Teaching old type systems new tricks with type providers

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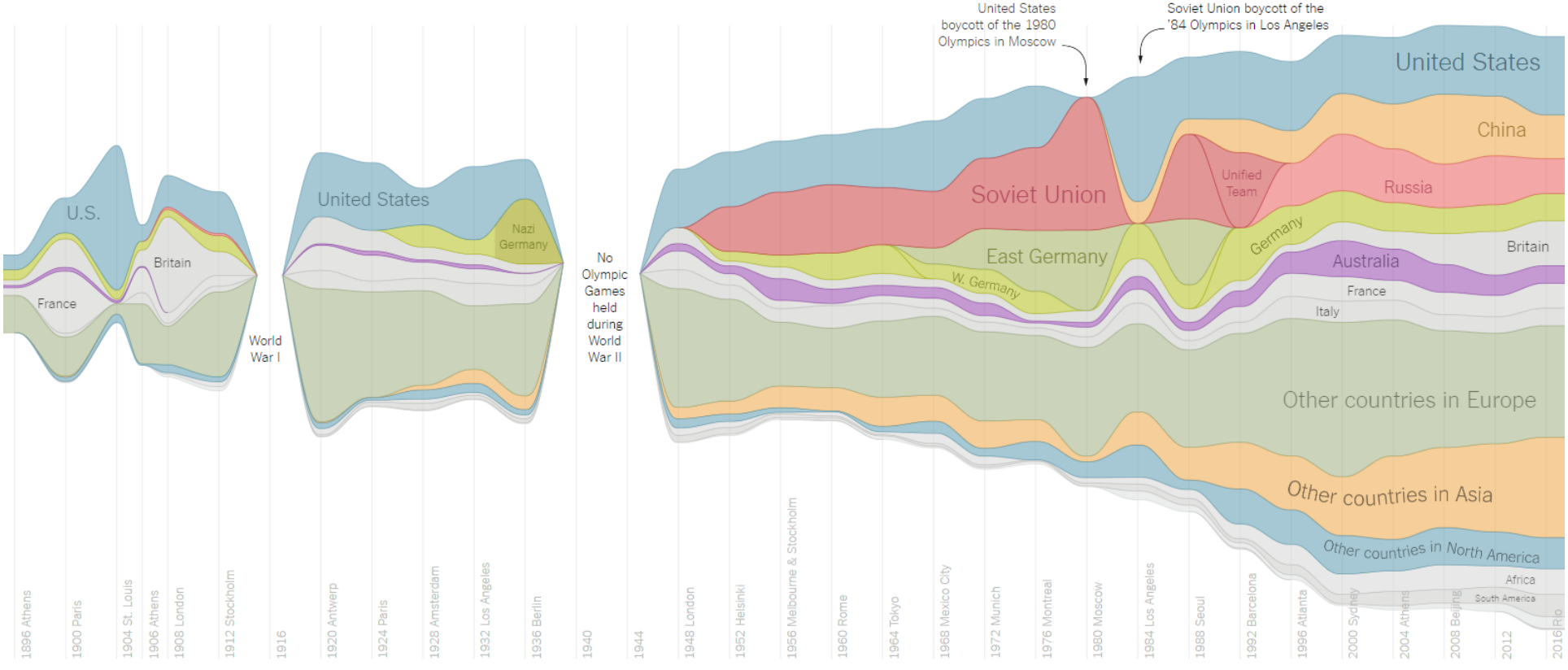
DATA SCIENCE

