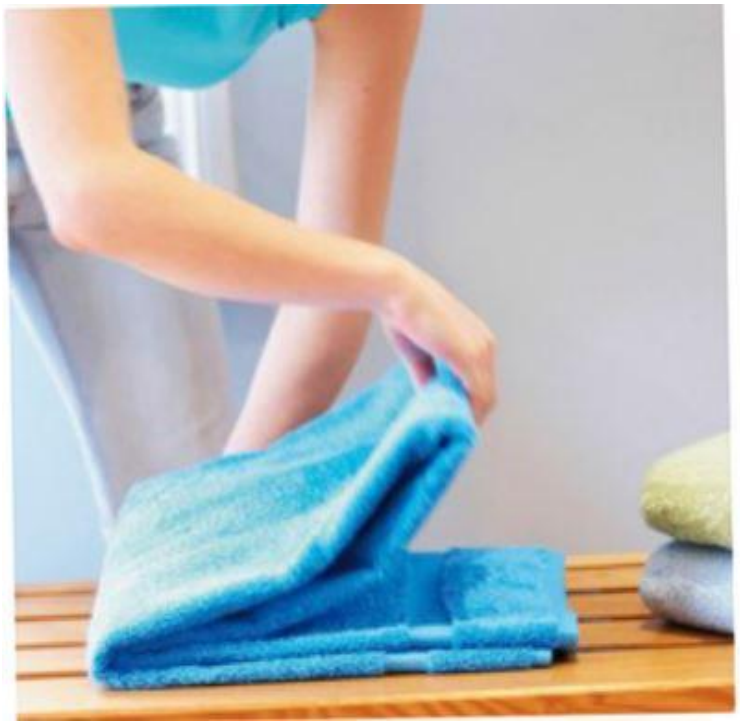
Spreadsheet Programming using Examples



Sumit Gulwani

Microsoft

Keynote at SEMS

July 2016

Motivation

99% of computer users cannot program!

They struggle with simple repetitive tasks.

Programming by examples (PBE) can revolutionize this landscape!

Spreadsheet help forums

Excel Forum
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Your One Stop for Excel Tips & Solutions
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Typical help-forum interaction

300_w30_aniSh_c1_b → w30

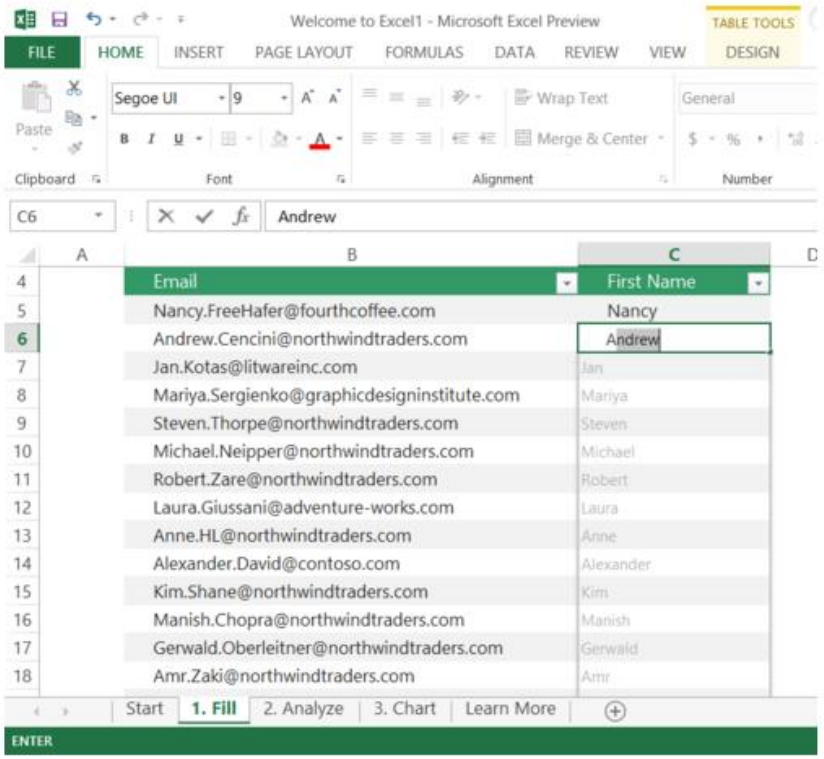
300_w5_aniSh_c1_b → w5

=MID(B1,FIND(“_”,$B:$B)+1,
FIND(“_”,REPLACE($B:$B,1,FIND(“_”,$B:$B), “”))-1)

Flash Fill (Excel 2013 feature) demo

CNN Money

Excel 2013's coolest new feature that should have been available years ago



"Automating string processing in spreadsheets using input-output examples"; POPL 2011; Sumit Gulwani

Number Transformations

Input	Output (Round to 2 decimal places)
123.4567	123.46
123.4	123.40
78.234	78.23

