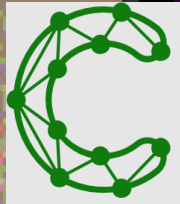


# Project Yellow – Bringing Data Types and Functional Programming to Excel

Virtual Master Class – Andy Gordon  
Senior Principal Research Manager  
Microsoft Research

London Tech Centre – JPMorgan Chase  
April 28, 2020




Future of Work

# Calc Intelligence





The background is a vibrant blue collage. At the center is a glowing globe with a grid overlay. Surrounding it are various digital elements: several data cards or SIM cards with different colors and patterns, some showing binary code (0s and 1s). In the bottom left, there's a close-up of a white computer keyboard. The overall aesthetic is futuristic and tech-oriented.

*Transforming the world  
through deep research*



# Project Yellow

Excel as a Programming Language

A long-term partnership between Excel and MSR Cambridge

Presented by Andy Gordon, MSR Cambridge – [adg@microsoft.com](mailto:adg@microsoft.com)

Microsoft Research



# Aim

Remove the “glass ceiling” that limits the scope and reach of what a domain expert can do with Excel:

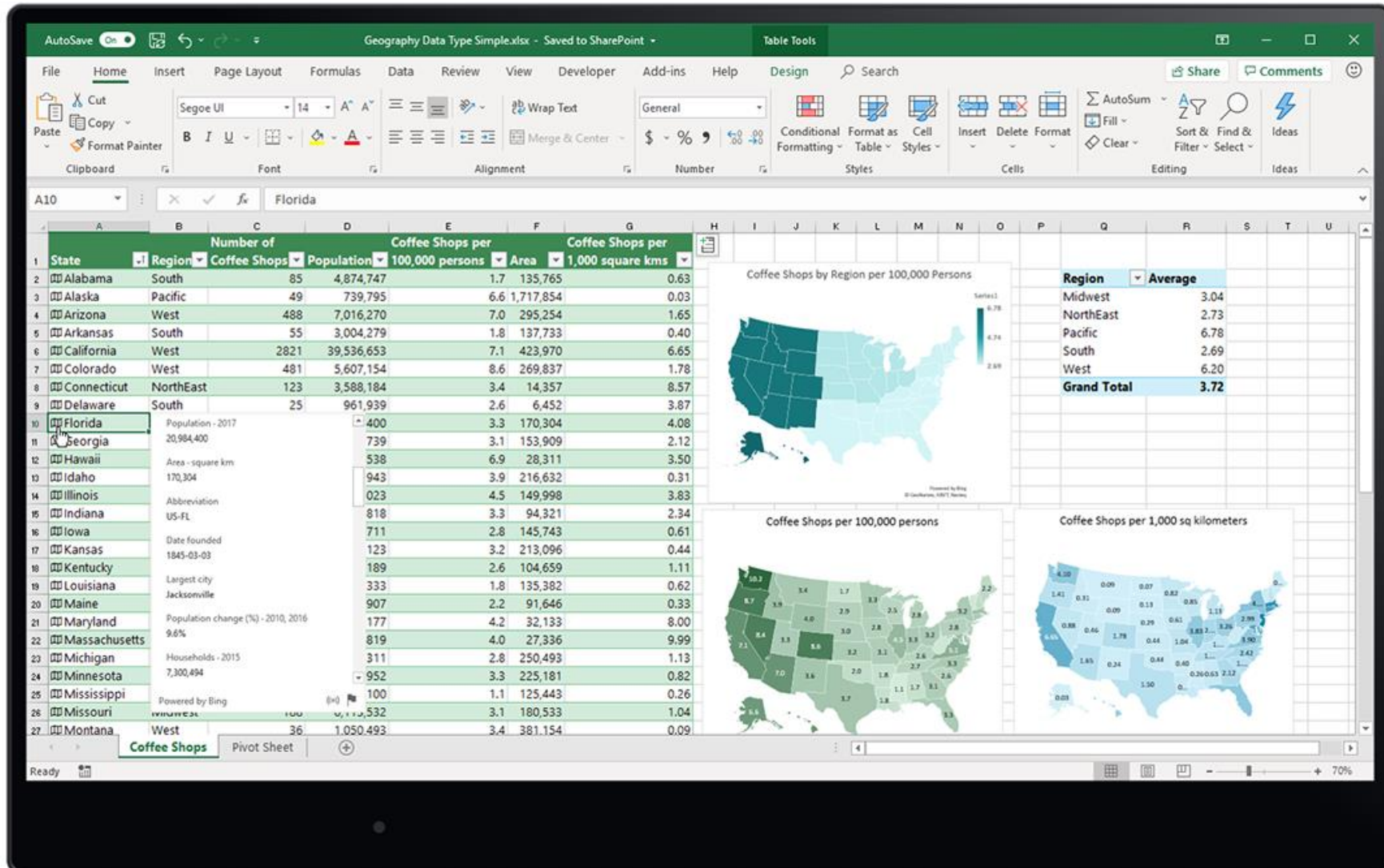
- **Make Excel functions reflect the abstractions of our end users**, by allowing end-users to define new functions using an ordinary worksheet.
- **Make Excel’s data values reflect the datatypes of our end users’ domains**, by adding arrays, vectors, records, and even domain-specific data types implemented by third parties.





# So far, we've taken Excel beyond text and numbers

Ignite 2018



*f<sub>x</sub>*

C	D	E	F	G	H
---	---	---	---	---	---

**Gloria's Food** **Daily Goals**

#MondayMotivation  
Keeping up with my nutrition goals = #livingmybestlife

32.1%

24.4%

46.6%

	Calories	Carbohydrates	Fat
Today	<b>641.4 cal</b>	<b>61.1g</b>	<b>23.3g</b>
Goal	2000	250	50

**My food**

food	calories	carbohydrates	fat
chicken breast	110.04	1.00	2.29
boiled egg (1 serving)	210.80	1.52	14.43
strawberry (4 items)	15.10	3.78	0.10
banana (1 item)	105.02	26.95	0.39
oatmeal cookie (2 items)	134.10	19.92	5.37
yogurt (3 ounces)	66.34	7.94	0.75

Entities from Wolfram



**Joe McDaid**  
@jjmcdaid

Starting today, the LET function is available to Excel users in the Insiders Ring to preview. The LET function allows you to define and use formula scoped names. Calculating a weighted average: =LET(values,A1:A4, weights,B1:B4, SUM(values\*weights)/SUM(weights)) 💡

6:16 PM · Mar 17, 2020 · [Twitter Web App](#)

28 Retweets 93 Likes



**David Benaim MVP** @DaveBenaim · Mar 17  
Replying to @jjmcdaid  
Let it be!

3 Likes



**Exceljet** @exceljet · Mar 17  
Replying to @jjmcdaid

Excellent. This will really streamline certain formulas that require the same operation more than 1x.