A Visual History of Which Countries Have Dominated the Summer Olympics

By **GREGOR AISCH** and **LARRY BUCHANAN** UPDATED August 22, 2016

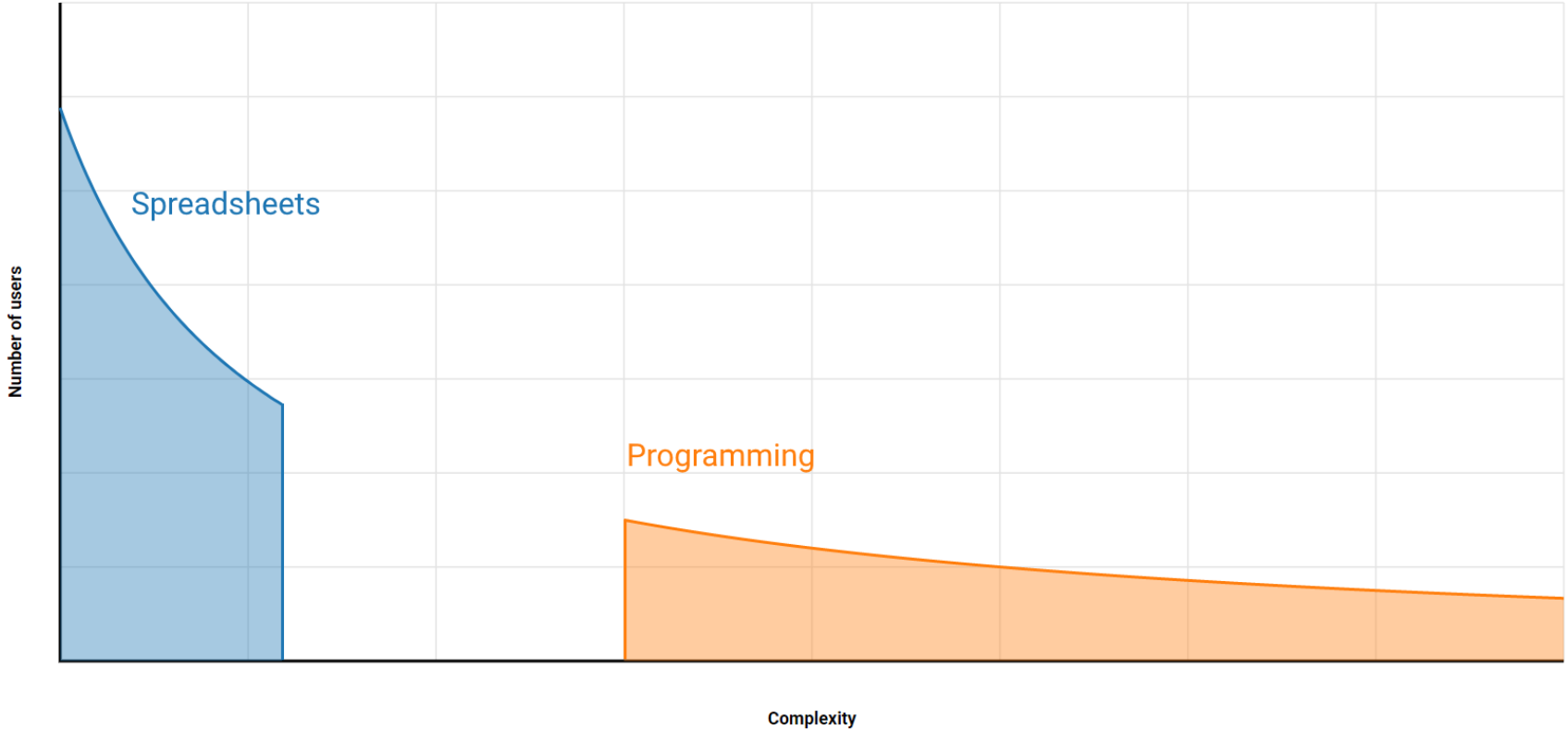


DEMO

Open, reproducible data visualizations

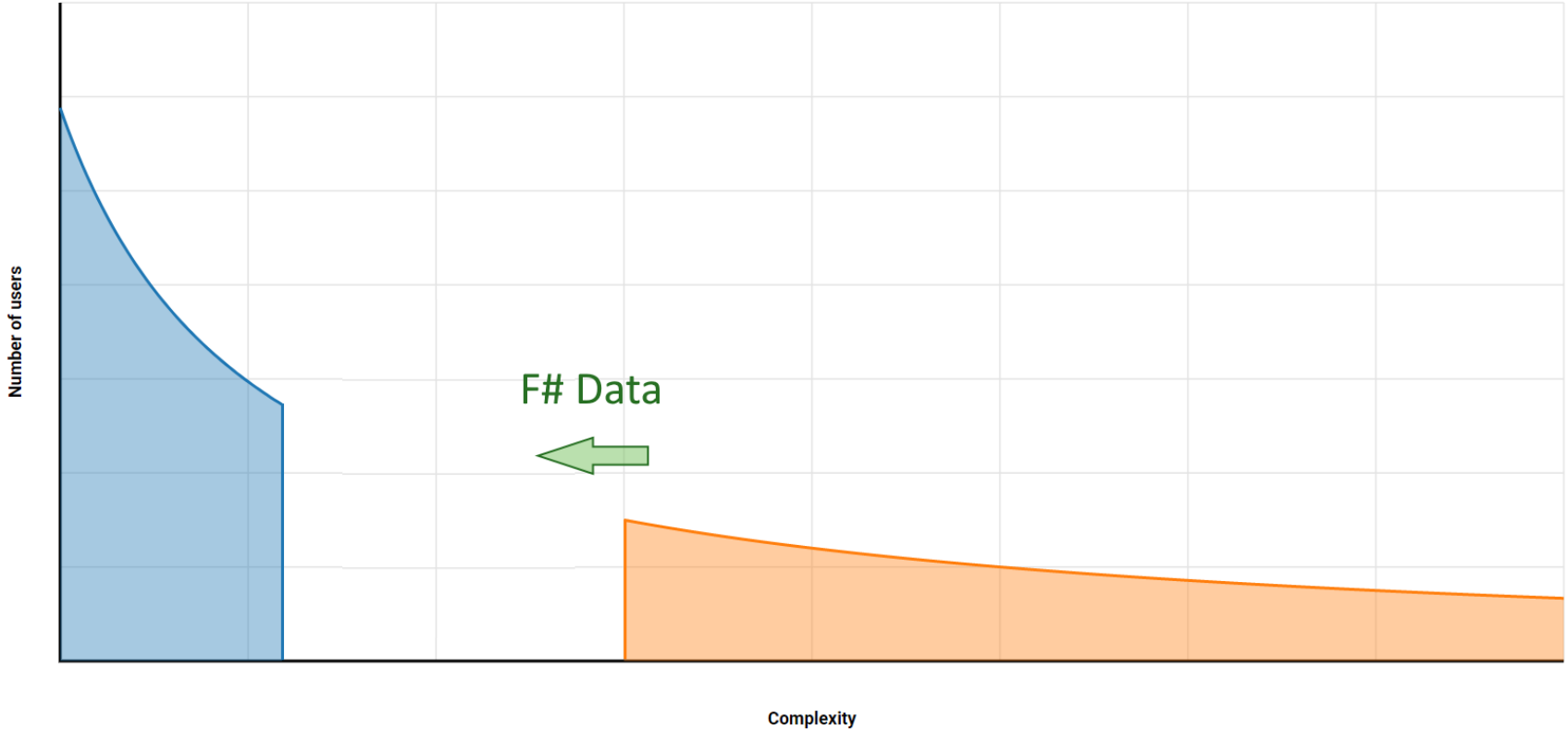
Tooling for data science

The gap between spreadsheets and programming



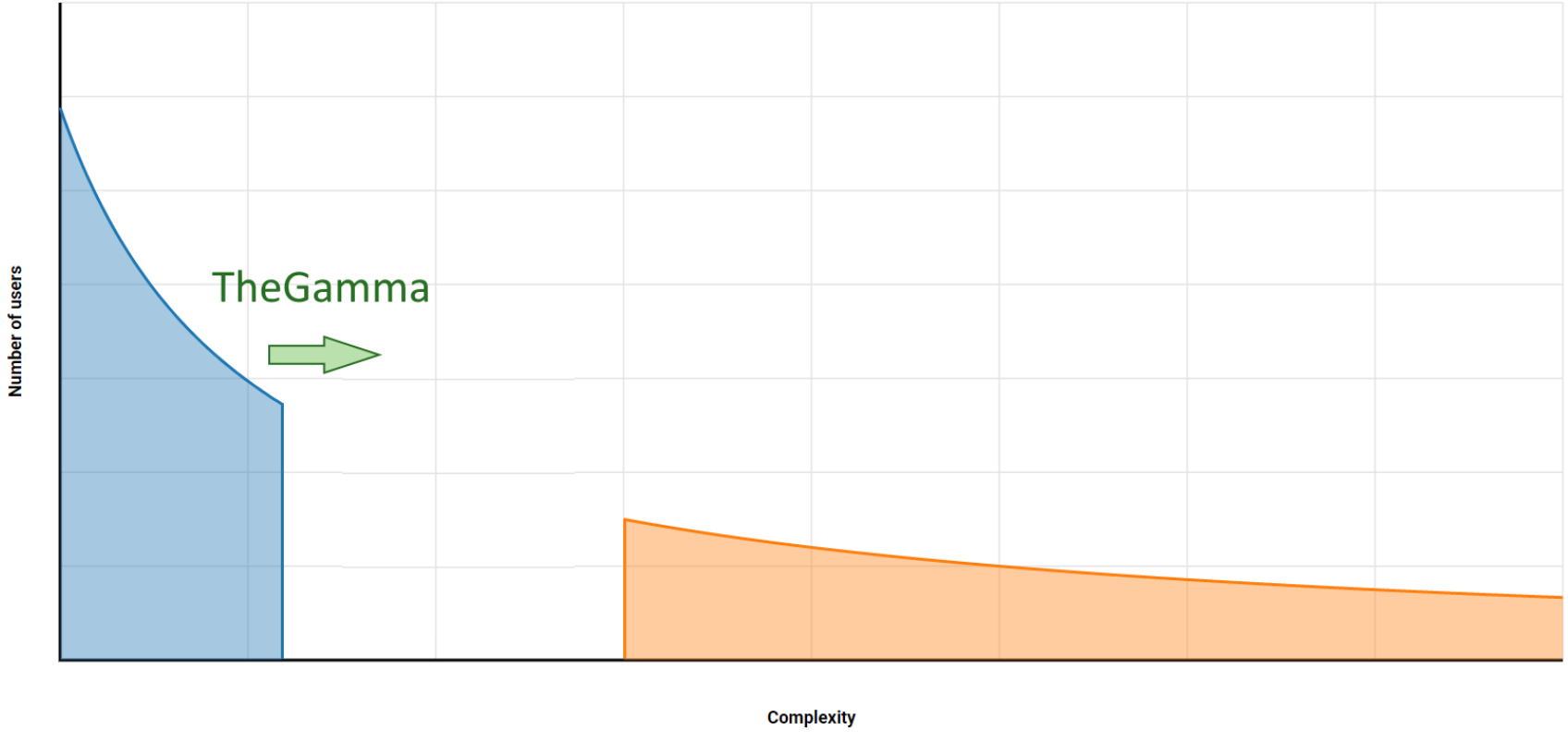
Tooling for data science

Making programming languages a bit easier



Tooling for data science

Learning from spreadsheet interaction model



Reading data

Unsafe dynamic access in a typed language

```
var url = "http://dvd.netflix.com/Top100RSS";
var rss = XDocument.Load(topRssFeed);
var channel = rss.Element("rss").Element("channel");

foreach(var item in channel.Elements("item")) {
  Console.WriteLine(item.Element("text").Value);
}
```

Not found!

Reading data

Unsafe dynamic access in a typed language

```
var url = "http://dvd.netflix.com/Top100RSS";
var rss = XDocument.Load(topRssFeed);
var channel = rss.Element("rss").Element("channel");

foreach(var item in channel.Elements("item")) {
  Console.WriteLine(item.Element("title").Value);
}
```

Reading data

Accessing data from external data sources

- Languages do not understand data
- There is rarely explicit schema
- Manually define types to caputre it
- Easier in dynamic languages

Aggregating data

Athletes by number of gold medals from Rio 2016

Unknown file

```
olympics = pd.read_csv("olympics.csv")
olympics[olympics["Games"] == "Rio (2016)"]
  .groupby("Athlete")
  .agg({"Gold": sum})
  .sort_values(by="Gold", ascending=False)
  .head(8)
```

Column name

Aggregating data

Language and data source features you need to know

- Python dictionaries `{"key": value}`
- Generalised indexers `.[ condition ]`
- Operation names `sort_values`
- Data column names `"Athlete"`