Excel/C#: #.00

Python/C: .2f

Java: #.##

Input	Output (Nearest lower half hour)
0d 5h 26m	5:00
0d 4h 57m	4:30
0d 4h 27m	4:00
0d 3h 57m	3:30

Synthesizing Number Transformations from Input-Output Examples; CAV 2012; Singh, Gulwani

Semantic String Transformations

MarkupRec Table

Id	Name	Markup
S33	Stroller	30%
B56	Bib	45%
D32	Diapers	35%
W98	Wipes	40%
A46	Aspirator	30%

CostRec Table

Id	Date	Price
S33	12/2010	$145.67
S33	11/2010	$142.38
B56	12/2010	$3.56
D32	1/2011	$21.45
W98	4/2009	$5.12

Input v_1	Input v_2	Output (Price + Markup*Price)
Stroller	10/12/2010	$145.67 + 0.30*145.67
Bib	23/12/2010	$3.56 + 0.45*3.56
Diapers	21/1/2011	
Wipes	2/4/2009	
Aspirator	23/2/2010	

Learning Semantic String Transformations from Examples;
VLDB 2012; Singh, Gulwani

Data Science Class Assignment


```
| style="text-align: center;"| {{Sort|01|[[Super Bowl I|I]]}}
|{{Dts|1967|January|15}}
| style="background:#d0e7ff;"|{{Sort|Green Bay Packers 01|[[1966 Green Bay Packers season|Green Bay Packers]]<sup>‡</sup>}}
| style="text-align: center;"| {{Sort|3510|35–10}}
| style="background:#fcc;"|{{Sort|Kansas City Chiefs 01|[[1966 Kansas City Chiefs season|Kansas City Chiefs]]<sup>^</sup>}}
|{{Sort|Los Angeles Memorial Coliseum 01|[[Los Angeles Memorial Coliseum]]}}
|{{Sort|Pasadena, California 01|[[Los Angeles]], [[California]]{{#tag:ref|Both [[Los Angeles, California|Los An
| style="text-align: center;"| {{Sort|061946|61,946}}
| style="text-align: center;"|<ref>{{Cite journal |last=Maule |first=Tex |url=http://sportsillustrated.cnn.com/vau
|-
| style="text-align: center;"| {{Sort|02|[[Super Bowl II|II]]}}
|{{Dts|1968|January|14}}
| style="background:#d0e7ff;"|{{Sort|Green Bay Packers 02|[[1967 Green Bay Packers season|Green Bay P
| style="text-align: center;"| {{Sort|3314|33–14}}
| style="background:#fcc;"|{{Sort|Oakland Raiders 01|[[1967 Oakland Raiders season|Oakland Raiders]]<su
|{{Sort|Orange Bowl 01|[[Miami Orange Bowl|Orange Bowl]]}}
|{{Sort|Miami, Florida 01|[[Miami]], [[Florida]]{{#tag:ref|[[Miami Gardens, Florida|Miami Gardens]] was incor
| style="text-align: center;"| {{Sort|075546|75,546}}
| style="text-align: center;"|<ref>{{Cite journal |url=http://aol.sportingnews.com/nfl/story/2008-01-15/super-b
|-
| style="text-align: center;"| {{Sort|03|[[Super Bowl III|III]]}}<!---During the AFL-NFL merger, As the Colts mo
|{{Dts|1969|January|12}}
| style="bac                                                    Jets season|New York Jets]]<sup>^</s
| style="text
| style="bac                                                    imore Colts season|Baltimore Colts]]<
|{{Sort|Ora
|{{Sort|Mia
| style="tex
| style="tex
<includeon
|-
| style="tex
|{{Dts|1970|January|11}}
| style="background:#fcc;"|{{Sort|Kansas City Chiefs 02|[[1969 Kansas City Chiefs season|Kansas City Chiefs]]<sup>^</sup> (2)}}
| style="text-align: center;"| {{Sort|2307|23–7&amp;nbsp;}}
| style="background:#d0e7ff;"|{{Sort|Minnesota Vikings 01|[[1969 Minnesota Vikings season|Minnesota Vikings]]<sup>‡</sup>}}
|{{Sort|Tulane Stadium 01|[[Tulane Stadium]]}}
|{{Sort|New Orleans, Louisiana|[[New Orleans]], [[Louisiana]]}}
| style="text-align: center;"| {{Sort|080562|80,562}}
| style="text-align: center;"|<ref>{{Cite web |url=http://www.cbsnews.com/htdocs/sports/football/history/superbowl_04.html |title=Super Bowl History: Super E
```

```
I,1967,Green Bay Packers 01,35-10,Kansas City Chiefs 01,Los Angeles Memorial Coliseum
III,1969,New York Jets 01,16-7,Indianapolis Colts 01,Orange Bowl 02 IV,1970,Kansas Ci
V,1971,Indianapolis Colts 02,16-13,Dallas Cowboys 01,Orange Bowl 03 VI,1972,Dallas Co
VII,1973,Miami Dolphins 02,14-7,Washington Redskins 01,Los Angeles Memorial Coliseum 0
IX,1975,Pittsburgh Steelers 01,16-6,Minnesota Vikings 03,Tulane Stadium 03 X,1976,Pit
XI,1977,Oakland Raiders 02,32-14,Minnesota Vikings 04,Rose Bowl 01 XII,1978,Dallas Co
XIII,1979,Pittsburgh Steelers 03,35-31,Dallas Cowboys 05,Orange Bowl 05 XIV,1980,Pitt
981,Oakland Raiders 03,27-10,Philadelphia Eagles 01,Louisiana Superdome 02 XVI,19
VII,1983,Washington Redskins 02,27-17,Miami Dolphins 04,Rose Bowl 03 XVIII,1984,Oakl
XIX,1985,San Francisco 49ers 02,38-16,Miami Dolphins 05,Stanford Stadium 01 XX,1986,C
XXI,1987,New York Giants 01,39-20,Denver Broncos 02,Rose Bowl 04 XXII,1988,Washington
XXIII,1989,San Francisco 49ers 03,20-16,Cincinnati Bengals 02,Joe Robbie Stadium 01 X
```