2 Likes



**Ryan Bond** @RyNBond · Mar 17  
Replying to @jjmcdaid

This is similar to 'With' in Power Apps

1 Like



**Ed Hansberry** @ehansalytics · Mar 18  
Replying to @jjmcdaid

Now we just need to be able to format formulas easier in Excel like we can in #PowerBI and #PowerApps

1 Like



**Abiola David | Excel MVP** 🇳🇮 🌍 🏆 🏆 @AbiolaDavid01 · Mar 17  
Replying to @jjmcdaid  
Really cool function

1 Like



**Reagan Onyango** @rigs12 · 18h

Now even before I breathe xlookup, the real bomb is here!

1 Like



**Oz du Soleil** @OzExcel · Mar 18  
Replying to @jjmcdaid  
So cool!

1 Like

Breaking News!!!

# Calculation View

What if we offered a code-centric view of the grid?

	A	B	C	D	E	F	G	H	I	J
1	Depreciation	99%		HoldingCost	0.10%					
2	Assets	Present value	2019	2020	2021	2022	2023	2024	2025	2026
3	Terminal with Electronic Components	£ 2,728.17	£ 2,698.16	£ 2,668.48	£ 2,639.13	£ 2,610.10	£ 2,581.39	£ 2,552.99	£ 2,524.91	£ 2,497.00
4	Accessories Others	£ 196.77	£ 194.61	£ 192.46	£ 190.35	£ 188.25	£ 186.18	£ 184.14	£ 182.11	£ 180.11
5	Accessories SAK	£ 10.32	£ 10.21	£ 10.09	£ 9.98	£ 9.87	£ 9.76	£ 9.66	£ 9.55	£ 9.45
6	Accessories SAK	£ 38.28	£ 37.86	£ 37.44	£ 37.03	£ 36.62	£ 36.22	£ 35.82	£ 35.43	£ 35.04
7	Other Terminals	£ 388.88	£ 384.60	£ 380.37	£ 376.19	£ 372.05	£ 367.95	£ 363.91	£ 359.91	£ 355.95
8	SAK-Series	£ 430.48	£ 425.70	£ 421.06	£ 416.44	£ 411.83	£ 407.22	£ 402.61	£ 398.01	£ 393.41
9	SAK-Series	£ 731.01	£ 722.97	£ 715.02	£ 707.15	£ 699.37	£ 691.68	£ 684.07	£ 676.55	£ 669.10
10	SAK-Series	£ 423.61	£ 418.95	£ 414.34	£ 409.78	£ 405.28	£ 400.82	£ 396.41	£ 392.05	£ 387.74
11	SAK-Series	£ 397.49	£ 393.12	£ 388.79	£ 384.52	£ 380.29	£ 376.10	£ 371.97	£ 367.87	£ 363.83
12	SAK-Series	£ 321.88	£ 318.34	£ 314.84	£ 311.37	£ 307.95	£ 304.56	£ 301.20	£ 297.87	£ 294.62
13	SAK-Series	£ 660.61	£ 653.30	£ 646.11	£ 639.05	£ 632.02	£ 625.07	£ 618.19	£ 611.39	£ 604.67
14	SAK-Series	£ 748.58	£ 740.35	£ 732.20	£ 724.15	£ 716.18	£ 708.30	£ 700.51	£ 692.81	£ 685.19
15	Coupler	£ 53.97	£ 53.38	£ 52.79	£ 52.21	£ 51.63	£ 51.07	£ 50.50	£ 49.95	£ 49.40
16	SAK-Series	£ 356.36	£ 352.44	£ 348.56	£ 344.73	£ 340.94	£ 337.19	£ 333.48	£ 329.81	£ 326.18
17	SAK-Series	£ 362.18	£ 358.20	£ 354.26	£ 350.36	£ 346.51	£ 342.69	£ 338.92	£ 335.20	£ 331.51
18	Coupler	£ 49.81	£ 49.26	£ 48.72	£ 48.18	£ 47.65	£ 47.13	£ 46.61	£ 46.10	£ 45.59
19	SAK-Series	£ 229.38	£ 226.86	£ 224.36	£ 221.89	£ 219.45	£ 217.04	£ 214.65	£ 212.29	£ 209.95
20	SAK-Series	£ 155.25	£ 153.54	£ 151.85	£ 150.18	£ 148.53	£ 146.90	£ 145.28	£ 143.68	£ 142.10
21	SAK-Series	£ 130.88	£ 129.44	£ 128.02	£ 126.61	£ 125.22	£ 123.84	£ 122.48	£ 121.13	£ 119.80
22	SAK-Series	£ 130.88	£ 129.44	£ 128.02	£ 126.61	£ 125.22	£ 123.84	£ 122.48	£ 121.13	£ 119.80
23	SAK-Series	£ 139.52	£ 137.99	£ 136.47	£ 134.97	£ 133.48	£ 132.01	£ 130.56	£ 129.13	£ 127.70
24	SAK-Series	£ 144.00	£ 142.42	£ 140.85	£ 139.30	£ 137.77	£ 136.25	£ 134.75	£ 133.27	£ 131.81
25	Accessories SAK	£ 37.59	£ 37.18	£ 36.77	£ 36.36	£ 35.96	£ 35.57	£ 35.18	£ 34.79	£ 34.41
26	Accessories Others	£ 3.16	£ 3.13	£ 3.09	£ 3.06	£ 3.02	£ 2.99	£ 2.96	£ 2.92	£ 2.89
27	Accessories Others	£ 1.91	£ 1.89	£ 1.87	£ 1.85	£ 1.83	£ 1.81	£ 1.79	£ 1.77	£ 1.75
28	Accessories SAK	£ 38.21	£ 37.79	£ 37.37	£ 36.96	£ 36.56	£ 36.15	£ 35.76	£ 35.36	£ 34.97
29	Accessories SAK	£ 34.69	£ 34.31	£ 33.93	£ 33.56	£ 33.19	£ 32.82	£ 32.46	£ 32.11	£ 31.75
30	Accessories SAK	£ 34.69	£ 34.31	£ 33.93	£ 33.56	£ 33.19	£ 32.82	£ 32.46	£ 32.11	£ 31.75

See and edit your formulae as a list.