TYPE PROVIDERS

$$\emptyset \vdash e : \tau$$


π( ) ⊢ e : τ

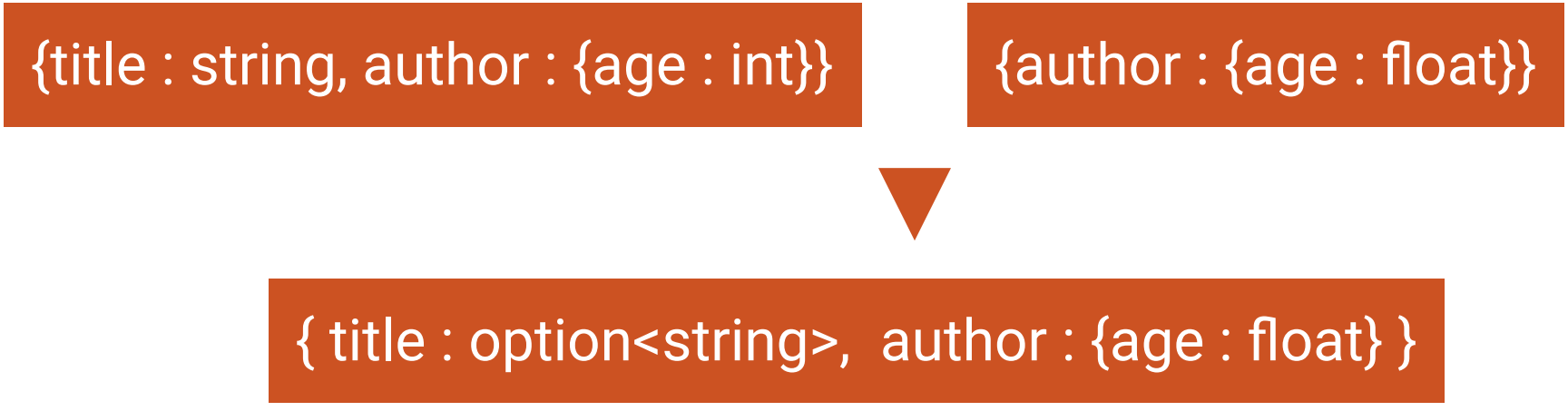
DEMO

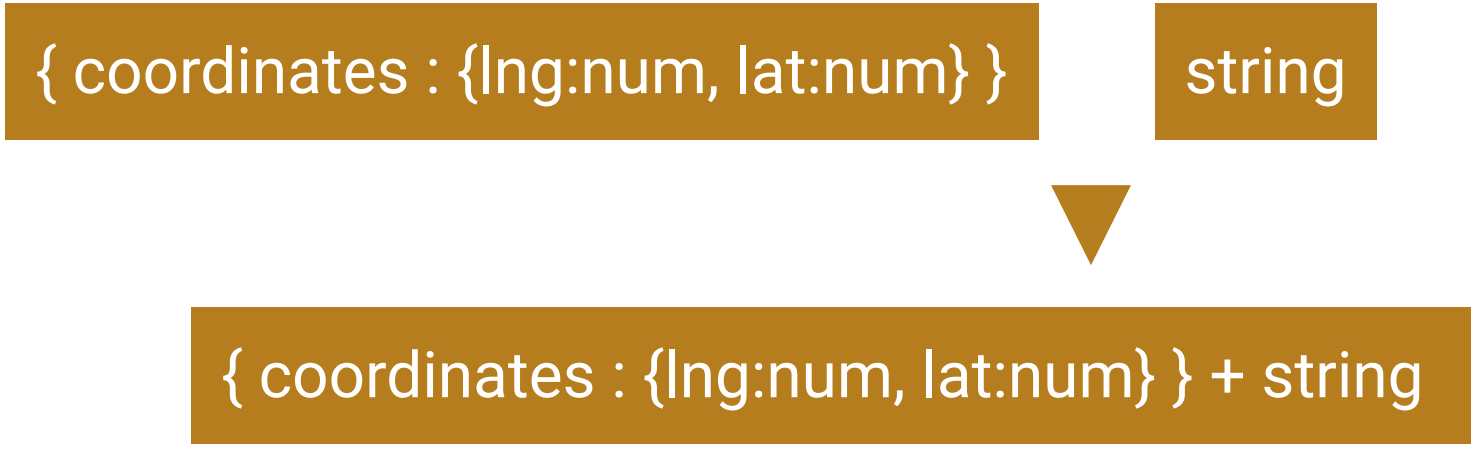
Reading data from an RSS feed

F# Data library

Type providers for structured data

- Structural shape inference
- Language integration via type providers
- Relative type safety


{title : string, author : {age : int}}
{author : {age : float}}
{ title : option<string>, author : {age : float} }


{ coordinates : {lng:num, lat:num} }
string
{ coordinates : {lng:num, lat:num} } + string

Shape inference

Pragmatic design choices for usability

- Prefers records for tooling
- Predictable and stable
- Open world assumption about sums

DEMO

Aggregating Olympic medalists

Dot-driven development

Encoding complex logic via simple member access

- Type providers for member generation
- Laziness for scaling to large hierarchies
- Fancy types for the masses!