To get Started!

```
cat superbowl.txt | awk '$1=$1' ORS=' ' | sed 's/|- |/\n|/g' | grep "^| style=\"t
ext-align: center;\"" | grep -v "Championship"
```

FlashExtract Demo

Ships inside two Microsoft products:

Powershell 

ConvertFrom-String cmdlet

Custom Log,
Custom Field

"*FlashExtract: A Framework for data extraction by examples*";
PLDI 2014; Vu Le, Sumit Gulwani

Layout Transformations

Input Table

Bureau of I.A.	
Regional Director	Numbers
Niles C.	Tel: (800)645-8397
	Fax: (907)586-7252
Jean H.	Tel: (918)781-4600
	Fax: (918)781-4604
Frank K.	Tel: (615)564-6500
	Fax: (615)564-6701

Output Table

	Tel	Fax
Niles C.	(800)645-8397	(907)586-7252
Jean H.	(918)781-4600	(918)781-4604
Frank K.	(615)564-6500	(615)564-6701

	A	B	C	D	E
1		value	year	value	year
2	Albania	1000	1950	930	1981
3	Austria	3139	1951	3177	1955
4	Belgium	541	1947	601	1950
5	Bulgaria	2964	1947	1959	1958
6	Czech . . .	2416	1950	2503	1960

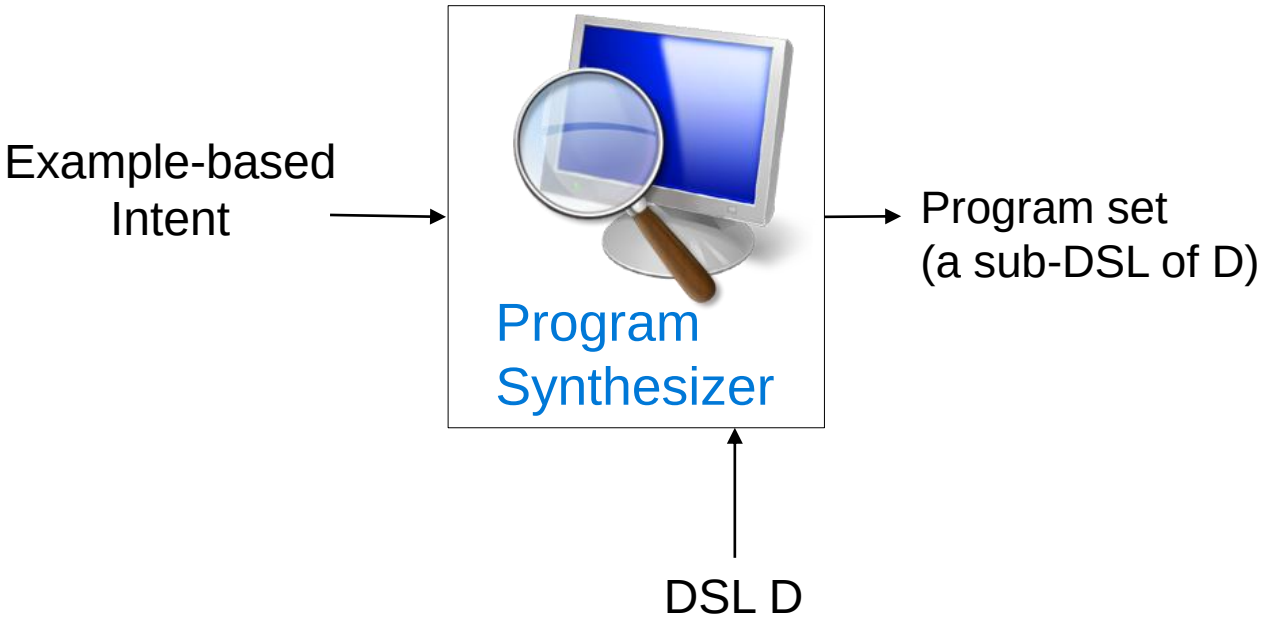
. . .

