Introduction to **R**esearch in **D**ata **S**cience

October 23, 2014

James Cheney

Big

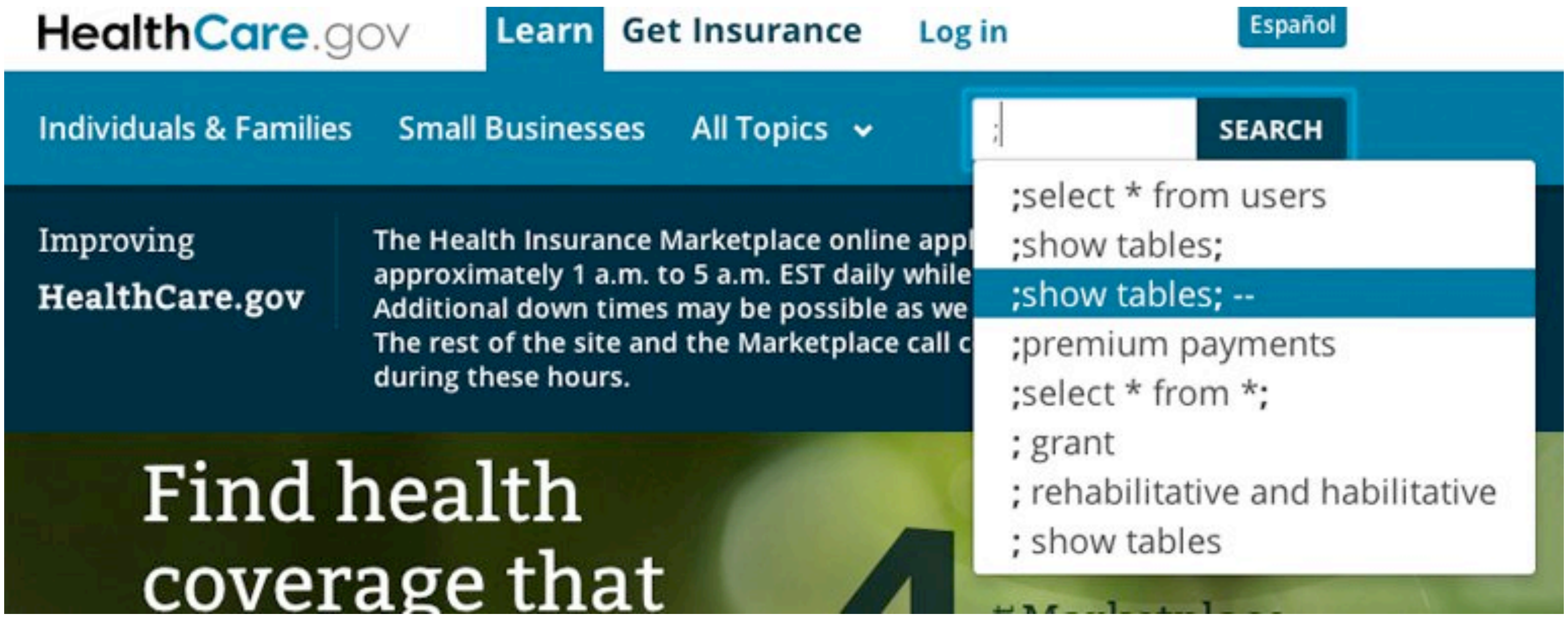
Data


Big
Data

Wicked Data

wicked problem, n. a problem that is difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognize

Research questions: Language-integrated query



How can we (safely/securely) program multiple layers (database, browser, regular PL)?