Calculation View

Show Formulas Only

- Depreciation B1=99%
- HoldingCost E1=0.1%
- C3:N1002=B3\*Depreciation-(B3\*HoldingCost)
- TotalPresentValue Q3=SUM(C3:C1002)
- TotalEndValue Q4=SUM(N3:N1002)
- TotalLoss Q5=TotalPresentValue-TotalEndValue

Function Library: Insert Function, AutoSum, Recently Used, Financial, Logical, Text, Date & Time, Lookup & Reference, Math & Trig, More Functions, Name Manager, Define Name, Use in Formula, Create from Selection, Trace Precedents, Trace Dependents, Remove Arrows, Show Formulas, Error Checking, Evaluate Formula, Watch Window, Calculation Options, Calculate Now, Calculate Sheet

C3 =B3\*Depreciation-(B3\*HoldingCost)

	A	B	C	D	E	F	G	H	I	J
1	Depreciation	99%		HoldingCost	0.10%					
2	Assets	Present value	2019	2020	2021	2022	2023	2024	2025	2026
3	Terminal with Electronic Components	£ 2,728.17	£ 2,698.16	£ 2,668.48	£ 2,639.13	£ 2,610.10	£ 2,581.39	£ 2,552.99	£ 2,524.91	£ 2,497.13
4	Accessories Others	£ 196.77	£ 194.61	£ 192.46	£ 190.35	£ 188.25	£ 186.18	£ 184.11	£ 182.04	£ 180.00
5	Accessories SAK	£ 10.32	£ 10.21	£ 10.09	£ 9.98	£ 9.87	£ 9.76	£ 9.65	£ 9.54	£ 9.43
6	Accessories SAK	£ 38.28	£ 37.86	£ 37.44	£ 37.03	£ 36.62	£ 36.21	£ 35.80	£ 35.39	£ 34.98
7	Other Terminals	£ 388.88	£ 384.60	£ 380.37	£ 376.19	£ 372.05	£ 367.91	£ 363.77	£ 359.63	£ 355.49
8	SAK-Series	£ 430.48	£ 425.74	£ 421.06	£ 416.43	£ 411.85	£ 407.31	£ 402.81	£ 398.35	£ 393.93
9	SAK-Series	£ 731.01	£ 722.97	£ 715.02	£ 707.15	£ 699.37	£ 691.68	£ 684.07	£ 676.54	£ 669.07
10	SAK-Series	£ 423.61	£ 418.95	£ 414.34	£ 409.78	£ 405.28	£ 400.82	£ 396.41	£ 392.05	£ 387.74
11	SAK-Series	£ 397.49	£ 393.12	£ 388.79	£ 384.52	£ 380.29	£ 376.10	£ 371.97	£ 367.87	£ 363.81
12	SAK-Series	£ 371.88	£ 367.74	£ 363.64	£ 359.58	£ 355.56	£ 351.58	£ 347.64	£ 343.74	£ 339.88
13	SAK-Series	£ 346.27	£ 342.34	£ 338.46	£ 334.62	£ 330.82	£ 327.06	£ 323.34	£ 319.66	£ 316.01
14	SAK-Series	£ 748.58	£ 740.53	£ 732.52	£ 724.55	£ 716.61	£ 708.30	£ 700.51	£ 692.81	£ 685.19
15	Coupler	£ 53.97	£ 53.38	£ 52.79	£ 52.21	£ 51.63	£ 51.07	£ 50.50	£ 49.95	£ 49.40
16	SAK-Series	£ 366.66	£ 362.44	£ 358.26	£ 354.13	£ 350.04	£ 346.01	£ 342.02	£ 338.07	£ 334.16
17	SAK-Series	£ 367.18	£ 363.18	£ 359.22	£ 355.30	£ 351.41	£ 347.56	£ 343.74	£ 339.95	£ 336.19
18	Coupler	£ 49.81	£ 49.26	£ 48.71	£ 48.17	£ 47.65	£ 47.13	£ 46.61	£ 46.10	£ 45.59
19	SAK-Series	£ 226.88	£ 226.86	£ 226.84	£ 226.82	£ 226.80	£ 226.78	£ 226.76	£ 226.74	£ 226.72
20	SAK-Series	£ 122.22	£ 122.22	£ 122.22	£ 122.22	£ 122.22	£ 122.22	£ 122.22	£ 122.22	£ 122.22
21	SAK-Series	£ 130.88	£ 129.44	£ 128.00	£ 126.56	£ 125.12	£ 123.68	£ 122.24	£ 120.80	£ 119.36
22	SAK-Series	£ 130.88	£ 129.44	£ 128.00	£ 126.56	£ 125.12	£ 123.68	£ 122.24	£ 120.80	£ 119.36
23	SAK-Series	£ 139.82	£ 138.40	£ 136.97	£ 135.55	£ 134.13	£ 132.71	£ 131.29	£ 129.87	£ 128.45
24	SAK-Series	£ 144.00	£ 142.56	£ 141.12	£ 139.68	£ 138.24	£ 136.80	£ 135.36	£ 133.92	£ 132.48
25	Accessories SAK	£ 37.59	£ 37.18	£ 36.77	£ 36.36	£ 35.96	£ 35.57	£ 35.18	£ 34.79	£ 34.41
26	Accessories Others	£ 3.16	£ 3.13	£ 3.09	£ 3.06	£ 3.03	£ 2.99	£ 2.96	£ 2.92	£ 2.89
27	Accessories Others	£ 1.91	£ 1.89	£ 1.87	£ 1.85	£ 1.83	£ 1.81	£ 1.79	£ 1.77	£ 1.75
28	Accessories SAK	£ 38.21	£ 37.79	£ 37.37	£ 36.96	£ 36.56	£ 36.15	£ 35.76	£ 35.36	£ 34.97
29	Accessories SAK	£ 34.69	£ 34.31	£ 33.93	£ 33.56	£ 33.19	£ 32.82	£ 32.46	£ 32.11	£ 31.75
30	Accessories SAK	£ 34.69	£ 34.31	£ 33.93	£ 33.56	£ 33.19	£ 32.82	£ 32.46	£ 32.11	£ 31.75