Country	Harvest	Date
Albania	1000	1950
Albania	930	1981
. . .		
Austria	3139	1951
Austria	3177	1955
. . .		
Belgium	541	1947
Belgium	601	1950
. . .		

PBE allows creation of output table from couple of example tuples.

Flashrelate: extracting relational data from semi-structured spreadsheets using examples; PLDI 2014; Barowy, Gulwani, Hart, Zorn

Programming-by-Examples Architecture



Domain-specific Language (DSL)

- Balanced Expressiveness
  - Expressive enough to cover wide range of tasks
  - Restricted enough to enable efficient search
    - Restricted set of operators
      - those with small inverse sets
    - Restricted syntactic composition of those operators

- Natural computation patterns
  - Increased user understanding/confidence
  - Enables selection between programs, editing

Flash Fill DSL (String Transformations)

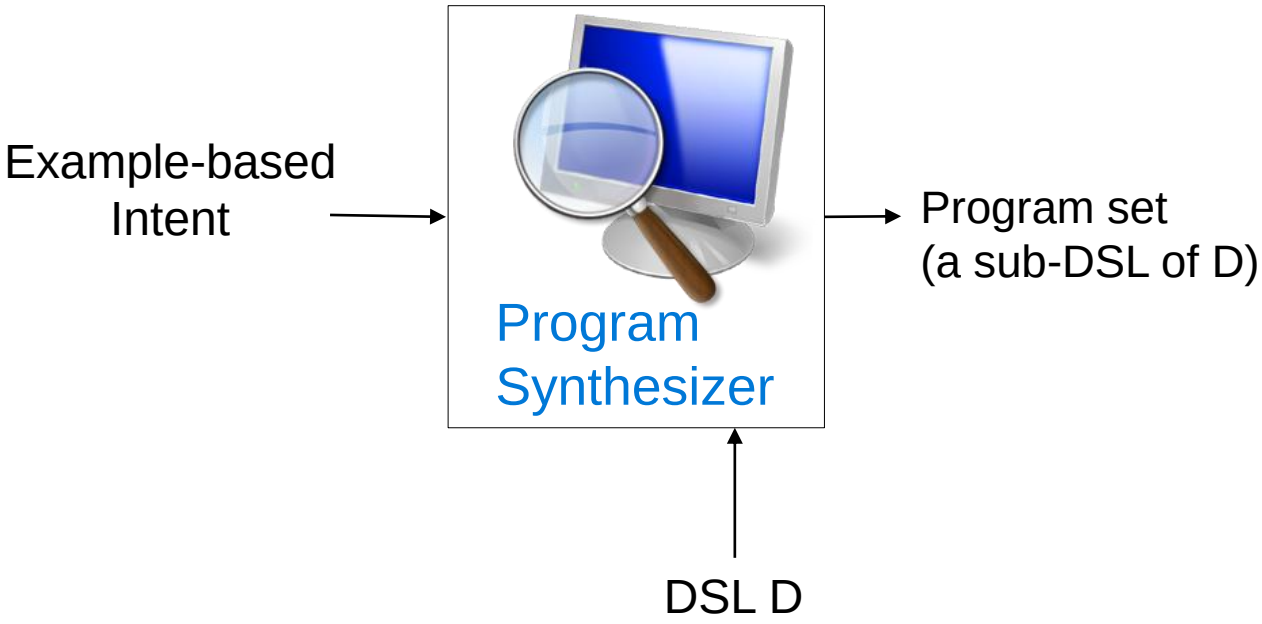
$$Tuple(String\ x_1, \ldots, String\ x_n) \rightarrow String$$

```
top-level expr T := if-then-else(B,C,T)
                  |  C

condition-free expr C := Concatenate(A,C)
                       |  A

atomic expression A := SubStr(X,P,P)
                     | ConstantString

input string X := x1 | x2 | …

position expression P := K
                       | Pos(X, R1, R2, K)
```

K^{th} position in X whose left/right side matches with R_1/R_2.

```
Boolean expression B := …
```

Programming-by-Examples Architecture



Search Methodology

Goal: Set of program expr of kind e that satisfies spec ϕ

[denoted $[e \vDash \phi]$]

e: DSL (top-level) expression

ϕ: Conjunction of (input state σ ⇝ output value v)

Methodology: Based on divide-and-conquer style problem decomposition.

- $[e \vDash \phi]$ is reduced to simpler problems (over sub-expressions of e or sub-constraints of ϕ).
- Top-down (as opposed to bottom-up enumerative search).

