  # Begin Prologue
  import math as mt
  import numpy as np
  from os import listdir
  from os.path import isfile, join
  import pandas as pd
  import scipy as sp
  from numpy import nan  # Must follow sympy import
  # End Prologue
  s.controller.endBlock()

#
  # Loop initialization
  s.controller.initializeLoop()
  while not s.controller.isTerminateLoop():
    s.controller.startAnIteration()

#
    # Formula evaluation blocks
    try:
      # Column INV_S
      s.controller.startBlock('INV_S')
      INV_S = 1/S
      s.controller.endBlock()
      INV_S = s.coerceValues('INV_S', INV_S)
    except Exception as exc:
      s.controller.exceptionForBlock(exc)

    try:
      # Column INV_V
      s.controller.startBlock('INV_V')
      INV_V = np.round(1/V,2)
      s.controller.endBlock()
      INV_V = s.coerceValues('INV_V', INV_V)
    except Exception as exc:
      s.controller.exceptionForBlock(exc)

#
    # Close of function
    s.controller.endAnIteration()

  if s.controller.getException() is not None:
    raise Exception(s.controller.formatError(
        is_absolute_linenumber=True))

  s.controller.startBlock('Epilogue')
  # Epilogue
  s.controller.endBlock()

  return V_MAX,K_M
```

Tests

```
from scisheets.core import api as api
from michaelis import michaelis
import unittest

#############################
# Tests
#############################
# pylint: disable=W0212,C0111,R0904
class Testmichaelis(unittest.TestCase):

  def setUp(self):
    from scisheets.core import api as api
    self.s = api.APIPlugin('michaelis.scish')
    self.s.initialize()
    _table = self.s.getTable()

  def testBasics(self):
    # Assign column values to program variables.
    S = self.s.getColumnValue('S')
    V = self.s.getColumnValue('V')
    V_MAX,K_M = michaelis(S,V)
    self.assertTrue(
        self.s.compareToColumnValues('V_MAX', V_MAX))
    self.assertTrue(
        self.s.compareToColumnValues('K_M', K_M))

if __name__ == '__main__':
  unittest.main()
```

Last, we consider performance. Typically, there are two causes of poor performance. The first is having a large amount of data, since the current implementation of SciSheets embeds data with the HTML document that is rendered by the browser. Note that this problem does not exist if the spreadsheet is exported and runs as a standalone Python program. That said, we do plan to implement a policy whereby data are downloaded on demand and cached locall.

The second cause of poor performance is having many iterations of the formula evaluation loop. If there are $N > 1$ formula columns, then the best case is to evaluate each formula column twice. The first execution produces the desired result (which is possible if the formula columns are in order of their data dependencies); the second execution confirms that the result has converged. Some efficiencies can be gained by using the Prologue and Epilogue for one-shot file I/O since this is often the most time consuming step in a calculation. Also, we are exploring the extent to which SciSheets can detect automatically when static dependency checking is possible so that formula evaluation is done only once.

Clearly, performance can be improved by reducing the number of formula columns since this reduces the maximum number of iterations of the formulation evaluation loop. SciSheets supports this strategy by permitting formulas to be scripts. This is a reasonable strategy for a Scripter, but it may work poorly for a Calcer who is unaware of data dependencies.

5. Future Directions

- Hierarchical tables with local scopes provides another approach to reuse.
- Graphics
- Multiple languages
- Github integration
  - Why version control
  - Structure of the serialization file
  - User interface for version control

Requirement	SciSheets Feature
• Expressivity	• python formulas • formula scripts
• Reuse	• program export • *hierarchical tables with local scopes*
• Complex Data	• hierarchical tables
• Performance	• progam export • prologue, epilogue
• Script Debuggablity	• localized exceptions
• Reproducibility	• *github integration*

TABLE 1: *Summary of requirements and SciSheets features that address these requirements. Features in italics are planned but not yet implemented.*

6. Conclusions

1. Discuss entries in table. For now, performance is not evaluated.

2. SciSheets seeks to improve the programming skills of its users. It is hoped that Calcers will start using scripts, and that Scripters will gain better insight into modularization and testing.

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