LINQ example

employees

dpt	name	salary
"Product"	"Alex"	40,000
"Product"	"Bert"	60,000
"Research"	"Cora"	50,000
"Research"	"Drew"	70,000
"Sales"	"Erik"	200,000
"Sales"	"Fred"	95,000
"Sales"	"Gina"	155,000

tasks

emp	tsk
"Alex"	"build"
"Bert"	"build"
"Cora"	"abstract"
"Cora"	"build"
"Cora"	"call"
"Cora"	"dissemble"
"Cora"	"enthuse"
"Drew"	"abstract"
"Drew"	"enthuse"
"Erik"	"call"
"Erik"	"enthuse"
"Fred"	"call"
"Gina"	"call"
"Gina"	"dissemble"

quotation
<@ @>

antiquote
(%)

```
let rec canDoAll(tsks) =
  match tsks with
    [] -> <@ fun name -> true @>
  | tsk::tsks' -> <@ fun name ->
      (%canDo) name tsk && (%canDoAll tsks') name @>
query {
  for x in employees
  where ((%canDoAll ["build","call"]) x.name)
  yield {name=x.name} }
```

LINQ example

employees

dpt	name	salary
“Product”	“Alex”	40,000
“Product”	“Bert”	60,000
“Research”	“Cora”	50,000
“Research”	“Drew”	70,000
“Sales”	“Erik”	200,000
“Sales”	“Fred”	95,000
“Sales”	“Gina”	155,000

tasks

emp	tsk
“Alex”	“build”
“Bert”	“build”
“Cora”	“abstract”
“Cora”	“build”
“Cora”	“call”
“Cora”	“dissemble”
“Cora”	“enthuse”
“Drew”	“abstract”
“Drew”	“enthuse”
“Erik”	“call”
“Erik”	“enthuse”
“Fred”	“call”
“Gina”	“call”
“Gina”	“dissemble”

name
Cora

quotation
<@ @>

antiquote
(%)

```
let rec canDoAll(tsks) =
  match tsks with
    [] -> <@ fun name -> true @>
  | tsk::tsks’ -> <@ fun name ->
      (%canDo) name tsk && (%canDoAll tsks’) name @>
query {
  for x in employees
  where ((%canDoAll ["build","call"]) x.name)
  yield {name=x.name} }
```

Example

```
let elem = <@ fun x xs ->
                 query { for y in xs
                         exists (y=x) } @>
let canDo = <@ fun name tsk ->
                 (%elem) tsk (for t in tasks
                              where (t.emp = name)
                              yield t.tsk ) @>
query { for x in employees
        where ((%canDo) x.name "build")
        yield {name = x.name}
```

Example

```
let elem = <@ fun x xs ->
```

```
let canDo = <@ fun name tsk ->
                  (fun x xs ->
                     query { for y in xs
                             exists (y=x) })
                     tsk (for t in tasks
                               where (t.emp = name)
                               yield t.tsk ) @>
query { for x in employees
        where ((%canDo) x.name "build")
        yield {name = x.name}
```

Example

```
let elem = <@ fun x xs ->
```

```
let canDo = <@ fun name tsk ->
```

```
query { for x in employees
        where ((fun name tsk ->
                  (fun x xs ->
                     query { for y in xs
                             exists (y=x) })
                     tsk (for t in tasks
                              where (t.emp = name)
                              yield t.tsk )) x.name "build")
        yield {name = x.name}
```

Example

```
let elem = <@ fun x xs ->
```

```
let canDo = <@ fun name tsk ->
```

```
query { for x in employees
        where ((fun name tsk ->
                 (fun x xs ->
                    query { for y in xs
                            exists (y=x) })
                    tsk (for t in tasks
                             where (t.emp = name)
                             yield t.tsk )) x.name "build")
        yield {name = x.name}
```

This is what LINQ normally sees.

X (failure or query avalanche)

Example

```
let elem = <@ fun x xs ->
```

```
let canDo = <@ fun name tsk ->
```

```
query { for x in employees
        where ((fun name tsk ->
                  (fun x xs ->
                     query { for y in xs
                             exists (y=x) })
                     tsk (for t in tasks
                              where (t.emp = name)
                              yield t.tsk )) x.name "build")
        yield {name = x.name}
```

Example

```
let elem = <@ fun x xs ->
```

```
let canDo = <@ fun name tsk ->
```

```
query { for x in employees
        where ((fun name tsk ->
```

```
query { for x in employees
        where ((fun name tsk ->
                 query { for y in (for t in tasks
                                   where (t.emp = name)
                                   yield t.tsk )
                         exists (y= tsk) }
               ) x.name "build")
        yield {name = x.name}
```