"FlashMeta: A Framework for Inductive Program Synthesis";
OOPSLA 2015; Alex Polozov, Sumit Gulwani

Problem Reduction Rules

$$[e \vDash \phi_1 \wedge \phi_2] = Intersect([e \vDash \phi_1], [e \vDash \phi_2])$$

An alternative strategy:

$$[e \vDash \phi_1 \wedge \phi_2] = Filter([e \vDash \phi_1], \phi_2)$$

Let e be a non-terminal defined as $e ::= e_1 \mid e_2$

$$[e \vDash \phi] = Union([e_1 \vDash \phi], [e_2 \vDash \phi])$$

Problem Reduction Rules

$$[F(e_1, \ldots, e_n) \vDash \sigma \rightsquigarrow v] =$$
$$Union(\{\mathrm{F}([e_1 \vDash \sigma \rightsquigarrow u_1], \ldots, [e_n \vDash \sigma \rightsquigarrow u_n]) \mid (u_1, \ldots, u_n) \in F^{-1}(v)\})$$

$F(S_1, \ldots, S_n)$ denotes $\{F(e_1, \ldots, e_n) \mid e_1 \in S_1, \ldots, e_n \in S_n\}$

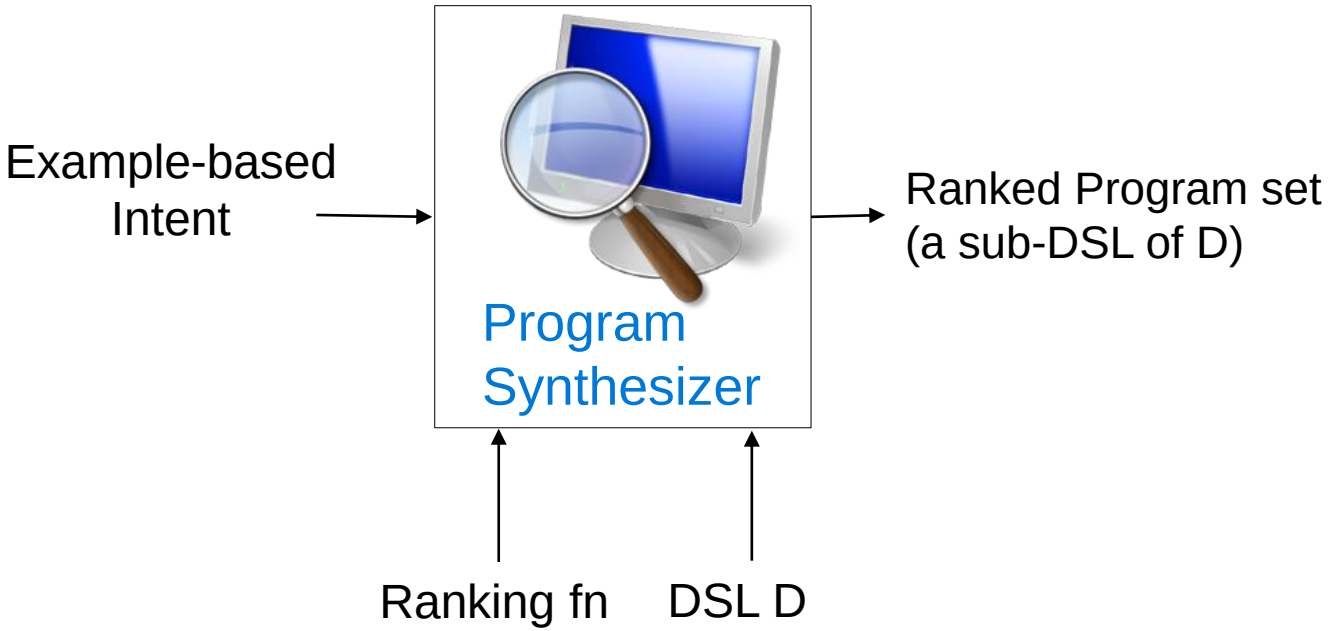
Inverse Set: Let F be an n-ary operator.

$$F^{-1}(v) = \{(u_1, \ldots, u_n) \mid F(u_1, \ldots, u_n) = v\}$$

$$Concat^{-1}(\text{"Abc"}) = \{(\text{"Abc"}, \epsilon), (\text{"}Ab\text{"}, \text{"c"}), (\text{"A"}, \text{"bc"}), (\epsilon, \text{"Abc"})\}$$

$$[Concat(X, Y) \vDash (\sigma \rightsquigarrow \text{"Abc"})] = \mathrm{Union}(\{$$
$$Concat([X \vDash (\sigma \rightsquigarrow \text{"Abc"})], [Y \vDash (\sigma \rightsquigarrow \epsilon)]),$$
$$Concat([X \vDash (\sigma \rightsquigarrow \text{"Ab"})], [Y \vDash (\sigma \rightsquigarrow \text{"}c\text{"})]),$$
$$Concat([X \vDash (\sigma \rightsquigarrow \text{"A"})], [Y \vDash (\sigma \rightsquigarrow \text{"}bc\text{"})]),$$
$$Concat([X \vDash (\sigma \rightsquigarrow \epsilon)], [Y \vDash (\sigma \rightsquigarrow \text{"}Abc\text{"})])\})$$

Programming-by-Examples Architecture



Ranking scheme: Program features

Prefer simpler programs

- Fewer constants.
- Smaller constants.