Calculation View

Show Formulas Only

Depreciation B1=99%

HoldingCost E1=0.1%

**C3:N1002 = B3\*Depreciation-(B3\*HoldingCost)**

TotalLoss Q5=TotalPresentValue-TotalEndValue

**Shared formulae (e.g., copy/pasted or drag-filled) are grouped and can be viewed and edited as one.**

TotalLoss =TotalPresentValue-TotalEndValue

	F	G	H	I	J	K	L	M	N	O	P	Q
1												
2	2022	2023	2024	2025	2026	2027	2028	2029	2030			
3	£ 2,610.10	£ 2,581.39	£ 2,552.99	£ 2,524.91	£ 2,497.13	£ 2,469.67	£ 2,442.50	£ 2,415.63	£ 2,389.06			
4	£ 188.25	£ 186.18	£ 184.14	£ 182.11	£ 180.11	£ 178.13	£ 176.17	£ 174.23	£ 172.31			
5	£ 9.87	£ 9.76	£ 9.66	£ 9.55	£ 9.45	£ 9.34	£ 9.24	£ 9.14	£ 9.04			
6	£ 36.62	£ 36.22	£ 35.82	£ 35.43	£ 35.04	£ 34.65	£ 34.27	£ 33.89	£ 33.52			
7	£ 372.05	£ 367.96	£ 363.91	£ 359.91	£ 355.95	£ 352.03	£ 348.16	£ 344.33	£ 340.54			
8	£ 411.85	£ 407.32	£ 402.84	£ 398.41	£ 394.02	£ 389.69	£ 385.40	£ 381.16	£ 376.97			
9	£ 699.37	£ 691.68	£ 684.07	£ 676.50	£ 668.97	£ 661.47	£ 654.00	£ 646.56	£ 639.15			
10	£ 405.28	£ 400.82	£ 396.41	£ 392.05	£ 387.74	£ 383.47	£ 379.25	£ 375.08	£ 370.96			
11	£ 380.29	£ 376.10	£ 371.97	£ 367.87	£ 363.83	£ 359.83	£ 355.87	£ 351.95	£ 348.08			
12	£ 307.95	£ 304.56	£ 301.10	£ 297.70	£ 294.35	£ 291.05	£ 287.81	£ 285.01	£ 281.87			
13	£ 632.02	£ 625.07	£ 618.19	£ 611.29	£ 604.57	£ 598.01	£ 591.61	£ 585.43	£ 578.50			
14	£ 716.18	£ 708.30	£ 700.51	£ 692.81	£ 685.19	£ 677.65	£ 670.19	£ 662.82	£ 655.53			
15	£ 51.63	£ 51.07	£ 50.50	£ 49.95	£ 49.40	£ 48.86	£ 48.33	£ 47.79	£ 47.26			
16	£ 340.94	£ 337.19	£ 333.48	£ 329.81	£ 326.19	£ 322.61	£ 319.07	£ 315.58	£ 312.16			
17	£ 346.51	£ 342.69	£ 338.92	£ 335.20	£ 331.51	£ 327.86	£ 324.26	£ 320.69	£ 317.16			
18	£ 47.65	£ 47.13	£ 46.61	£ 46.10	£ 45.59	£ 45.09	£ 44.59	£ 44.10	£ 43.62			
19	£ 219.45	£ 217.04	£ 214.65	£ 212.28	£ 209.95	£ 207.65	£ 205.36	£ 203.10	£ 200.87			
20	£ 148.53	£ 146.90	£ 145.28	£ 143.68	£ 142.10	£ 140.54	£ 138.99	£ 137.46	£ 135.95			
21	£ 125.22	£ 123.84	£ 122.48	£ 121.13	£ 119.80	£ 118.48	£ 117.18	£ 115.89	£ 114.61			
22	£ 125.22	£ 123.84	£ 122.48	£ 121.13	£ 119.80	£ 118.48	£ 117.18	£ 115.89	£ 114.61			
23	£ 133.48	£ 132.01	£ 130.56	£ 129.13	£ 127.70	£ 126.30	£ 124.91	£ 123.54	£ 122.18			
24	£ 137.77	£ 136.25	£ 134.75	£ 133.27	£ 131.81	£ 130.36	£ 128.92	£ 127.50	£ 126.10			
25	£ 35.96	£ 35.57	£ 35.18	£ 34.79	£ 34.41	£ 34.03	£ 33.65	£ 33.28	£ 32.92			
26	£ 3.02	£ 2.99	£ 2.96	£ 2.92	£ 2.89	£ 2.86	£ 2.83	£ 2.80	£ 2.77			
27	£ 1.83	£ 1.81	£ 1.79	£ 1.77	£ 1.75	£ 1.73	£ 1.71	£ 1.69	£ 1.67			
28	£ 36.56	£ 36.15	£ 35.76	£ 35.36	£ 34.97	£ 34.59	£ 34.21	£ 33.83	£ 33.46			
29	£ 33.19	£ 32.82	£ 32.46	£ 32.11	£ 31.75	£ 31.40	£ 31.06	£ 30.72	£ 30.38			
30	£ 33.19	£ 32.82	£ 32.46	£ 32.11	£ 31.75	£ 31.40	£ 31.06	£ 30.72	£ 30.38			

It's easy to name cells and use names in formulae. This makes formulae more readable.

Formulas Only

Depreciation B1 = 99%

HoldingCost E1 = 0.1%

C3:N1002 = B3\*Depreciation-(B3\*HoldingCost)

TotalPresentValue Q3 = SUM(C3:C1002)

TotalEndValue Q4 = SUM(N3:N1002)

TotalLoss Q5 = TotalPresentValue-TotalEndValue

T260

	A	B	C	D	E	F	G	H	I	J	K	L	
1	Particip	First condition	Task 1	Task 1	Task 2	Task 2	Task 3	Task 3	Task 4	Task 4	Secon	Task 5 c	Tas
2	1	Normal	W1A 158		W2A 283		D1A 63		D2A 77		Calc View	W1B 104	
3	2	Normal	W1B 170		W2B 182		D1B 246		D2B 122		Calc View	W1A 60	
4	3	Calc View	W2A 258		W1A 80		D2A 213		D1A 78		Normal	W2B 235	
5	4	Calc View	W2B 313		W1B 31		D2B 125		D1B 100		Normal	W2A 185	
6	5	Normal	W1A 172		W2A 129		D1A 262		D2A 22		Calc View	W1B 61	
7	6	Normal	W1B 512		W2B 215		D1B 223		D1A 40		Calc View	W1A 45	
8	7	Calc View	W2A 400		W1A 68		D2A 160		D1A 124		Normal	W2B 307	
9	8	Calc View	W2B 144		W1B 64		D2B 58		D1B 52		Normal	W2A 102	
10	9	Normal	W1A 164		W2A 110		D1A 70		D2A 110		Calc View	W1B 59	
11	10	Normal	W1B 193		W2B 287		D1B 75		D2B 59		Calc View	W1A 120	
12	11	Calc View	W2A 240		W1A 120		D2A 83		D1A 23		Normal	W2B 266	
13	12	Calc View	W2B 178		W1B 38		D2B 27		D1B 14		Normal	W2A 163	
14	13	Normal	W1A 450		W2A 337		D1A 394		D2A 83		Calc View	W1B 103	
15	14	Normal	W1B 73		W2B 134		D1B 120		D2B 55		Calc View	W1A 68	
16	15	Calc View	W2A 110		W1A 50		D2A 50		D1A 44		Normal	W2B 175	
17	16	Calc View	W2B 88		W1B 44		D2B 24		D1B 53		Normal	W2A 202	
18	17	Normal	W1A 69		W2A 60		D1A 54		D2A 32		Calc View	W1B 27	
19	18	Normal	W1B 341		W2B 388		D1B 72		D2B 22		Calc View	W1A 62	
20	19	Calc View	W2A 80		W1A 72		D2A 27		D1A 26		Normal	W2B 428	
21	20	Calc View	W2B 64		W1B 48		D2B 22		D1B 44		Normal	W2A 181	
22	21	Normal	W1A 157		W2A 222		D1A 68		D2A 38		Calc View	W1B 52	
23	22	Normal	W1B 375		W2B 408		D1B 63		D2B 33		Calc View	W1A 60	
24	23	Calc View	W2A		W1A		D2A		D1A		Normal	W2B	
25	24	Calc View	W2B		W1B		D2B		D1B		Normal	W2A	