Example

```
let elem = <@ fun x xs ->
```

```
let canDo = <@ fun name tsk ->
```

```
query { for x in employees
        where ((fun name tsk ->
```

```
query { for x in employees
        where ((fun name tsk ->
```

```
query { for x in employees
        where (query { for y in (for t in tasks
                                     where (t.emp = x.name)
                                     yield t.tsk )
                          exists (y= "build") } )
        yield {name = x.name}
```

Example

```
let elem = <@ fun x xs ->
```

```
let canDo = <@ fun name tsk ->
```

```
query { for x in employees
        where ((fun name tsk ->
```

```
query { for x in employees
        where ((fun name tsk ->
```

```
query { for x in employees
```

```
query { for x in employees
        where (query { for t in tasks
                       where (t.emp = x.name)
                       exists (t.tsk = "build") } )
        yield {name = x.name}
```

Example

```
let elem = <@ fun x xs ->
```

```
let canDo = <@ fun name tsk ->
```

```
query { for x in employees
        where ((fun name tsk ->
```

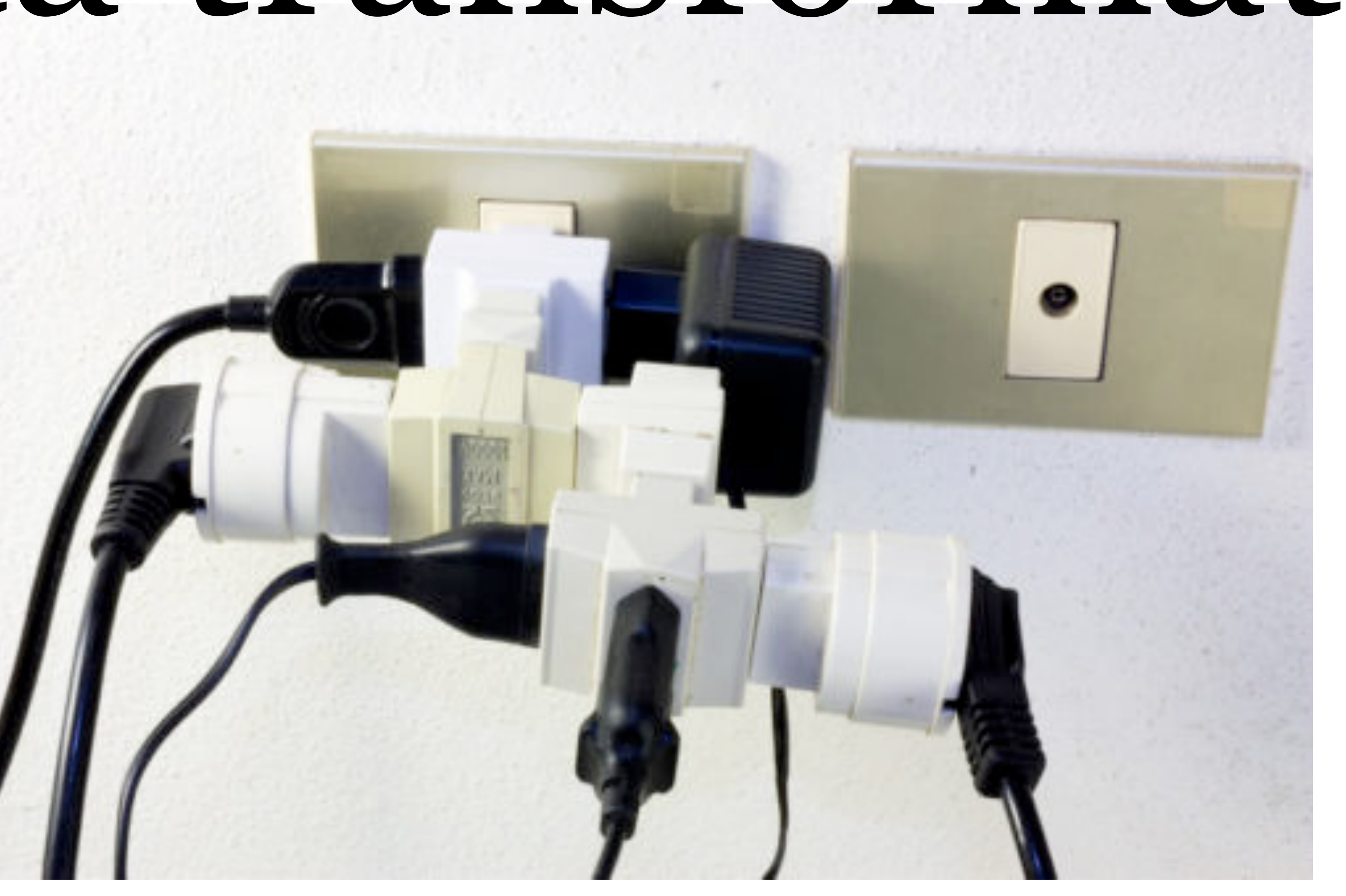
```
query { for x in employees
        where ((fun name tsk ->
```

```
query { for x in employees
```

```
query { for x in employees
        where (query { for t in tasks
                       where (t.emp = x.name)
                       exists (t.tsk = "build") } )
        yield {name = x.name}
```

```
SELECT x.name
FROM employees x
WHERE EXISTS (SELECT t.tsk FROM tasks t WHERE t.emp = x.name)
```