Input	Output
Rishabh Singh	Rishabh
Ben Zorn	Ben

- 1st Word
- If (input = “Rishabh Singh”) then “Rishabh” else “Ben”
- “Rishabh”

“*Predicting a correct program in Programming by Example*”;
[CAV 2015] Rishabh Singh, Sumit Gulwani

Ranking scheme: Data features

Prefer simpler programs

- Fewer constants.
- Smaller constants.

Input	Output
Missing page numbers, 1993	1993
64-67, 1995	1995

- 1st Number from the beginning
- 1st Number from the end

How to select between programs with same number of same-sized constants?

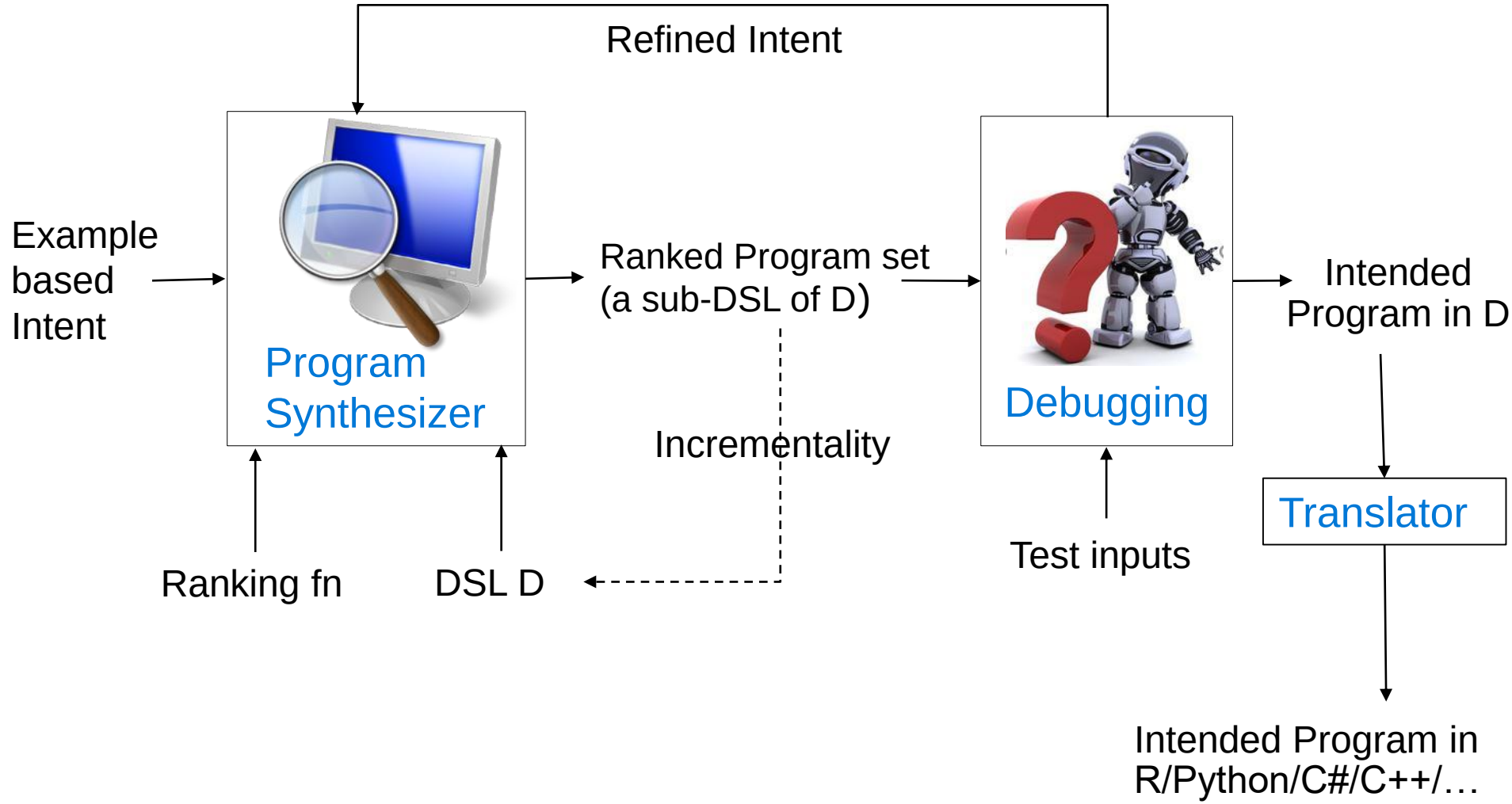
Prefer programs that generate more uniform output.