Row types and phantom types

Row types to track names and types of fields

$$\frac{\Gamma \vdash e : [f_1 : \tau_1, \ldots, f_n : \tau_n]}{\Gamma \vdash e.\,\mathrm{drop}\ f_i : [f_1 : \tau_1, \ldots, f_{i-1} : \tau_{i-1}, f_{i+1} : \tau_{i+1}, \ldots, f_n : \tau_n]}$$

Embed row types in provided nominal types

$$\frac{\Gamma \vdash e : C_1}{\Gamma \vdash e.\,\mathrm{drop}\ f_i : C_2} \quad \text{where}$$

$$fields(C_1) = \{f_1 : \tau_1, \ldots, f_n : \tau_n\}$$
$$fields(C_2) = \{f_1 : \tau_1, \ldots, f_{i-1} : \tau_{i-1}, f_{i+1} : \tau_{i+1}, \ldots, f_n : \tau_n\}$$

Fancy types for the masses!

Powerful idea that works in other contexts

- Row types and phantom types
- Session types for communication
- Add your own fancy type here!

BEHIND THE SCENES

Relative type safety

Well typed programs do not go wrong.

(As long as the world is well-behaved.)

F# Data and safety

Given *representative samples* and *an input* value

$$S(d) \sqsubset S(d_1, \ldots, d_n)$$

Any program written using a type provider reduces

$$e_{user}[x \leftarrow \textbf{new}\ C(d)] \rightsquigarrow^* v$$

DEMO

Handling schema change and errors

F# Data and schema change

Provided type can change only in limited ways

$$C[e] \rightarrow C[e.M]$$

$$C[e] \rightarrow C[\textsf{match } e \textsf{ with } \ldots]$$

$$C[e] \rightarrow C[int(e)]$$

Structure of a type provider

Context L maps names to definitions and nested contexts

$$L(C) = \text{type } C(x : \tau) = \overline{m}, L'$$

Pivot provider takes schema and provides a class with context

$$\text{pivot}(F) = C, L$$

DEMO

Fancy types in action

Pivot type provider

Generate classes that drop individual columns

$$\mathsf{drop}(F) = C, \{C \mapsto (l, L' \cup \bigcup L_f)\}$$

$$l = \text{type } C(x : \mathsf{Query}) =$$
$$\quad \text{member } \text{«drop } f\text{»} : C_f = C_f(\Pi_{\mathsf{dom}(F')}(x))$$
$$\quad \text{member } \mathsf{then} : C' = C'(x)$$

$$\forall f \in \mathsf{dom}(F) \text{ where } C_f, L_f = \mathsf{drop}(F')$$
$$\quad \text{and } F' = \{f' \mapsto \tau' \in F, f' \neq f\}$$
$$\text{where } C', L' = \mathsf{pivot}(F)$$

JSON type provider

Generate class corresponding to a record shape

$$\mathsf{provide}(\{\nu_1 : \sigma_1, \ldots, \nu_n : \sigma_n\}) = C, \{C \mapsto (l, L_1 \cup \ldots \cup L_n \cup)\}$$

$$l = \mathsf{type}\ C(x_1 : \mathsf{Data}) = \mathsf{member}\ \nu_1 : C_1 = \mathsf{convField}(\nu, \nu_1, x_1, C_1) \quad (\ldots) \mathsf{member}\ \nu_n : C_n = \mathsf{convField}(\nu, \nu_n, x_n, C_n)$$

$$\text{where } C_i, L_i = \mathsf{provide}(\sigma_i)$$

SUMMARY

Future work

Making programming with data easier

- Learning from spreadsheets
- Understanding programmer interactions
- Handling joins and data cleaning
- Read, analyse and visualize!

DEMO
Learning from spreadhseets

Thank you!

Teaching old type systems new tricks with type providers

Dot-driven	Towards minimal calculus of interactions
Fancy types	Encoding row types via type providers
Relative safety	Necessity when working with data

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References

Don Syme, Keith Battocchi, Kenji Takeda, Donna Malayeri and Tomas Petricek. **Themes in Information-Rich Functional Programming for Internet-Scale Data Sources**. In proceedings of DDFP 2013

Tomas Petricek, Gustavo Guerra and Don Syme. **Types from data: Making structured data first-class citizens in F#**. PLDI 2016

Tomas Petricek. **Data exploration through dot-driven development**. In proceedings of ECOOP 2017