Sorting

calculation-view

Sort Filter Search Refresh

- Sort Descending
- Sort by:
- Row wise
- Column wise
- Formula length
- Alphabetical

T206:U206=MEDIAN(T184:T205)  
 AB206:AC206=MEDIAN(AB184:AB205)  
 K222=MEDIAN([Difference])  
 L222=MEDIAN([Difference %])  
 C229:D316=LOG10(F229)  
 T248:U248=MEDIAN(T226:T247)  
 AB248:AC248=MEDIAN(AB226:AB247)

	Minutes	Secon	Particip	Task cc	Task ty	Normal	CV	Differ	Differen
33	3	180	1	D1	D	63	161	-98	-155.56
34	4	240	1	D2	D	77	180	-103	-133.77
37	7	420	2	D1	D	246	90	156	63.41
38	8	480	2	D2	D	122	67	55	45.08
41			3	D2	D	54	219	-165	-305.56
42			3	D1	D	65	78	-13	-20.00
45			4	D2	D	300	125	175	58.33
46			4	D1	D	143	100	43	30.07
49			5	D1	D	262	83	179	68.32
50			5	D2	D	182	59	123	67.58
53			6	D1	D	223	48	175	78.48
54			6	D2	D	40	20	20	50.00
57			7	D2	D	136	160	-24	-17.65
58			7	D1	D	178	124	54	30.34
61			8	D2	D	24	58	-34	-141.67



T260

	A	B	C	D	E	F	G	H	I	J	K	L	
1	Particip	First condition	Task 1	Task 1	Task 2	Task 2	Task 3	Task 3	Task 4	Task 4	Secon	Task 5 c	Tas
2	1	Normal	W1A 158	W2A 283	D1A 77	D2A 77	Calc View	W1B 104					
3	2	Normal	W1B 170	W2B 182	D1B 122	D2B 122	Calc View	W1A 60					
4	3	Calc View	W2A 258	W1A 80	D2A 219	D1A 78	Normal	W2B 235					
5	4	Calc View	W2B 313	W1B 31	D2B 125	D1B 100	Normal	W2A 185					
6	5	Normal	W1A 172	W2A 178	D1A 262	D2A 182	Calc View	W1B 61					
7	6	Normal	W1B 512	W2B 223	D1B 223	D2B 40	Calc View	W1A 45					
8	7	Calc View	W2A 400	W1A 260	D1A 124	Normal	W2B 307						
9	8	Calc View	W2B 144	W1B 4	D2B 13	D1B 9	Normal	W2A 102					
10	9	Normal	W1A 164	W2A 110	D1A 10	D2A 10	Normal	W1B 59					
11	10	Normal	W1B 193	W2B 287	D1B 75	D2B 8	Calc View	W1A 120					
12	11	Calc View	W2A 240	W1A 120	D2A 83	D1A 23	Normal	W2B 266					
13	12	Calc View	W2B 178	W1B 38	D2B 27	D1B 14	Normal	W2A 163					
14	13	Normal	W1A 450	W2A 337	D1A 394	D2A 83	Calc View	W1B 103					
15	14	Normal	W1B 73	W2B 134	D1B 120	D2B 55	Calc View	W1A 68					
16	15	Calc View	W2A 110	W1A 50	D2A 50	D1A 44	Normal	W2B 175					
17	16	Calc View	W2B 88	W1B 44	D2B 24	D1B 53	Normal	W2A 202					
18	17	Normal	W1A 69	W2A 60	D1A 54	D2A 32	Calc View	W1B 27					
19	18	Normal	W1B 341	W2B 388	D1B 72	D2B 22	Calc View	W1A 62					
20	19	Calc View	W2A 80	W1A 72	D2A 27	D1A 26	Normal	W2B 428					
21	20	Calc View	W2B 64	W1B 48	D2B 22	D1B 44	Normal	W2A 181					
22	21	Normal	W1A 157	W2A 222	D1A 68	D2A 38	Calc View	W1B 52					
23	22	Normal	W1B 375	W2B 408	D1B 63	D2B 33	Calc View	W1A 60					
24	23	Calc View	W2A	W1A	D2A	D1A	Normal	W2B					
25	24	Calc View	W2B	W1B	D2B	D1B	Normal	W2A					

Sort by formula length

calculation-view

Sort	Filter	Search	Refresh
K2:K25=IF([@[First condition]]="Normal","Calc View","Normal")			
L31:L118=([@Difference]/[@Normal])*100			
L222=MEDIAN([Difference %])			
L171=MEDIAN([Difference %])			
L119=MEDIAN([Difference %])			
K222=MEDIAN([Difference])			
K171=MEDIAN([Difference])			
K119=MEDIAN([Difference])			
AB248:AC248=MEDIAN(AB226:AB247)			
AB206:AC206=MEDIAN(AB184:AB205)			
T248:U248=MEDIAN(T226:T247)			
T206:U206=MEDIAN(T184:T205)			
K31:K118=[@Normal]-[@CV]			
C31:C40=[@Minutes]*60			
C229:D316=LOG10(F229)			
H31:H118=LEFT(G31,1)			

	Minutes	Secon	Particip	Task cc	Task ty	Normal	CV	Differe	Differen
33	3	180	1	D1	D	63	161	-98	-155.56
34	4	240	1	D2	D	77	180	-103	-133.77
37	7	420	2	D1	D	246	90	156	63.41
38	8	480	2	D2	D	122	67	55	45.08
41			3	D2	D	54	219	-165	-305.56
42			3	D1	D	65	78	-13	-20.00
45			4	D2	D	300	125	175	58.33
46			4	D1	D	143	100	43	30.07
49			5	D1	D	262	83	179	68.32
50			5	D2	D	182	59	123	67.58
53			6	D1	D	223	48	175	78.48
54			6	D2	D	40	20	20	50.00
57			7	D2	D	136	160	-24	-17.65
58			7	D1	D	178	124	54	30.34
61			8	D2	D	24	58	-34	-141.67