Outline

- Core Synthesis Architecture
  - Domain-specific Language
  - Search methodology
  - Ranking function

➢ Next generation Synthesis
  - Interactive
  - Predictive
  - Adaptive

Programming-by-Examples Architecture



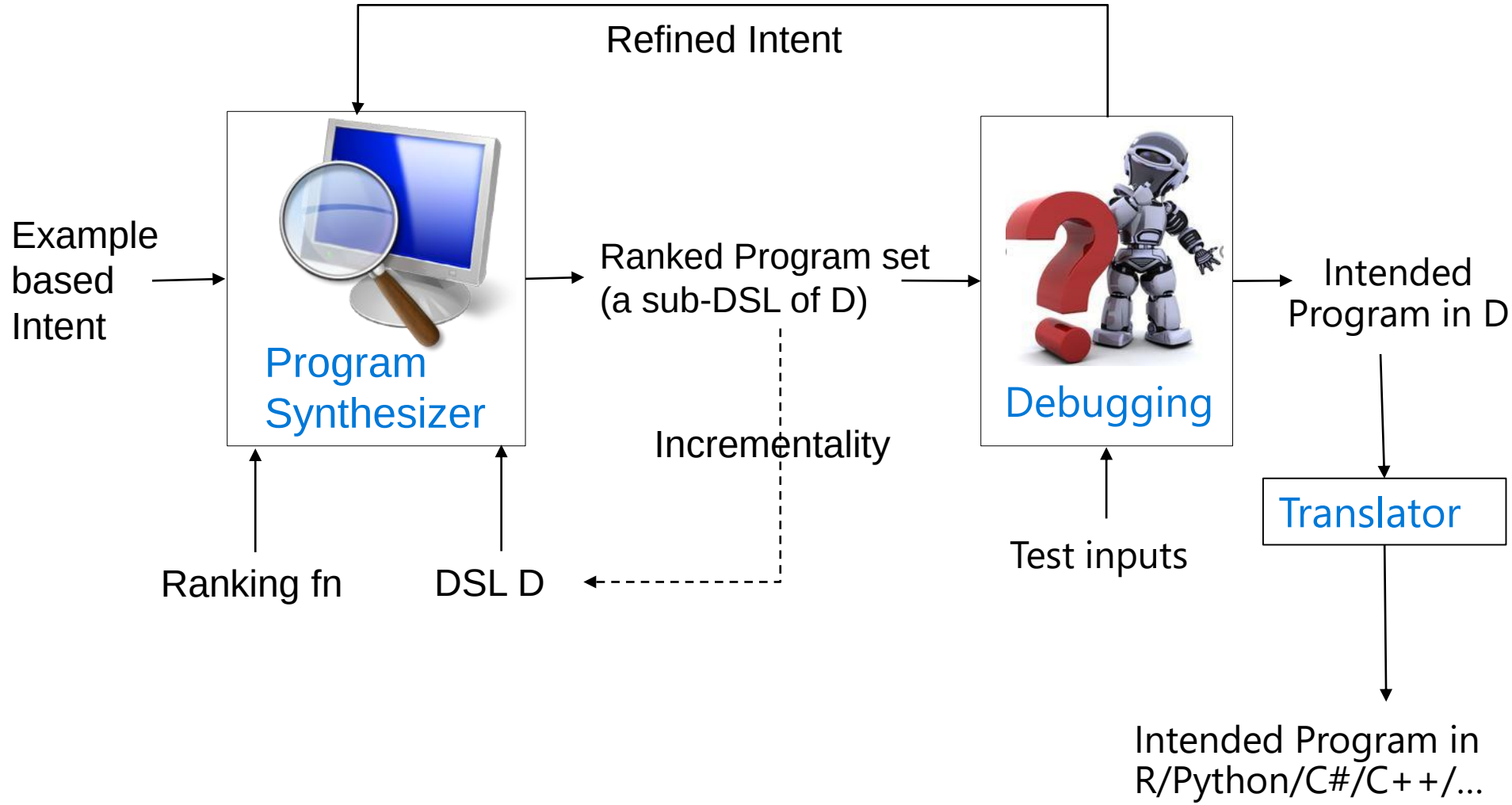
Interactive Debugging

- Sampling inputs
- Asking questions
- Visual explanations of the synthesized program

Predictive

- Intended programs can sometimes be synthesized from just the input.
  - Tabular data extraction, Sort, Join
- Can save large amount of user effort.
  - User need not provide examples for each of tens of columns.

