CSCI 334: Principles of Programming Languages

Lecture 22: Domain Specific Languages

Instructor: Dan Barowy

Williams

Announcements

Exam Study Session:
Monday, May 14 2-4pm
TBL 202

Exercise

- Construct the a knowledge base containing the following facts:
  - "Giants eat people."
  - "Giants eat bunnies."
  - "Bunnies eat grass."
  - "People eat bunnies."
  - "People eat people."
  - "Those who are eaten by others hate those others."
  - "Monsters love those who hate themselves."
- Then supply a query that can answer:
  - "Who do monsters love?"

Domain Specific Languages

- A domain specific language (DSL) is a language designed to solve a small set of tasks.
- DSLs frequently sacrifice expressiveness in favor of ease of use.

Examples

- SQL, used to manipulate tabular data
- HTML, used to represent web documents
- Verilog, a hardware description language
- PCRE, a string matching language based on regular expressions
- Make, used to describe software build dependencies
- XPath, used to query XML
- Postscript, used to describe printed documents
- LaTeX, used to cause undergraduates great anguish

Examples

- SQL cannot be used to perform arbitrary calculations; until recently (1999), it could not compute "reachability queries."
- E.g., the transitive closure of "city y is reachable from city x via direct flight" computes the set of all cities reachable from city x.
- Why? Presumably the designers intended to disallow expensive queries.
- In fact, SQL is not Turing Complete. All SQL programs halt, by design.

Examples

- Postscript is Turing Complete.
- But writing arbitrary programs is a huge pain.
  - Commands are in Reverse Polish Notation ("operands first")
  - The stack must be explicitly maintained
  - No user-defined types, etc.
- Great for offloading complex print jobs to a printer, though!
- Laser printers often ship with highly optimized Postscript interpreters (Raster Image Processor)

Completeness

- A formal system is a logical system for generating formulas.
- A formal system is complete with respect to a property if all formulas having that property can be derived using the rules (axioms) of the system.

Soundness

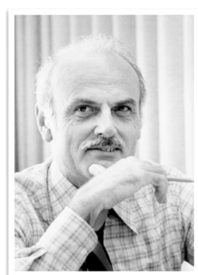
- A formal system is sound with respect to a property if all derivable formulas are true.

Incompleteness Theorem

- Kurt Gödel proved that mathematics (i.e., mathematical logic) cannot be both sound and complete wrt "provability."
- Either:
  - you can define a formal system in which you can derive all the true mathematical statements, but which also admits false statements (inconsistent), or
  - you can define a formal system in which all statements are true, but in which you cannot derive all the true mathematical statements (incomplete).
- https://youtu.be/O4ndIDcDSGc

SQL

- SQL is a DSL for querying data, invented by E. F. Codd in 1970.
- SQL limits itself to only certain kinds of queries.
- All of those queries can be answered efficiently (and by implication, they terminate).
- The language is based on a theory of data and data queries called the relational algebra.
- The relational algebra lets users efficiently query data in a form that is largely independent of the organization of the data on disk.
- This was considered a major breakthrough when it was invented.
- For many practical reasons, SQL has diverged somewhat from the relational algebra.



Relational Algebra

- The relational algebra is based on set theory.
- A relation R is a set of tuples.
  - Remember that sets contain only unique elements.
  - Also, the order of elements in a set does not matter.
- The members of a tuple are called attributes.
  - Note that the order of attributes in a tuple does not matter.
- We often think of relations as tables. But since relations are really sets of tuples, the order of attributes and rows in a table *does not matter*.
- A schema is the set of all defined relations.
- A database is a collection of instances of relations for a given schema.

Employee

Name	EmpId	DeptName
Harry	3415	Finance
Sally	2241	Sales
George	3401	Finance
Harriet	2202	Sales

Dept

DeptName	Manager
Finance	George
Sales	Harriet
Production	Charles

Relational Algebra: Closure Property

- All operations in the relational algebra are closed, meaning that every operation on a relation yields a relation.
- Primitive operations:
  - Projection
  - Selection
  - Rename
  - Cartesian Product
- Complex operations:
  - Join, etc.