	A	B	C	D	E	F	G	H	I	J	K	L	
1	Particip	First condition	Task 1	Task 1	Task 2	Task 2	Task 3	Task 3	Task 4	Task 4	Secon	Task 5 c	Tas
2	1	Normal	W1A 158		W2A 283		D1A 63		D2A 77		Calc View	W1B 104	
3	2	Normal	W1B 170		W2B 182		D1B 246		D2B 122		Calc View	W1A 60	
4	3	Calc View	W2A 258		W1A 80		D2A 219		D1A 78		Normal	W2B 235	
5	4	Calc View	W2B 313		W1B 31		D1B 125		D1B 100		Normal	W2A 185	
6	5	Normal	W1A 172		W2A 129		D2A 258		D2A 38		Calc View	W1B 61	
7	6	Normal	W1B 512		W2B 215		D1B 23		D1B 4		Calc View	W1A 45	
8	7	Calc View	W2A 400		W1A 68		D2A 160		D1A 14		Normal	W2B 307	
9	8	Calc View	W2B 144		W1B 64		D2B 58		D1B 52		Normal	W2A 102	
10	9	Normal	W1A 164		W2A 110		D1A 70		D2A 110		Calc View	W1B 59	
11	10	Normal	W1B 193		W2B 287		D1B 75		D2B 59		Calc View	W1A 120	
12	11	Calc View	W2A 240		W1A 120		D2A 83		D1A 23		Normal	W2B 266	
13	12	Calc View	W2B 178		W1B 38		D2B 27		D1B 14		Normal	W2A 163	
14	13	Normal	W1A 450		W2A 337		D1A 394		D2A 83		Calc View	W1B 103	
15	14	Normal	W1B 73		W2B 134		D1B 120		D2B 55		Calc View	W1A 68	
16	15	Calc View	W2A 110		W1A 50		D2A 50		D1A 44		Normal	W2B 175	
17	16	Calc View	W2B 88		W1B 44		D2B 24		D1B 53		Normal	W2A 202	
18	17	Normal	W1A 69		W2A 60		D1A 54		D2A 32		Calc View	W1B 27	
19	18	Normal	W1B 341		W2B 388		D1B 72		D2B 22		Calc View	W1A 62	
20	19	Calc View	W2A 80		W1A 72		D2A 27		D1A 26		Normal	W2B 428	
21	20	Calc View	W2B 64		W1B 48		D2B 22		D1B 44		Normal	W2A 181	
22	21	Normal	W1A 157		W2A 222		D1A 68		D2A 38		Calc View	W1B 52	
23	22	Normal	W1B 375		W2B 408		D1B 63		D2B 33		Calc View	W1A 60	
24	23	Calc View	W2A		W1A		D2A		D1A		Normal	W2B	
25	24	Calc View	W2B		W1B		D2B		D1B		Normal	W2A	

Filtering

calculation-view

Sort Filter Search Refresh

- Formulas only
- Values only
- Named items only
- Precedents and Dependents
- Clear Filters

K2:K25=IF([@F...al")

L31:L118=([@D...)

L222=MEDIAN(...)

L171=MEDIAN(...)

L119=MEDIAN(...)

K222=MEDIAN(...)

K171=MEDIAN(...)

K119=MEDIAN([Difference])

AB248:AC248=MEDIAN(AB226:AB247)

AB206:AC206=MEDIAN(AB184:AB205)

T248:U248=MEDIAN(T226:T247)

T206:U206=MEDIAN(T184:T205)

K31:K118=[@Normal]-[@CV]

C31:C40=[@Minutes]\*60

C229:D316=LOG10(F229)

H31:H118=LEFT(G31,1)

	Minutes	Secon	Particip	Task cc	Task ty	Normal	CV	Differ	Differ
33	3	180	1	D1	D	63	161	-98	-155.56
34	4	240	1	D2	D	77	180	-103	-133.77
37	7	420	2	D1	D	246	90	156	63.41
38	8	480	2	D2	D	122	67	55	45.08
41			3	D2	D	54	219	-165	-305.56
42			3	D1	D	65	78	-13	-20.00
45			4	D2	D	300	125	175	58.33
46			4	D1	D	143	100	43	30.07
49			5	D1	D	262	83	179	68.32
50			5	D2	D	182	59	123	67.58
53			6	D1	D	223	48	175	78.48
54			6	D2	D	40	20	20	50.00
57			7	D2	D	136	160	-24	-17.65
58			7	D1	D	178	124	54	30.34
61			8	D2	D	24	58	-34	-141.67

E36 =R9-E9

Precedents and dependents

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Normal																
2	Partici	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Aver	Partici	Q1	Q2	Q3	
3		1	2	0	3	4	7	7	5	4	5	4.4		5	3		
4		2	6	0	6	4	8	7	5	4	5	5.5		2	4	0	
5		3	9	7	7	7	8	8	4	4	7	7.5		3	7	2	
6		4	7	4	5	8	8	8	3	3	8	7.3		4	4	2	
7		5	3	3	4	7	8	8	3	3	8	5.5		5	5	10	1
8		6	5	6	5	8	7	7	7	6	6	6		6	5		
9		7	8	5	7	7	8	8.5	8.5	8	8.5	6		7	9	3	
10		8	8	5	6	8	10	7	10	10	7	7.2		8	8	5	
11		9	7	0	5	5	8	8	8	7	7	6.4		9	8	0	
12		10	9	2	6	7	8	8	8	9	8	7.2		10	9	2	
13		11	8	4	8	8	9	9	10	7	10	8.3		11	6	3	
14		12	9	6	10	9	10	10	9	10	10	9.2		12	7	6	1
15		13	1	0	2	1	2	1	0	1	2	1.3		13	4	0	
16		14	9	3	8	10	9	9	10	9	10	9	8.6		14	6	2
17		15	5	4	7	8	8	8	8	6	8	7	6.9		15	4	4
18		16	7	7	4	8	10	9	9	7	10	8	7.9		16	7	7
19		17	10	6	8	5	10	10	10	7	10	10	8.6		17	10	7
20		18	2	3	6	10	10	9	8	7	9	9	7.3		18	2	3
21		19	7	0	7	8	0	8	7	5	8	8	5.8		19	4	0
22		20	5	2	8	8	10	10	8	8	10	8	7.7		20	5	2
23		21	7	3	7	7	8	8	8	8	8	8	7.2		21	9	8
24		22	3	1	3	5	10	10	4	10	8	8	6.2		22	3	1
25																	
26																	
27																	
28	Difference (CV - Normal), higher is better																
29	Partici	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Aver	Question				
30		1	3	3	3	1	-2	0	0	1	3	2	1.4	1	...	if there was no one around	
31		2	-2	0	0	2	0	1	1	2	-2	1	0.3	2	...	if I had never used a packa	
32		3	-2	-5	-2	-1	-4	-2	-5	0	0	0	-2.1	3	...	if I only had the manual for	
33		4	-3	-2	1	-1	2	1	-5	0	1	0	-0.6	4	...	if I had seen someone else	
34		5	7	7	6	3	2	2	7	7	2	2	4.5	5	...	if I could call someone for	
35		6	5	-1	2	-1	0	0	1	1	0	2	0.9	6	...	if someone else had helpe	
36		7	1	-2	-2	1	1	0.5	0.5	1	0.5	1	0.25	7	...	if I had a lot of time to com	
37		8	0	0	0	-1	0	1	0	1	1	1	0.3	8	...	if I had only the built-in hel	
38		9	1	0	3	3	0	0	0	0	0	1	0.8	9	...	if someone showed me hc	
39		10	0	0	1	1	0	1	0	1	0	-1	0.3	10	...	if I had used similar packa	
40		11	-2	-1	0	1	0	0	0	0	-1	-7	-1				
41		12	-2	0	0	0	0	0	0	0	0	-1	-0.3				
42		13	3	0	1	2	0	2	2	2	3	0	1.5				
43		14	-3	-1	0	0	0	0	0	-1	0	0	-0.5				
44		15	-1	0	0	0	0	0	0	-1	0	0	-0.2				
45		16	0	0	0	0	0	0	0	0	0	0	0				