Programming-by-Examples Architecture

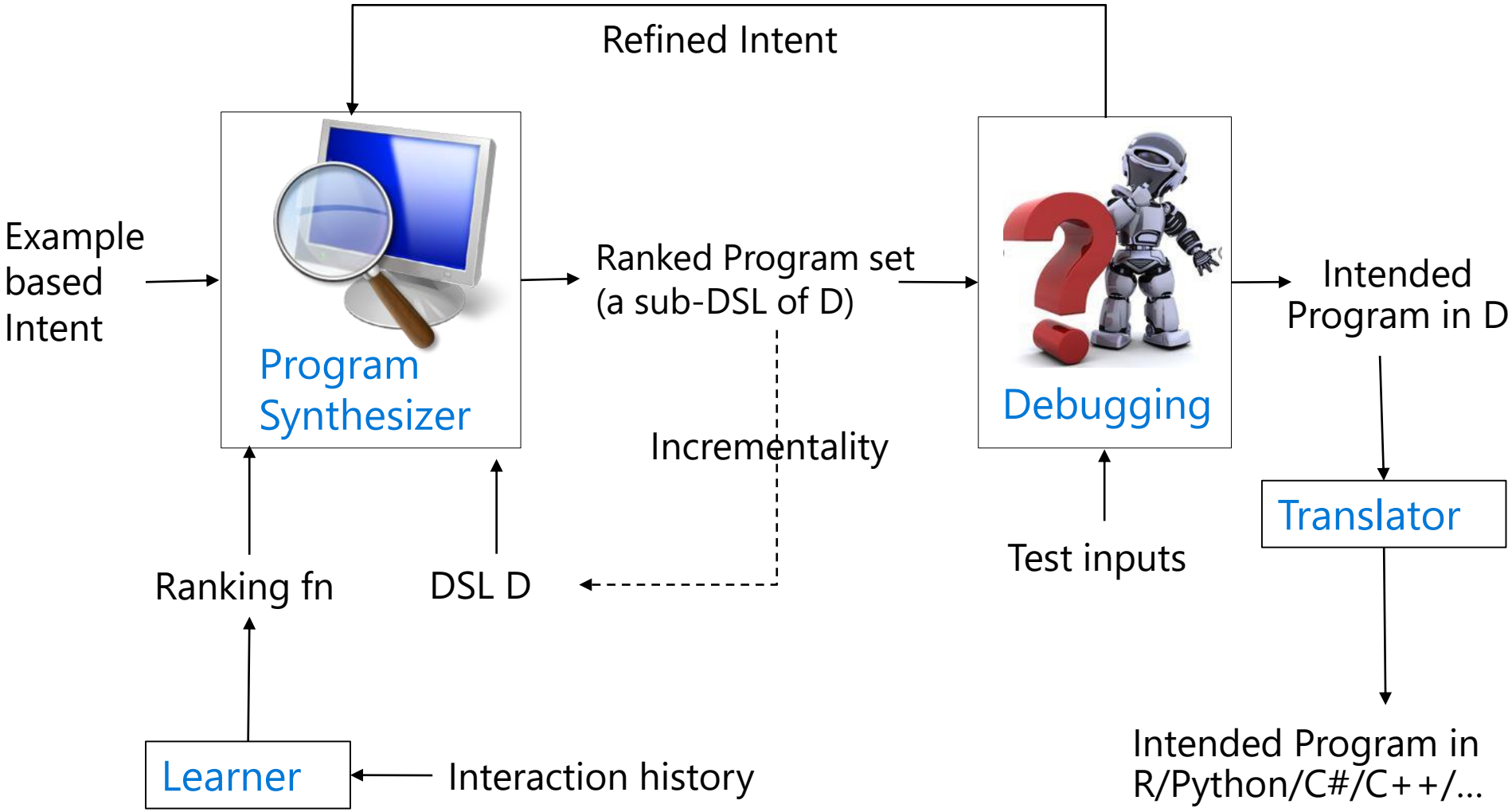


Adaptive

- Learn from past interactions
  - of the same user (personalized experience).
  - of other users in the enterprise/cloud.

- The synthesis sessions now require less interaction.

Programming-by-Examples Architecture



PROSE Framework

https://microsoft.github.io/prose

- Efficient implementation of the generic search methodology.
- Provides a library of reduction rules.

Role of synthesis designer

- Implement a DSL and provide reduction rules for new operators.
- Provide ranking strategy.
- Can specify tactics to resolve non-determinism in search.

The PROSE Team

Allen Cypher

Sumit Gulwani

Ranvijay Kumar

Vu Le

Daniel Perelman

We are hiring interns/full-time!

Alex Polozov

Mohammad Raza

Danny Simmons

Adam Smith

Abhishek Udupa

Future Directions

- Learn from usage data
- Probabilistic noise handling
- Programming using natural language
- Application to robotics

Conclusion

- PBE can enable easier & faster data wrangling.
  - 99% of computer users are non-programmers.
  - Data scientists spend 80% time cleaning data.

- Algorithmic search
  - Domain-specific language
  - Deductive methodology based on back-propagation
- Ambiguity resolution
  - Ranking
  - Interactivity

Reference: "*Programming by Examples (and its applications in Data Wrangling)*", In *Verification and Synthesis of Correct and Secure Systems*; IOS Press; 2016
[based on Marktoberdorf Summer School 2015 Lecture Notes]