Relational Algebra: Projection

- Projection selects columns of a relation.
- Formally,

  $\Pi_{a_1, \ldots, a_n}(R)$ yields the relation R' such that R' is restricted on attributes $a_1, \ldots, a_n$.
- For example, $\Pi_{Name, DeptName}(Employee)$ yields

Employee

Name	EmpId	DeptName
Harry	3415	Finance
Sally	2241	Sales
George	3401	Finance
Harriet	2202	Sales

$\Pi_{Name, DeptName}(Employee)$

Name	DeptName
Harry	Finance
Sally	Sales
George	Finance
Harriet	Sales

Relational Algebra: Selection

- Selection selects rows of a relation.
- Formally,

  $\sigma_{\varphi}(R)$ yields the relation R' such that R' is restricted on the predicate φ.
- For example, $\sigma_{EmpId > 3000}(Employee)$ yields

Employee

Name	EmpId	DeptName
Harry	3415	Finance
Sally	2241	Sales
George	3401	Finance
Harriet	2202	Sales

$\sigma_{EmpId > 3000}(Employee)$

Name	EmpId	DeptName
Harry	3415	Finance
George	3401	Finance

Relational Algebra: Rename

- Rename renames an attribute in a relation.
- Formally,

  $\rho_{a/b}(R)$ yields the relation R' such that attribute a is renamed to b in R'.
- For example, $\rho_{EmpId/Id}(Employee)$ yields

Employee

Name	EmpId	DeptName
Harry	3415	Finance
Sally	2241	Sales
George	3401	Finance
Harriet	2202	Sales

$\rho_{EmpId/Id}(Employee)$

Name	Id	DeptName
Harry	3415	Finance
Sally	2241	Sales
George	3401	Finance
Harriet	2202	Sales

Relational Algebra: Cartesian Product

- Cartesian product pairs every tuple in relation R with a tuple in relation S.
- Formally,
  R×S yields the relation T = { $(r_1,\ldots,r_n,s_1,\ldots,s_n)$ | $(r_1,\ldots,r_n) \in R$, $(s_1,\ldots,s_n) \in S$ }
- Note that this is not quite the set theory Cartesian product because tuples are "flattened".
- For example, Employee×Dept yields

Employee

Name	EmpId	DeptName
Harry	3415	Finance
Sally	2241	Sales
George	3401	Finance
Harriet	2202	Sales

Dept

DeptName	Manager
Finance	George
Sales	Harriet
Production	Charles

Employee×Dept

Name	EmpId	DeptName	DeptName	Manager
Harry	3415	Finance	Finance	George
Harry	3415	Finance	Sales	Harriet
Harry	3415	Finance	Production	Charles
Sally	2241	Sales	Finance	George
Sally	2241	Sales	Sales	Harriet
Sally	2241	Sales	Production	Charles

…

Relational Algebra: Natural Join

- A number of useful operations called "joins" can be defined in terms of the primitive projection, selection, rename, and Cartesian product operations we just defined.
- Natural join pairs every tuple in relation R with a tuple in relation S where they agree on an attribute value.
- Formally,
  $R \bowtie_i S$ yields the relation T = { $(r_1,\ldots,r_n,s_1,\ldots,s_n)$ | $(r_1,\ldots,r_n) \in R$, $(s_1,\ldots,s_n) \in S$ } where $r_i = s_i$ for a given i.

Employee

Name	EmpId	DeptName
Harry	3415	Finance
Sally	2241	Sales
George	3401	Finance
Harriet	2202	Sales

Dept

DeptName	Manager
Finance	George
Sales	Harriet
Production	Charles

$\text{Employee} \times_{\text{DeptName}} \text{Dept}$

Name	EmpId	DeptName	Manager
Harry	3415	Finance	George
Sally	2241	Sales	Harriet
George	3401	Finance	George
Harriet	2202	Sales	Harriet

Optimizations

- Because relational algebra abstracts queries from data representation, data can be organized on disk in whatever manner is the most efficient.
- Furthermore, the actual execution plan can be computed dynamically to take full advantage of hardware resources.
- For example, selection and projection both produce smaller relations than their inputs. Thus, if a query combines joins and selection/projection, a query planner can reorder operations so that selection/projection come first, reducing the number of tuples that must be computed in a join. This optimization is called predicate pushdown.
- Efficient database implementation is an active area of research (VLDB, SIGMOD, etc).

Importance of SQL

- SQL is one of the most important and successful languages ever invented.
- E.F., Codd won a Turing Award for his work on the relational algebra and relational database management systems.
- As of 2017, relational database systems alone were a $50 billion market.