Research questions: Data transformation



- How do I make use of data in format X with tools that expect Y?
- What if some of X is missing or Y requires information that X doesn't provide?

Bidirectional transformations

- Can synchronize two data sources using functions:
  - $get : A \to B$, $put : A \to B \to A$
- satisfying laws: $put(get\ a) = a$, $get(put\ a\ b) = b$
  - generalizing view updates in databases
- Current projects:
  - bidirectional transformations with effects
    - extending classical framework to allow *monadic effects*
    - (e.g. $put : A \to B \to M\ A$)
  - investigating "least change" principles
    - give change to one side, minimize the "damage" done to the other side

Research questions: Provenance

SCIENTIFIC PUBLISHING

A Scientist's Nightmare: Software Problem Leads to Five Retractions

Until recently, Geoffrey Chang's career was on a trajectory most young scientists only dream about. In 1999, at the age of 28, the protein crystallographer landed a faculty position at the prestigious Scripps Research Institute in San Diego, California. The next year, in a ceremony at the White House, Chang received a 2001 *Science* paper, which described the structure of a protein called MsbA, isolated from the bacterium *Escherichia coli*. MsbA belongs to a huge and ancient family of molecules that use energy from adenosine triphosphate to transport molecules across cell membranes. These so-called ABC transporters perform many

Science 22 December 2006:
Vol. 314 no. 5807 pp. 1856-1857
DOI: 10.1126/science.314.5807.1856

- How can we trust the results of
  - large programs (P(bugs) = 1.0)
  - running on large infrastructure where failure during run is expected
  - over large amounts of uncertain/noisy data ?

Foundations for trust and accountability

- Provenance and annotation
  - Understanding derivation process / history of data
- Seems to mean different things in different settings:
  - to DB people: semiring interpretations of relational algebra
  - to PL/security people: information flow, dependency tracking
  - to scientists: version management / smart replay / quality control for data (and derived results)
- Are we solving the right problem(s)?
  - Many ad hoc solutions; few specifications or "correct" implementations
- My view: mathematical foundations/attempts to specify problems **essential** to progress

Mathematical foundations of provenance

- Dependency: understanding how outputs depend on inputs (see also: noninterference in security)
  - "if I change this part, what parts of output will/may change?"
- Explanation: Galois connections between "parts" of input and output
  - "what part of input was needed to force this part of the output to be 42?"
- View maintenance/incremental computation
  - "if I change this part, how can I recompute the output most efficiently?"
- Bidirectionality/view update
  - "if I want to change this part of the output, what input changes could do this?"
- justifications/witnesses (why-provenance)
- reasoning about knowledge/uncertainty (multi-modal logic)
- mathematical modeling of causality (see also: Bayes nets)

Summary

- My work explores the interaction between language design, semantics, and data management.
- Emphasis on applying formal foundations
  - particularly concepts from programming language semantics
- to improve understanding of, address "wicked problems" coming from scientists working with data
  - Programmability, data versioning/synchronization, provenance/accountability
  - Relevant to "science data", though maybe not what people currently think of as mainstream "data science"