calculation-view

Sort Filter Search Refresh

Precedents (current sheet only):

Y3:Y24=AVERAGE(Table5[@[Q1]:[Q10]])

L3:L24=AVERAGE(Table57[@[Q1]:[Q10]])

Grid selection:

B30:L51=O3-B3

Dependents (current sheet only):

O44=E36

H62 -7.666666666666667

	A	B	C	D	E	F	G	H	I	J
1	Normal									Calcu
2	Participar	Mental deman	Physical deman	Temporal Deman	Performanc	Effor	Frustratio	Average		Partici
3	1	18		2						
4	2	19		10	11	13	16	16	14.17	
5	3	3		16	7	3	4	7	6.67	
6	4	15		7	16	6	16	7	12.83	
7	5	12		10	18			19	15.67	
8	6	5		2	2	11	7	14	7.00	
9	7	11		2	11	4	11	7	7.67	
10	8	11	6		6	2	11	2	6.33	
11	9	15	11		18	4	15	5	11.33	
12	10	4	3		15	4	4	3	5.50	
13	11	12	1		4	4	11	6	6.33	
14	12	15	2		1	4	10	2	5.67	
15	13	15	3		11	8	15	14	11.00	
16	14	7	1		3	3	8	2	4.00	
17	15	4	2		5	5	5	2	3.83	
18	16	14	10		3	6	11	9	8.83	
19	17	3	1		5	1	2	6	3.00	
20	18	13	4		4	13	16	12	10.33	
21	19	2	2		2	8	6	6	4.33	
22	20	17	1		11	6	16	6	9.50	
23	21	13	11		13	5	12	6	10.00	
24	22	14	1		1	17	11	11	9.17	
25										
26										

# Grid-aware search

**Difference (CV - normal), lower is better**

	Participar	Mental deman	Physical deman	Temporal Deman	Performanc	Effor	Frustratio	Average
29	1	-14	0	-8	-3	-2	-2	-4.83
30	2	-9	1	-3	-6	-7	-6	-5.00
31	3	3	-1	-2	2	4	-3	0.50
34	6	-3	0	0	-8	-5	-12	-4.67
38	10	3	0	-11	5	-1	0	-0.67
41	13	-8	-1	-2	0	-4	-6	-3.50
46	18	-4	-2	-1	-2	-6	-6	-3.50

## calculation-view

Sort Filter H15 Refresh

Search Results for: H15

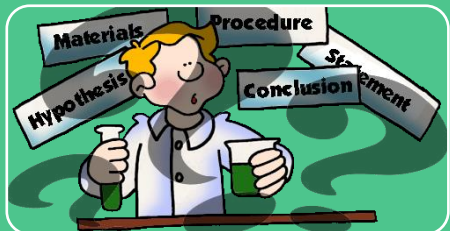
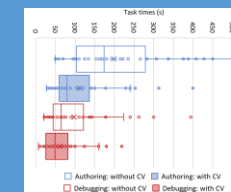
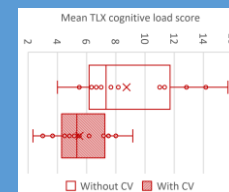
H3:H24=AVERAGE(Table4[@[Mental demand]:[Frustration]])

# Studying calculation view



## Authoring & debugging

- 20 participants, variety of backgrounds & expertise
- Improvement in task time and cognitive load



## Comprehension

- 14 participants, spreadsheet comprehension test
- Improvement in comprehension and cognitive load in half the participants



## Longitudinal deployment

- 7 MVPs, using CV for day to day work, ongoing reporting back
- Many uses, most positive feedback around auditing and comprehension

# MVP feedback

- Solves the problem that formula view is aimed at
  - P6: *"[The current show formulas feature] is useless to me. [...] One of the most particular things that accountants do is get column size exactly right. And I need to see what the numbers are. I'm going to say words I've never said before. I like the fact that [Calc View] is in a task pane. That makes me feel dirty inside. But I love that I don't have to manipulate the sheet to flip it into formula view. Don't have to flip the grid. You guys are absolutely on the right track."*
- Very helpful for auditing and debugging
  - P17: *"Calc View has already been extremely useful to me in identifying spurious formulae, no longer needed, and the situation where not all formulae in a row had been amended to the newer [...] version. Calc View is already a winner!!"*
  - P9: *"Just plain text search is really good."*
  - P6: *"Cool to have name, location and formula in one place. Formula evaluation tool is kind of weak. Calc View is a logical place to enable stepping from one thing to another. Maybe don't want to make calc view as rich as formula bar. Maybe just need a quick way to get to the formula bar"*

# Calculation View: multiple-representation editing in spreadsheets

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- Results from over a year of testing, across three studies, with ~40 total participants from a diverse range of backgrounds.
- A powerful successor to ‘show formulas’.

Calculation View helps people author, debug, and comprehend their spreadsheets.

