

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 avoids the mental burdens of programming, especially considerations of 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-loops and if-then statements, and they can use simple data structures such as lists and 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, and testing.

We find that the bulk of spreadsheet users who employ formulas are Calcers and then Scripters. Programmers are more likely to use a mix of formulas and macros (e.g., Visual Basic for Microsoft Excel or AppScript in Google Sheets).

Despite their appeal, the use of spreadsheet formulas has severe shortcomings.

- poor scalability because executing formulas within the spreadsheet system has high overhead;
- great difficulty with reuse because there is no concept of encapsulation (and even different length data are problematic);
- great difficulty with transitioning from a spreadsheet to a program to facilitate integration into software systems;
- limited ability to handle complex data because there is no concept of structured data;
- poor readability because formulas must be expressions (not scripts) and any cell may have a formula; and
- limited ability to express calculations because formulas are restricted to using a few hundred or so functions provided by the spreadsheet system (or specially coded macros).

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 about addressing the shortcomings of spreadsheets. Outside of academia there has been significant interest in innovating spreadsheets. Google Fusion Tables [Gonz2010] uses 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 increases the expressivity of formulas. A more radical approach is taken by the Stencila system [Stencila], which provides a document structure that includes cells that execute formulas, including the display of data tables; cells may execute statements from many languages including Python and R.

Even with these innovations, serious deficiencies remain in spreadsheets:

1. The expressivity of formulas is limited because formulas are restricted to being expressions, not scripts (although Stencila does provide a limited form of scripting).
2. It is almost impossible to reuse spreadsheet formulas, especially to allow software systems to reuse calculations done in spreadsheets.
3. It remains burdensome to deal with complex data relationships in spreadsheets, such as hierarchically structured data.

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| 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.

- Very little has been done to address the performance problems that occur as spreadsheets scale.

This paper introduces SciSheets [SciSheets], a new spreadsheet system with the goal of delivering the power of programming with the simplicity of spreadsheets. Our target users are technical professionals, such as scientists and financial engineers, who do complex calculations on structured data. To date, our focus has been on calculations, not features such as formatting.

SciSheets addresses the deficiencies enumerated above by introducing several novel features.

- Formulas can be Python scripts, not just expressions. This increases the expressiveness of formulas.
- Tables can have nested columns (columns within columns). This provides a conceptually simple way to express complex data relationships, such as n-to-m relationships.
- Spreadsheets can be exported as standalone Python programs. This provides for sharing and reuse since the exported codes can be used by other SciSheets spreadsheets or by python programs. This feature also improves scalability since calculations can be executed without the overhead of the spreadsheet system.

Further, 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.

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

2. Use Cases

We present our driving use cases by giving examples of spreadsheet uses.

- Michaelis-Menten calculation of enzyme activity.
 - Background. Common processing of biochemical assays to compute key characteristics of enzymes
 - Use cases
 - Expressivity: limited ability specify calculations as expressions
 - Reuse: Cannot

| | 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.

| MichaelisMenten (T | | | | elis_menten_demo) | | | |
|--------------------|------|------|------------------|-------------------|-------|--------|-------|
| 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 | 8.33333333333333 | | | | |
| 4 | 0.2 | 0.22 | 5.0 | | | | |
| 5 | 0.5 | 0.21 | 2.0 | | | | |
| 6 | 1.0 | 0.24 | 1.0 | | | | |

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

reuse (robustly) formulas in other spreadsheets or in software systems

2. Managing multiple tables

- Background. Multiple departments in the school of engineering, keeping records in slightly different ways.
- Use cases
 - 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.

3. How SciSheets Addresses the Use Cases

1. SciSheets UI structure

- Elements - sheet, tables, columns, rows, cells (Fig)
- Popup menus
- Execution model: prologue, formula evaluations, epilogue. (Dependency checking is not possible because users can employ "eval" statement.)

| INV_S | |
|-------|-----|
| 1 | 1/S |
| 2 | |

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

INTERCEPT

```

1 import scipy.stats as ss
2 SLOPE, INTERCEPT, _, _, _ = ss.linregress(INV_S, INV_V)
3 SLOPE = np.round(SLOPE, 3)
4 INTERCEPT = np.round(INTERCEPT, 3)
5

```

Fig. 5: Formula for computing the slope and intercept of a regression line for the Michaelis-Menten calculation. Note that One column assigns values to another column and that a script is used. label:fig-simpleformula

Table Export

Function name:

michaelis

List of input columns:

S, V

List of output columns:

V_MAX, K_M

Submit Cancel

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 | 8.333333333333333 | 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.

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

4. SciSheets Design

To enable a zero-install deployment and leverage the rapid pace of UI innovation happening with web technologies, SciSheets is a client-server application in which the front

| row | Engineering | | | [Biology] | | | |
|-----|-------------|------------|------------|-----------|------------|-------|-----|
| | [CSE] | | | | | | |
| 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.

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

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

| row | Engineering | | | [Biology] | | | |
|-----|-------------|------------|------------|-----------|------------|-------|-----|
| | [CSE] | | | | | | |
| 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. 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.

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.

UC1-UC3 pose several challenges. Prominent among these are that: (a) the user need not be aware of data dependencies between columns and (b) column formulas may be arbitrary Python scripts. In particular,

1. Automated detection of data dependencies is not possible since there made be code with "eval" statements or calls to external python functions.

2. Error localization must be more sophisticated than identify the column in which a syntax error occurred since the column formula may be a lengthy script.

We begin with (1), our inability to use automated dependency detection. Our solution here is ...

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()

```

K_M

```

1 # Compute K_M and V_MAX for each CSV file
2 K_M = []
3 V_MAX = []
4 for csv_file in CSV_FILE:
5     df = pd.read_csv(join(PATH, csv_file))
6     s_val = df['S']
7     v_val = df['V']
8     v_max, k_m = michaelis(s_val, v_val)
9     K_M.append(k_m)
10    V_MAX.append(v_max)
11

```

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

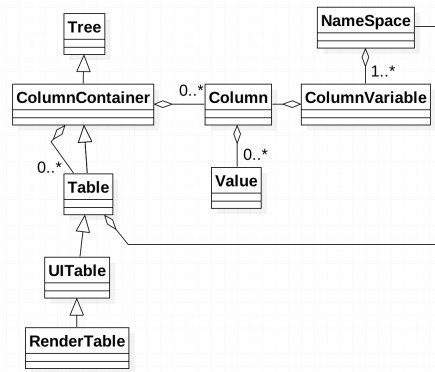


Fig. 12: SciSheets core classes.

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_lineumber=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()

```

5. Future Work

- Realizing the full power of hierarchies - reuse with "copy" action but with different technical semantics.
- Graphics
- Github integration
 - Why version control
 - Structure of the serialization file
 - User interface for version control

6. Conclusions

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| Problem | Solution |
|--|--|
| <ul style="list-style-type: none"> expressivity | <ul style="list-style-type: none"> python formulas formula scripts |
| <ul style="list-style-type: none"> reuse | <ul style="list-style-type: none"> program export <i>hierarchical tables with local scopes</i> |
| <ul style="list-style-type: none"> complex data | <ul style="list-style-type: none"> hierarchical tables |
| <ul style="list-style-type: none"> performance | <ul style="list-style-type: none"> program export |
| <ul style="list-style-type: none"> debuggability of scripts | <ul style="list-style-type: none"> localized exceptions |
| <ul style="list-style-type: none"> reproducibility | <ul style="list-style-type: none"> <i>github integration</i> |

TABLE 1: Summary of the problems in current spreadsheets and SciSheets features that are a solution to these problems. Features in italics are planned but not yet implemented.