# Elastic Sheet-Defined Functions

Generalising Spreadsheet Functions to Variable-Size Input Arrays



# Sheet defined functions

Peyton Jones, S.L., Blackwell, A.F., Burnett, M.M.:  
A user-centred approach to functions in Excel. ICFP 165–176 (2003)

1: define function

	A	B	C	D	E	F
1	<b>Average function</b>					
2						
3	<b>Input:</b>	4		<b>Count:</b>	5	=COUNT(B3:B7)
4		5		<b>Sum:</b>	42	=SUM(B3:B7)
5		23		<b>Average:</b>	8.4	=E4/E3
6		4				
7		6				

2: use like any other

8.4
-----

# Elastic SDFs

	A	B	C	D	E	F
1	<b>Average function</b>					
2						
3	<b>Input:</b>	4		<b>Count:</b>	5	=COUNT(B3:B7)
4		5		<b>Sum:</b>	42	=SUM(B3:B7)
5		23		<b>Average:</b>	8.4	=E4/E3
6		4				
7		6				

In CalcView:

**function** AVERAGE( B3:B7 ) **returns** E5 {

E3 = COUNT( B3:B7 )

E4 = SUM( B3:B7 )

E5 = E4/E3

}

# Elastic SDFs

	A	B	C	D	E	F
1	<b>Average function</b>					
2						
3	<b>Input:</b>	4		<b>Count:</b>	5	=COUNT(B3:B7)
4		5		<b>Sum:</b>	42	=SUM(B3:B7)
5		23		<b>Average:</b>	8.4	=E4/E3
6		4				
7		6				

In CalcView:

```
function AVERAGE( B3:B7 ) returns E5 {  
  E3 = COUNT( B3:B7 )  
  E4 = SUM( B3:B7 )  
  E5 = E4/E3  
}
```

## Problem:

- =AVERAGE( X5:X7) too small!
- =AVERAGE( G2:G200 ) too big!

# Elastic SDFs

## Solution:

- Somehow generalize what the user wrote

	A	B	C	D	E	F
1	<b>Average function</b>					
2						
3	<b>Input:</b>	4		<b>Count:</b>	5	=COUNT(B3:B7)
4		5		<b>Sum:</b>	42	=SUM(B3:B7)
5		23		<b>Average:</b>	8.4	=E4/E3
6		4				
7		6				

**function** AVERAGE( B3:B7 ) **returns**

```
E5 {  
  E3 = COUNT( B3:B7 )  
  E4 = SUM( B3:B7 )  
  E5 = E4/E3  
}
```

**function** AVERAGE < $\alpha$ >( B3:B{3+ $\alpha$ } ) **returns**

```
E5 {  
  E3 = COUNT( B3:B{3+ $\alpha$ } )  
  E4 = SUM( B3:B{3+ $\alpha$ } )  
  E5 = E4/E3  
}
```

# Elastic SDFs

	A	B	C	D	E	F
1	<b>Average function</b>					
2						
3	<b>Input:</b>	4		<b>Count:</b>	5	=COUNT(B3:B7)
4		5		<b>Sum:</b>	42	=SUM(B3:B7)
5		23		<b>Average:</b>	8.4	=E4/E3
6		4				
7		6				

```
function AVERAGE< $\alpha$ >( B3:B{3+ $\alpha$ } ) returns  
E5 {  
    E3 = COUNT( B3:B{3+ $\alpha$ } )  
    E4 = SUM( B3:B{3+ $\alpha$ } )  
    E5 = E4/E3  
}
```

Elastic SDF can be called with any  $\alpha \geq 0$   
=AVERAGE(G2:G200 )

- Figure out  $\alpha = 198$  from the arguments
- Instantiate the SDF sheet with  $\alpha = 198$
- Calc it
- Return the result
- Discard the instantiated sheet

**TIMESHEET**

First na	Last na	Catego	Rate	Date	01/04/2017	02/04/2017	03/04/2017	04/04/2017	05/04/2017	*****	*****	Total hours	Payment
John	Wire	Full-Time	20		0	0	4	8	0	4	0	16	320
Sophie	Gallaghe	Contract	25		0	0	0	0	8	8	4	20	500
												<b>Total to be pai</b>	820

First na	Last na	Catego	Rate	Date	01/08/2017	02/08/2017	03/08/2017	04/08/2017	05/08/2017	*****	*****	08/08/2017	*****	*****	11/08/2017	*****	*****	14/08/2017	Total hours	Payment
David	Green	Full-Time	20		0	0	3	0	0	5	0	9	4	0	0	5	0	0	0	0
Sarah	Jones	Full-Time	20		5	7	8	9	0	5	5	10	0	0	4	4	4	4	4	4
Edward	Muller	Contract	25		0	0	0	0	0	8	10	0	5	0	0	8	0	0	0	0
Hannah	Kirk	Part-Tim	15		8	0	0	4	0	8	4	0	3	5	3	0	8	8	8	8
Jo	Carter	Contract	25		8	8	8	8	8	0	0	8	8	8	9	0	8	8	0	0
Max	Wells	Full-Time	20		8	0	0	0	8	8	8	8	0	0	0	8	8	8	8	8
																			<b>Total to be p</b>	3:518)

=E(PAYMENT(D13:D18,F13:S18))

# User's eye view

- Write a function with fixed-size inputs, using familiar copy/paste
- Magic happens
- The function works on input of arbitrary size

**Main point:** we think that automatically inferred elasticity will dramatically broaden the audience that can use SDFs effectively.

# The magic

- It really is quite amazing to
  - Take a single, concrete function working on fixed size inputs
  - And generalise it to arbitrary size inputs
  - In a predictable way
- But we can do it.
- We can even prove that the generalisation we find is the “**best generalisation**” in a very precise sense. Not just a set of heuristics.



# Findings from user study (N=20, 7 female)

People perceived **significantly lower cognitive workload** for elastic SDFs than with SDFs based on map/reduce.

*I think elastic functions are easier to work with, also with the "mental model" that you have of Excel, because you can more just follow your normal Excel **workflow**. – P9*

*It'd be nice to have this kind of **middle ground**, of not having to write the same things over and over again, but not having to persuade someone to make a macro either. – P7*

# Elastic Sheet-Defined Functions

Automatic generalization of map/reduce programs from example

Theorem: Elasticization yields most general generalization

User study: Easier for end-users than map/reduce programs

## Elastic Sheet-Defined Functions: Generalising Spreadsheet Functions to Variable-Size Input Arrays\*

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# Aim

Remove the “glass ceiling” that limits the scope and reach of what a domain expert can do with Excel:

- **Make Excel functions reflect the abstractions of our end users**, by allowing end-users to define new functions using an ordinary worksheet.
- **Make Excel’s data values reflect the datatypes of our end users’ domains**, by adding arrays, vectors, records, and even domain-specific data types implemented by third parties.

# Yellow Related Links

[aka.ms/CalcIntel](https://aka.ms/CalcIntel)

[Dynamic Arrays and New Functions in Excel! - Office Insider Blog](#)

[Video tour of Microsoft Research Cambridge](#)

( [gif2xlsx: Convert GIFs to XLSX format](#) )

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